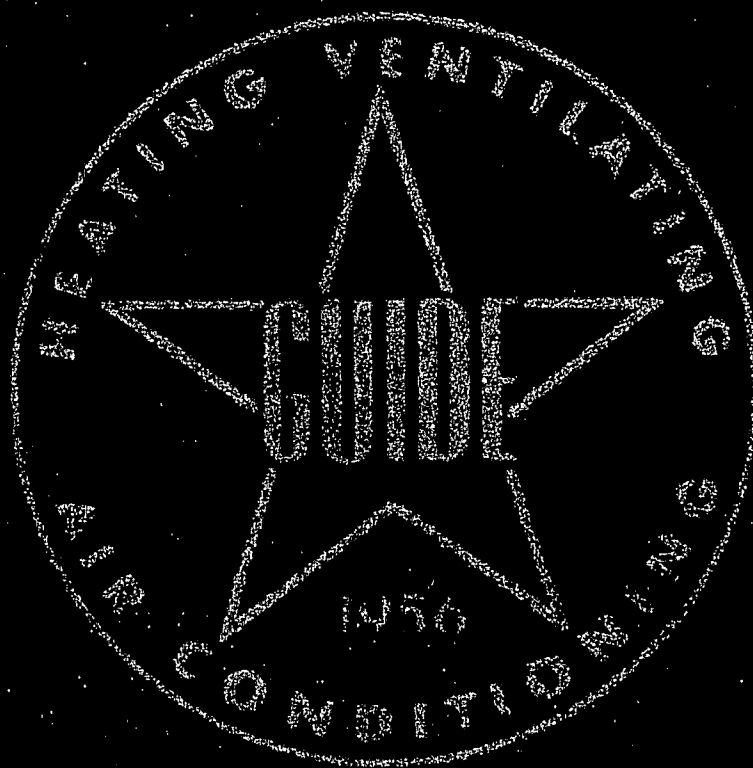


HEATING  
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AIR-CONDITIONING  
**GUIDE**  
**1956**



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**HEATING VENTILATING  
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GUIDE 1956**

Applied Science Department

# HEATING VENTILATING AIR CONDITIONING GUIDE 1956



*An Instrument of Service  
Prepared for the Profession  
containing*

A TECHNICAL DATA SECTION OF REFERENCE MATERIAL ON THE DESIGN AND SPECIFICATION OF HEATING, VENTILATING, AND AIR CONDITIONING SYSTEMS BASED ON—THE TRANSACTIONS—THE INVESTIGATIONS OF THE RESEARCH LABORATORY AND COOPERATING INSTITUTIONS—AND THE PRACTICE OF THE MEMBERS AND FRIENDS OF THE SOCIETY; A MANUFACTURERS' CATALOG DATA SECTION CONTAINING ESSENTIAL AND RELIABLE INFORMATION CONCERNING MODERN EQUIPMENT; COMPLETE INDEXES TO TECHNICAL AND CATALOG DATA SECTIONS.

A521000

**Vol. 34**

\$12.00 per copy

PUBLISHED ANNUALLY BY THE

AMERICAN SOCIETY OF HEATING AND  
AIR-CONDITIONING ENGINEERS, INC.

62 WORTH ST.  
NEW YORK 13, N. Y.

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Ref. 628.8  
PREFACE TO THE 34th EDITION

The 34th Edition of the HEATING VENTILATING AIR CONDITIONING GUIDE, 1956, contains 1176 pages of technical text—16 pages more than the largest previous edition. In addition, new material equivalent to 14 pages has been added where condensation of previous text was possible.

Substantial improvements have been made in 16 chapters, some of which have been almost completely rewritten. In the outline of changes which follows, it will be noted that special attention has been given to subjects dealing with heat transmission of building materials, cooling load, chimneys, estimating fuel consumption, baseboard and finned-tube radiation, snow melting, central systems for air conditioning, air duct design, air heating and cooling coils, automatic control, pipe and tube characteristics and insulation, automobile air conditioning, heat transfer measurements, and codes and standards.

The following paragraphs describe the significant changes in the chapters having the most important revisions:

*Chapter 1—Terminology.* Revisions have been made in several definitions to obtain agreement with values adopted by the 9th and 10th General Conference on Weights and Measures.

*Chapter 4—Fluid Flow.* Most of the illustrations have been improved. A number of clarifications have been made in the text.

*Chapter 9—Heat Transmission Coefficients of Building Materials.* The chapter has been enlarged to permit addition of many materials to the list showing design values for conductivity and conductance. New information has been included for estimating the conductances of air spaces bounded by reflective surfaces. New tables facilitate the determination of the effect of adding insulation to wall, floor, and roof sections. A new chart makes it possible to correct quickly for the effect of framing members. The revision was prepared by the ASHAE Technical Advisory Committee on Insulation assisted by staff members of the ASHAE Research Laboratory.

*Chapter 13—Cooling Load.* Weather design data have been added for 21 Canadian cities, and a number of improvements have been made in the text.

*Chapter 17—Chimneys and Draft Calculations.* The discussion of the theory of draft calculations has been rewritten. The sections on residential chimneys and gas appliance chimney requirements have been revised and enlarged.

*Chapter 18—Estimating Fuel Consumption for Space Heating.* The table of degree days has been extended to include 287 U. S. and 40 Canadian cities using up-to-date information furnished by the U. S. Weather Bureau and the Canadian Meteorological Service.

*Chapter 22—Hot Water Heating Systems.* A number of improvements have been made in the section on high temperature systems.

*Chapter 23—Radiators, Convectors, Baseboard and Finned-Tube Units.* Sections were added to supply information on baseboard and finned-tube units of present design. The chapter was largely rewritten.

*Chapter 24—Panel Heating.* The section on snow melting was rewritten and enlarged to include recent developments in this field and to provide new viscosity and other data for the designer.

*Chapter 26—Unit Air Conditioners and Unit Air Coolers.* Much of the text was rewritten to describe present types of units as well as up-to-date practice in their application.

*Chapter 27—Pipe, Fittings, Welding.* New tables were added to indicate the suitability of various pipe, tube, and fitting materials for different applications. Characteristics of drainage, waste and vent pipe and tube were discussed in the text and added to the table on dimensions and properties of copper tube.

*Chapter 28—Pipe and Industrial Insulation.* Typical conductivities of insulating materials were affirmed or revised by the ASHAE Technical Advisory Committee on Insulation.

*Chapter 30—Central Systems for Air Conditioning.* The chapter was enlarged and largely rewritten with new text and diagrams describing year-round systems, unitary systems, high- and low-pressure induction convectors, and both dual duct and fan coil units.

**Chapter 32—Air Duct Design.** The chapter was rewritten by a subcommittee of the Technical Advisory Committee on Air Distribution to simplify explanation and use of formulas for duct design. New tables were added to extend the data on friction losses in elbows and fittings, and those due to area changes.

**Chapter 36—Heating and Cooling Coils.** Information on use of coils and their selection was revised to indicate practical considerations involved. An example was added to show method of calculating the cooling load on coils.

**Chapter 39—Automatic Control.** This enlarged chapter was completely rewritten employing current nomenclature in the field to describe up-to-date automatic controls, their application and coordination.

**Chapter 48—Transportation Air Conditioning.** The sections on automobile and railway passenger car air conditioning were revised and enlarged.

**Chapter 52—Instruments and Measurements.** The text describing the use of thermocouples and the measurement of thermal conductivity and conductance was enlarged and revised.

**Chapter 53—Codes and Standards.** Revisions were made where necessary to show latest editions and to include new standards in the field of heating and air conditioning which have become available.

In addition to changes mentioned for specific chapters, many improvements in other chapters were made as a result of a general review given the previous edition by the Guide Committee.

The 24-page detailed subject index has been continued to facilitate the finding of information under the various subject headings which readers might be expected to use.

The Catalog Data Section has been expanded to include reference material on products of 335 manufacturers of heating, ventilating, cooling and air conditioning equipment. A comprehensive subject index makes it easy to find names of manufacturers and their products available for use by the designer.

The complete list of Society committee members, other engineers, and authorities who have contributed material and assistance in the preparation of this edition cannot be given here because of lack of space. These sources of information are extremely important in keeping *THE GUIDE* up to date with current practice. The Guide Committee wishes to express its appreciation of the assistance received from all sources, and takes particular pleasure in mentioning the following individuals who have been especially helpful:

|                    |                 |                     |
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| H. W. ALTEA        | W. S. HARRIS    | F. J. REED          |
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This 34th edition of *THE GUIDE* is presented by the Guide Committee with the anticipation and hope that it will be of great value as a means of keeping users abreast of current practice in the heating, ventilating, cooling, and air conditioning field.

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## CONTENTS

|                                                                 | PAGE |
|-----------------------------------------------------------------|------|
| TITLE PAGE                                                      | iii  |
| PREFACE                                                         | v    |
| INDEX TO TECHNICAL DATA                                         | ix   |
| <b>SECTION I. FUNDAMENTALS</b>                                  |      |
| Chapter 1. Terminology                                          | 1    |
| 2. Abbreviations, Symbols, Conversion Factors                   | 11   |
| 3. Thermodynamics                                               | 23   |
| 4. Fluid Flow                                                   | 67   |
| 5. Heat Transfer                                                | 83   |
| <b>SECTION II. HUMAN REACTIONS</b>                              |      |
| Chapter 6. Physiological Principles                             | 111  |
| 7. Air Conditioning in the Prevention and Treatment of Disease  | 131  |
| 8. Air Contaminants                                             | 151  |
| <b>SECTION III. HEATING AND COOLING LOADS</b>                   |      |
| Chapter 9. Heat Transmission Coefficients of Building Materials | 167  |
| 10. Moisture in Building Construction                           | 205  |
| 11. Infiltration and Ventilation                                | 227  |
| 12. Heating Load                                                | 249  |
| 13. Cooling Load                                                | 275  |
| <b>SECTION IV. COMBUSTION AND CONSUMPTION OF FUELS</b>          |      |
| Chapter 14. Fuels and Combustion                                | 331  |
| 15. Automatic Fuel Burning Equipment                            | 367  |
| 16. Heating Boilers, Furnaces, Space Heaters                    | 395  |
| 17. Chimneys and Draft Calculations                             | 421  |
| 18. Estimating Fuel Consumption for Space Heating               | 445  |
| <b>SECTION V. SYSTEMS AND EQUIPMENT</b>                         |      |
| Chapter 19. Gravity Warm Air Systems                            | 463  |
| 20. Forced Warm Air Systems                                     | 475  |
| 21. Steam Heating Systems                                       | 493  |
| 22. Hot Water Heating Systems                                   | 535  |
| 23. Radiators, Convectors, Baseboard and Finned-Tube Units      | 561  |
| 24. Panel Heating                                               | 571  |
| 25. Unit Heaters and Unit Ventilators                           | 595  |
| 26. Unit Air Conditioners and Unit Air Coolers                  | 609  |
| 27. Pipe, Fittings, Welding                                     | 623  |
| 28. Pipe and Industrial Insulation                              | 653  |
| 29. District Heating                                            | 671  |
| 30. Central Systems for Air Conditioning                        | 685  |
| 31. Air Distribution                                            | 701  |
| 32. Air Duct Design                                             | 731  |
| 33. Fans                                                        | 763  |
| 34. Air Cleaning                                                | 781  |
| 35. Spray Apparatus                                             | 803  |
| 36. Air Heating and Cooling Coils                               | 829  |
| 37. Refrigeration                                               | 847  |
| 38. Dehumidification by Sorbent Materials                       | 885  |
| 39. Automatic Control                                           | 895  |
| 40. Motors and Motor Controls                                   | 923  |
| 41. Sound Control                                               | 941  |
| 42. Electric Heating                                            | 963  |

## CONTENTS (CONCLUDED)

### SECTION V. SYSTEMS AND EQUIPMENT (Continued)

- Chapter 43. Corrosion and Water Formed Deposits, Causes and Prevention 981  
44. Owning and Operating Costs .....1005

### SECTION VI. SPECIAL SYSTEMS

- Chapter 45. Industrial Air Conditioning .....1015  
46. Industrial Exhaust Systems .....1041  
47. Industrial Drying Systems .....1061  
48. Transportation Air Conditioning .....1089  
49. Water Services .....1105  
50. Residential Summer Air Conditioning .....1129  
51. Schoolhouse Heating and Ventilating .....1137

### SECTION VII. INSTRUMENTS AND CODES

- Chapter 52. Instruments and Measurements .....1145  
53. Codes and Standards .....1167

### CATALOG DATA SECTION .....1177

- Index to Advertisers .....1179  
Index to Modern Equipment .....1187  
Manufacturers' Catalog Data .....1217

# INDEX

## HEATING VENTILATING AIR CONDITIONING GUIDE 1956

### TECHNICAL DATA SECTION

CHAPTERS 1-53 and PAGES 1-1176

Cross Reference to Subjects in  
Chapters 1-53 Alphabetically Listed

34th EDITION

# INDEX

## HEATING VENTILATING AIR CONDITIONING

### GUIDE 1956

#### Technical Data Section

#### Chapters 1-53 and Pages 1-1176

#### A

**Abatement**  
 air pollution, 151, 154  
 smoke, 8, 153, 332

**Abbreviations, 11**  
 Absolute  
 humidity, 5  
 pressure, 7  
 temperature, 9, 30  
 zero, 1, 9

**Absorbent, 885, 889, 890**  
 equipment, 891  
 process, 890  
 temperature, pressure, concentration, 891

**Absorbers, 799**  
 duct, sound, 950  
 outlet, 955  
 plate cells, 953  
 plenums, 955

**Absorption systems, 863**

**Acceleration, 1**

**Acclimatization, 118**

**Acoustics, 941**

**Activated alumina, 886**

**Activated carbon, 148, 1092**

**Activated bauxite, 887**

**Adiabatic, 1**  
 mixing  
 two air streams, 57  
 saturation, 80

**Adsorbents, 799, 885**  
 equipment, 888  
 process, 887  
 temperature, pressure, concentration, 885

**Adsorption, odor, vapor, 156, 792**

**Aerosol, 1, 134, 151**

**Air**  
 change measurement, 1158  
 change method, 232, 293  
 chemical vitiation of, 111, 152, 156  
 circulation, 112, 463, 475, 685, 731, 1090  
 circulation in dry, 1080  
 classification of impurities, 151, 782  
 dust, 151, 782  
 lint, 151, 782  
 cleaner, 151, 781, 1090  
 viscous impingement type, 783  
 cleaning, 781  
 cleaning devices, 781, 799, 800  
 charged media, 788  
 classification of, 781  
 electrostatic, 788  
 installation, 790  
 maintenance, 789  
 performance, 787  
 safety requirements, 791  
 selection, 789, 793  
 testing, 787  
 vapor adsorption, 792  
 combustion, 357, 358

**Air (continued)**  
 conditioning process, 685, 1005  
 contaminants, 111, 151, 164, 732, 1041, 1163  
 cooled condensers, 872  
 coolers, 615, 619  
 cooling, tropics, 136  
 current measurement, 1157  
 dehumidification, 885  
 distribution, 463, 475, 701, 703, 1086, 1090, 1100, 1134  
 air entrainment, 713  
 application of methods, 727, 1090  
 balancing the system, 722  
 ceiling outlets, 719  
 definitions, 701  
 design methods, 748  
 directional control, 724  
 duct approaches to outlets, 455, 723  
 entrainment ratios, 713  
 flow patterns, 723  
 friction chart, 734, 735  
 furnace systems, 463, 475  
 jet pattern, 715  
 long slot, discharge from, 711  
 noise level, 717  
 outlet location, 476, 477, 720, 726  
 outlet performance, 715, 721  
 outlets, 704, 718  
 perforated panels, 711  
 principles, 703  
 radial jets, 710  
 railway car, 1090  
 recommended velocity, 476, 747  
 return and exhaust intakes, 726, 958  
 return grille, 465, 958  
 room air motion, 703, 717  
 selection, 720  
 smudging, 718  
 spread, 702, 704  
 standards for, 702  
 throw, 709, 715, 716  
 vanes, 715, 716  
 velocity, 697, 705, 747  
 velocity across jets, 706, 707, 709  
 velocity profiles, 709  
 vertical drop and rise, 716  
 volume control, 723, 725  
 wall outlets, 476, 718  
 duct construction, 755, 1053  
 duct design, 478, 731, 749, 757, 1053  
 duct friction loss, 731  
 dust concentrations, 155, 160, 161  
 excess, 340, 354, 358, 387  
 filter, 783, 790  
 flow measurement, 78, 1152  
 flow resistance of coils, 840  
 impurities, 113, 151, 782  
 infiltration, 227  
 causes of, 227  
 due to wind pressure, 228  
 through walls, 228  
 leakage, 229, 231

**Air (continued)**  
 moist, 25  
 motion, 122  
 movement, influence of, 117  
 movement, measurement of, 1152, 1156  
 outdoor, 113, 685  
 physical impurities in, 113, 151, 155, 782  
 pollution, 151, 154  
 abatement, 153, 336, 1071  
 primary, 338, 350, 354  
 quantity required, 113, 357, 358, 1091, 1093  
 refrigeration cycle, 880  
 requirements, 113, 356, 358, 1094  
 room motion, 703, 717  
 saturated, 1  
 secondary, 338, 354, 387  
 space conductance, 170, 178  
 standard, 1  
 sterilization of, 132, 142  
 supply and return openings, 464, 465, 476, 718, 726  
 supply opening noise, 717, 955  
 temperature requirements, 122, 123, 251, 276, 1016-1026, 1101  
 thermodynamics of, 23  
 unit cleaning devices, 781, 803  
 washers, 1, 803

**Air change method**  
 computing infiltration, 230, 265

**Air conditioning, 1**  
 aircraft, 1097  
 automobiles in summer, 1095  
 central system, 685, 1131  
 comfort, 2  
 hospitals, 131-148  
 humidity, tables, 1016  
 industrial, 1015  
 atmospheric conditions required, 277, 1016-1026  
 calculations, 1031  
 general requirements, 1015  
 problem classification, 1015  
 typical applications, 1015  
 owning and operating cost, 1005, 1134  
 passenger bus, 1094  
 processes, 54  
 adiabatic mixing, 57  
 adiabatic saturation, 60  
 cooling, 55  
 heating, 54  
 railway passenger car, 1039  
 residential, 1129  
 ship, 1100  
 stoker-fired units, 368  
 storage systems, 865  
 streetcar, 1093  
 summer design conditions, 276, 277, 279  
 temperature table, 276, 279, 1016  
 transportation, 1089  
 treatment of disease, 131  
 unit, 609

Air cooler, 609  
units, 609, 619  
defrosting, 621  
design, 619  
operation, 621  
performance, 621  
ratings, 621  
types of, 619  
Air filters, 785  
Air pollution, 154  
control, 155, 792  
Air requirements, 118, 338, 1091  
Air supply opening noises, 717, 735  
Air velocity, 476, 597, 703, 747, 1042, 1044  
cooling towers, 818  
design, 747  
unit heaters, 597  
Air washer, 1, 803, 805, 807  
Airborne matter, 152, 782  
Airborne infection, 132, 184  
control, 132, 184  
Aircraft air conditioning, 1097  
Allergic disorders, 144  
apparatus, 145  
asthma symptoms, 145  
hay fever symptoms, 144  
limitations of air conditioning methods, 145  
Altitude, pressure and temperature, 63  
Anemometer, 1, 1155, 1156, 1157  
deflecting vane, 1156  
propeller, 1155  
revolving vane, 1155  
thermal, 1157  
Anesthetics, 138  
Anthracite coal, 332-335  
firing methods, 335  
Apparatus dew point, 278, 320  
Aspect ratio, 1, 701  
Asthma symptoms, 145  
Atmosphere, standard, 63  
Atmospheric conditions for industrial processes, 1016-1026  
cooling towers, 818  
make-up water, 827  
winter freezing, 827  
Atomizing humidifiers, 807  
Atomizing oil burner, 375  
Attenuation, 949  
ducts, 949  
duct branches, 949  
elbows, 949  
grilles, 949  
Attic fans, 779  
location, 779  
types, 779  
temperature, 261  
Automobile air conditioning, 1095  
Axial flow fans, 763

## B

Baffle, 1, 385  
Bare pipe heat loss, 653  
Barometer, 1151  
Basement coefficients of transmission, 190  
heat loss, 262, 263  
temperatures, 262  
Basementless houses, 264, 492  
Bernoulli equation, 68  
Biochemical reactions control of rate of, 1029  
Bituminous coal, 332, 333, 338  
firing methods, 335  
Blast heater, 2  
Blow, 2, 597

Body adaptation to hot conditions, 118  
heat loss, 113, 120  
odor, 111  
thermal interchanges, 119, 120  
Boiler, boilers, 395  
capacity for unit heaters, 603  
care, 408  
cast-iron, 395, 404  
cleaning, 408  
combustion rates, 405  
connections, 406, 620  
Hartford return, 520  
return, 520  
sizing, 521  
steam, 520  
construction, 395  
design, 397  
efficiency, 402  
erection, 407  
fittings, 406  
furnace design, 397  
gas-fired, 384, 406  
selection of, 403, 406  
gas-fired units, 384  
conversions, 385  
grate area, 404  
heating, 395  
heating surface, 2, 397  
heat transfer rates, 397  
horsepower, 2  
hot water supply, 403, 1118  
loss, 397  
maintenance, 407  
oil-fired units, 373  
operation, 407  
output, 400  
rating, 398, 399, 402, 405  
rating codes, 398  
selection of, 403  
based on heating surface and grate area, 404  
cast-iron, 404  
estimated design load, 403  
estimated maximum load, 403  
gas-fired, 406  
hot water supply load, 403, 1115  
piping tax, 403, 634  
radiation load, 403  
steel, 396, 398, 404  
warming up allowance, 403, 406  
soot, 384  
space limitations, 406  
steel, 396, 398, 404  
stoker-fired units, 368  
testing codes, 398, 1167  
troubles, 407  
types, 395  
working pressure, 395  
British thermal unit, 2  
Bucket trap, 524, 525  
Building, buildings condensation, 207  
heat transfer through surfaces, 158  
infiltration, 227, 296, 311  
intermittently heated, 270  
materials, heat transfer through, 170, 175, 188, 195, 253  
multi-story, air leakage, 233  
Burner, oil, 375  
Bus air conditioning, 1094  
Bypass, 3, 680  
factor, 313

## C

Calcium chloride, 885, 890  
Calculated heat loss method, 249  
Calorie, 2  
Caloric value, 332, 343, 348, 349, 356

Carbon activated, 148, 885, 1092  
dioxide, 111, 158, 338, 346, 351, 353-363  
monoxide, 158, 352-353  
Cast-iron boilers, 395  
Ceiling cooling units, 620  
high, 210, 1091  
outlets, 719, 1091  
perforated, 720, 1091  
unit heater, 596  
Central air conditioning systems, 685  
accessibility, 700  
air quantity, 691  
apparatus dewpoint, 276, 320  
control, 687, 915  
cooling load, 275, 689  
corrosion, 938  
design procedure, 685, 731  
duct, 685  
effective temperature difference, 691  
equipment arrangement, 688  
equipment selection, 688  
evaporative cooling, 697  
fan and coil units, 696  
fan system, 2, 685  
features, 685  
heating load, 349, 690  
humidity control, 688  
individual room control, 689  
induction units, 692  
high pressure type, 693  
low pressure type, 692  
location of apparatus, 700, 1133  
outdoor air, 685  
precooling, 697  
reheating, 698  
selection, 698  
sensible cooling, 697  
summer only, 1121  
temperature differential, 691  
unitary central types, 692  
year-round, 685  
zoning, 687  
Centrifugal compressors, 871  
condensing unit, 871  
fan, 757  
Charcoal, 800  
Chart air elimination, 505  
air flow unequal openings, 238  
air flow and sound level, 957  
air friction, 734, 735  
axial jet velocities, 708  
chimney capacity, 426, 427, 429-432, 434, 435  
chimney draft, 423, 426, 429-432  
chimney flow, 427, 428, 429, 431, 438  
coil temperature, 583  
color, 22  
comfort, 126  
compressor and coil performance, 883  
correction for pipe roughness, 735  
dehumidifier performance, 894  
design temperature map, 257  
disease frequency, 133, 134  
draft required, 423  
dry vs. wet weight, 1063  
drying time, 1064, 1065  
dust particle size, 153  
economical thickness pipe insulation, 669  
edge loss, 265  
effective diameter, 707  
effective temperature, 124-127  
elbow loss, 742, 743  
entrainment ratio, 713  
estimating surface temperature, 202, 579  
expansion factor, 81, 82  
evaporation chart, 1077  
fan characteristics, 768-770

Chart (continued) fan sound level, 768-770, 949  
fan system characteristics, 771  
filter resistance, 790  
firebox dimensions, 374  
flow coefficients, 79, 80  
flow due to wind, 238  
flow through opening, 238, 239  
flow area, 244  
flow loss, 353  
friction air ducts, 734, 735  
friction factor, 71  
friction in pipes, 537, 639, 1108-1110  
fuel consumption, 391, 392  
fuel oil index, 346  
gas vents, 438  
head due to temperature, 536  
heat flow, glass, 300  
heat emission by radiation from panels, 576  
heat endurance, 119  
heat loss body, 115, 116, 120, 121, 122  
canvas surface, 662  
coefficients, insulated ducts, 760  
convection from panel, 577  
duct, 760  
floor, 255  
insulated pipe, 658-660, 662  
insulation, 647, 658-660  
humidity, 1075  
infiltration, 229  
inside surface temperature, 579, 580  
insulation of cold pipe, 664  
Langlier formula, 989  
moisture loss from body, 122  
motor characteristics, 628-632  
MRT elevation, 119  
orifice coefficient, 77  
orifice installation, 83  
panel heat output, 576-578  
permissible relative humidities for various transmission coefficients, 217  
pressure loss in ducts, 732  
742, 743  
pressure loss in faucets, 1111  
pressure loss in meters, 1111  
psychrometric charts, 61, 63, 1075  
persons at rest, 124  
pump performance, 546  
radial jet velocities, 708  
radiation between black bodies, 99  
radiation shape factor, 98  
refrigerant pressure-enthalpy, 850, 852  
refrigeration horsepower, 1018  
room absorption correction, 959  
solubility of calcium salts, 986, 987  
solubility of gases, 985  
sound attenuation, 953  
static deflection, 961  
static regain, 732, 733  
system characteristics, 771  
temperature in panel, 583  
thickness pipe insulation to prevent sweating, 664  
velocity and velocity head, 742  
vents contracts location, 85  
viscosity, air, 69  
viscosity, water, 70  
well water temperatures, 808  
Chemical, chemicals laboratory hoods, 1045  
reactions, 1028  
control of rate of, 1027  
vitiation of air, 111, 156  
water treating, 992, 993, 996, 1002  
Chimney, chimneys, 421  
available draft, 422, 429  
construction details, 439

## Index to Technical Data Section

Chart (continued) fan sound level, 768-770, 949  
fan system characteristics, 771  
filter resistance, 790  
firebox dimensions, 374  
flow coefficients, 79, 80  
flow due to wind, 238  
flow through opening, 238, 239  
flow area, 244  
flow loss, 353  
friction air ducts, 734, 735  
friction factor, 71  
friction in pipes, 537, 639, 1108-1110  
fuel consumption, 391, 392  
fuel oil index, 346  
gas vents, 438  
head due to temperature, 536  
heat flow, glass, 300  
heat emission by radiation from panels, 576  
heat endurance, 119  
heat loss body, 115, 116, 120, 121, 122  
canvas surface, 662  
coefficients, insulated ducts, 760  
convection from panel, 577  
duct, 760  
floor, 255  
insulated pipe, 658-660, 662  
insulation, 647, 658-660  
humidity, 1075  
infiltration, 229  
inside surface temperature, 579, 580  
insulation of cold pipe, 664  
Langlier formula, 989  
moisture loss from body, 122  
motor characteristics, 628-632  
MRT elevation, 119  
orifice coefficient, 77  
orifice installation, 83  
panel heat output, 576-578  
permissible relative humidities for various transmission coefficients, 217  
pressure loss in ducts, 732  
742, 743  
pressure loss in faucets, 1111  
pressure loss in meters, 1111  
psychrometric charts, 61, 63, 1075  
persons at rest, 124  
pump performance, 546  
radial jet velocities, 708  
radiation between black bodies, 99  
radiation shape factor, 98  
refrigerant pressure-enthalpy, 850, 852  
refrigeration horsepower, 1018  
room absorption correction, 959  
solubility of calcium salts, 986, 987  
solubility of gases, 985  
sound attenuation, 953  
static deflection, 961  
static regain, 732, 733  
system characteristics, 771  
temperature in panel, 583  
thickness pipe insulation to prevent sweating, 664  
velocity and velocity head, 742  
vents contracts location, 85  
viscosity, air, 69  
viscosity, water, 70  
well water temperatures, 808  
Chemical, chemicals laboratory hoods, 1045  
reactions, 1028  
control of rate of, 1027  
vitiation of air, 111, 156  
water treating, 992, 993, 996, 1002  
Chimney, chimneys, 421  
available draft, 422, 429  
construction details, 439

Chimney, chimneys (continued) determining sizes, 426, 434  
effect, 2  
efficiency, 431, 433  
factors affecting draft, 422  
gas heating, 437  
general considerations for, 436, 442  
industrial, 424, 426, 427  
performance, 421, 426, 427  
residential, 423, 429  
short, 431, 433  
sizes, 426, 427, 434  
static draft, 421  
theoretical draft, 421  
Chimneys, 154  
Circular equivalents of rectangular ducts, 737  
Circulators, 546  
Cleaning boilers, 408  
Climate conditions, 251, 279  
Closed expansion tank, 548, 549  
sizing formula, 549  
Coal, coals anthracite, 332-335  
bituminous, 332, 333, 336-340  
classification of, 332  
combustion, 335  
draft required, 339, 422  
dustless treatment, 334  
estimating consumption, 445, 457  
firing methods, 335-338  
lignite, 333  
Codes, 1187  
Installation, 1167  
rating, 1167  
testing, 1167  
Coefficients of transmission, 2, 167, 190-200, 657, 841  
basement, 262  
floor, 195, 264  
wall, 262  
coils, 566, 841  
correction for insulation, 182-183  
correction for framing, 186  
doors, 200  
floors and ceilings, 194  
frame construction, 190, 194  
glass, 200  
glass block walls, 200  
insulating materials, 171, 172  
masonry partitions, 193  
masonry walls, 191  
overall, 167, 566  
formulas for calculating, 168  
practical, 180  
roofs, 196-200  
skylights, 200  
windows, 200  
Coll, coils, 829  
air flow resistance, 840  
applications, 834  
arrangement, 830, 834  
bypass factor, 832  
construction, 830  
cooling, 829  
dehumidifying, 839, 842  
direct-expansion, 832  
dry cooling, 841  
fin coefficient, 842  
flow arrangement, 834  
heat emission, 566, 842, 1132  
heat transfer surface, 840  
heating, 838  
performance, 841, 843  
cooling, 841  
dehumidification, 843, 844  
heating, 841  
pipe, 566  
rating, 839  
selection, 837  
cooling, 839  
dehumidifying, 839  
heating, 838  
steam, 831  
uses, 829  
water, 833

Coke classification of, 334  
estimating consumption, 457  
firing methods, 337  
Cold therapy, 145  
Color, piping systems, 22  
Combustion, 331  
adjustments, 372, 375, 387  
air required, 357  
analysis, 358  
chamber, 373, 381  
dew-point, 364  
efficiency, 253, 380  
flue gas, 358, 360  
gas, 350  
heat balance, 361  
heat of, 355  
index, 345  
losses, 362  
oil, 344  
process, 369, 387  
principles of, 352  
rates, 366, 391, 392, 423  
smokeless, 336  
Comfort air conditioning, 2  
air conditioning systems, 685, 1089  
chart, 126  
line, 2  
zone, 2  
Compartment dryer, 1082  
Compressor, compressors, 869  
centrifugal, 871  
clearance, 869  
reciprocating, 869  
refrigeration, performance of, 880, 881  
rotary, 870  
volumetric efficiency, 859  
Condensates, 677, 993  
Condensate return pumps, 522  
Condensation buildings, 217, 219  
ceaseless, 219  
control, 221  
flue gas, 355  
surface, 217  
visible, 217  
Condensers, 872  
air cooled, 872  
design data, 820  
evaporative, 872  
water cooled, 872  
Condition line, 62, 320  
Conductance, 3, 167, 170, 178, 179  
air space, 170, 178  
building materials, 171, 178  
insulators, 171, 178, 657  
soil, 169  
surface, 175, 662  
Conduction, 3, 69  
drying methods, 1080  
electric heaters, 963  
equation, 90  
steady-state solutions, 101-102  
Conductivity, 3, 69, 175, 178  
batt type insulation, 171, 178  
building boards, 171, 178  
building materials, 171, 178  
homogeneous materials, 169  
insulating materials, 171, 172, 178, 179, 657  
insulation blankets, 171, 178  
loose-fill insulation, 172, 178  
masonry materials, 171, 178  
plastering materials, 171, 178  
rigid insulation, 172  
roofing construction, 172  
soil, 174, 175  
woods, 173, 179



Conductor, 3  
Conduits for piping, 875  
Connections  
boiler, 406, 520  
heating units, 532  
Control, controls  
airborne infection, 132  
aircraft temperature, 1097  
automatic, 895  
automobile temperature, 1096  
biochemical reactions, 1029  
central fan systems, 638  
chemical reactions, 1027  
contaminant by exhaust, 1041  
corrosion, 995  
crystallization, 1029  
dehydrating equipment, 864  
dew-point, 1030  
effect of hot environment, 1033  
high temperature water system, 538  
ice bunker water, 865  
laboratory conditions, 1030  
motor, 923  
panel heating, 911  
passenger bus temperature, 1095  
passenger car  
temperature, 1092  
humidity, 1093  
refrigeration, 874, 876  
service water temperature, 1123  
ship air conditioning, 1102  
sinks, 993  
sound, 941  
static electricity, 1030  
street car and coach temperature, 1093  
temperature for machining, 1030  
vibration, 959  
Control, automatic, 895  
action types, 896  
air washers, 915  
applications, 904  
auxiliary equipment, 903  
central fan systems, 912  
components of systems, 898  
controlled devices, 902  
controllers, 898  
controlling elements, 899  
cooling, 914  
dehumidification, 914  
design coordination, 917  
electric, 896, 900  
electronic, 896, 900  
equipment selection, 919  
floating, 997  
fuel burning equipment, 904  
fundamentals, 895  
gas burners, 907  
hot water heating, 910  
humidity, 914  
hydraulic, 898  
indicating, 900  
individual room, 912  
measuring elements, 898  
oil burners, 906  
operating, 905  
panel heating, 911  
pneumatic, 896, 900  
preheater coil, 913  
primary, 906  
proportional, 897  
recording, 900  
residential, 907  
size of area, 913  
space conditions, 915  
static pressure, 902, 915  
steam flow, 920  
steam heating, 909  
stokers, 908  
system types, 896  
typical system, 915  
unit heaters, 917  
unit ventilators, 916  
valves, 902  
water flow, 922  
zone, 908

Control, automatic (continued)  
some systems, 909  
Controllers, 895  
functions, 895  
types, 895  
Convection, 3, 89, 99  
equation, 91  
unit conductances, 93  
Convactor, convectors, 3, 561, 563  
correction factor, 563, 569  
heat emission, 564  
heating effect, 567  
induction, 592, 693  
ratings, 566  
Converging vanes, 716  
Conversion  
burners, 385  
equations, 15, 212  
Coolers, 609, 619, 873  
Cooling, 275, 603  
air conditioning units, 609, 1132  
atmospheric water, 803  
coil selection, 836  
evaporative, 697  
load, 275, 689  
methods, 1129  
performance of coils, 841, 843  
ponds, 811  
residential, 1129, 1122  
sensible, 697  
spray, 809, 811  
effect of wind, 812  
make-up water, 827  
size of equipment, 813  
winter freezing, 828  
systems, 685, 1090, 1094  
towers, 810  
atmospheric, 813  
design, 819, 820  
mechanical, 815  
operation, 827  
performance, 822  
selection, 825  
units, 609  
component parts, 610  
control, 615  
definitions, 609  
defrosting, 620  
design, 610  
performance, 609, 617  
ratings, 618, 620  
remote, 614  
sound insulation, 613  
types of, 619  
water, 811, 818  
water piping, 1114  
Copper elbow equivalents, 537  
Copper tube dimensions, 626  
Core area, 701, 1156  
Corrosion, 625, 981  
air ducts, 1000  
atmospheric, 989, 999  
boilers, 992  
cathodic protection, 1001  
coal storage equipment, 999  
cold water, 982  
condensates, 983, 984, 997, 998  
flue gas, 984  
flues, 999  
heating systems, 991  
hot water, 983  
industrial exhaust systems, 1006  
minimizing condensate, 997  
pipe, 993, 1000  
prevention, 985, 1038  
refrigerating systems, 986  
underwater, 993  
Cost of air conditioning, 1005, 1134  
amortization, 1005  
condenser water, 1013  
first, 1003  
fixed charges, 1005

Cost of air conditioning (continued)  
heating, 1014  
interest, 1008  
installed, 1006  
insurance, 1009  
labor, 1010  
maintenance, 1009  
owning and operating, 1011  
rent, 1009  
service, 1009  
taxes, 1008  
refrigeration equipment, 1011  
water, 1011  
Crack length  
method, 229  
used for computations, 267  
Crystallization  
control rate of, 1029  
Cylinder dryer, 1032  
D  
Dalton's rule, 28  
Damper, dampers, 340, 477, 685, 701, 719, 725, 775, 912  
Darcy formula, 69  
Decibel, 941  
Definitions, 1  
Defrosting, 821  
Degree-day, 3, 449  
for cities, 451, 460  
formula for, method, 450  
industrial, 460, 461  
operating unit, 459  
unit fuel consumption, 456  
Degree of saturation, 8, 25, 31  
Dehumidification, 687, 807, 885  
air conditioning units, 613  
air washers, 897  
coil selection, 829, 839  
comparison of methods, 885  
control, 889  
definitions and methods, 885  
equipment, 807, 885, 888  
performance, 888  
estimating loads, 892  
liquid methods, 890, 891  
moisture load, 892  
ships, 1102  
solid methods, 887, 888  
vapor transfer, 893  
Dehumidifying agents, 885  
absorbents, 885  
adsorbents, 885  
Density of air, 1  
Design conditions  
summer, 276, 279  
winter, 251-258  
Dew point  
apparatus temperature, 276, 320  
flue gas, 394, 999  
temperature, 9, 26, 1159  
Dichlorodifluoromethane, 849-851, 878, 879  
Dielectric heating, 977  
Diffusivity, thermal, 3  
Direct  
expansion coils, 832  
fired unit heater, 965  
indirect heating unit, 3  
radiator, 7  
return system, 3, 542  
Disc fan, 763  
Distribution of air (see Air Distribution), 463, 475, 701, 1090, 1098  
District heating, 671  
condensate return, 677  
meters, 653  
operation, 681  
pipe insulation, 677  
piping, 667, 679  
conduits for, 668  
inside, 679  
size, 673  
tunnels, 678

Index to Technical Data Section

District heating (continued)  
steam requirement, 671  
zoning, 681  
Diverging vanes, 716  
Domestic oil burners, 375  
Door, doors  
coefficients of transmission, 200  
leakage, 229, 231  
natural ventilation, 240  
Down-feed  
one-pipe riser, 3, 6, 495  
steam heating, 4, 501  
system, 4, 493  
Draft, drafts, 4, 421  
available, 424, 429  
calculations, 421  
chimney, 421  
control, 440  
factors, 422  
forced, 421  
general equation, 421  
head, 4  
industrial chimneys, 423  
natural, 233, 421  
regulation, 429  
residential chimneys, 428  
requirements, 339, 422, 436  
appliance, 436  
theoretical, 421  
Drawing symbols, 17  
Drip, drips, 4, 494, 529  
Drum dryer, 1082  
Dry air, 1  
composition, 25, 356  
filters, 753  
properties of, 30  
velocity, head, 742  
Dry-bulb temperature, 9  
Dry cooling coils, 829, 842  
Dry return, 8, 493  
Dryer, dryers, 1080  
cabinet, 1076, 1082  
calculations, 1076  
compartment, 1082  
cylinder, 1082  
drum, 1082  
rotary, 1082  
spray, 1083  
tunnel, 1082  
Drying, 1027, 1081  
application of hygrometry, 1075  
calculations, 1076  
chart, 1067, 1075, 1077  
conduction, 1081  
constant rate period, 1065, 1067  
convection, 1081  
critical moisture, 1072  
effect of air velocity, 1066  
equations, 1070  
equilibrium moisture, 1073  
equipment, 1080  
example, 1084  
external conditions, 1063  
factors influencing, 1062  
falling rate period, 1069  
internal conditions, 1063  
mechanism of, 1062  
methods, 1080  
conduction, 1081  
convection, 1081  
radiant, 1080  
periods, 1064  
problem, 1084  
radiant, 1080  
surface temperature, 1066  
systems, 1061  
terminology, 1061  
Duct, ducts, 465-467, 477, 723  
air velocities in, 476, 747, 1044, 1052  
approaches to outlets, 723  
area change, 744  
attenuation, 949, 953

Duct, ducts (continued)  
circular equivalents, 757  
construction details, 755, 1053  
design, 465, 478, 747, 748, 1048  
design methods, 748  
equal friction, 748  
static regain, 751  
velocity reduction, 748  
duct, 695  
dynamic losses, 740  
elbow friction losses, 742  
exhaust design, 1048  
friction losses, 733  
heat loss coefficients, 759, 760  
lining, 952  
measurement of velocities, 1152  
noise transmitted, 944  
pressure changes, 731  
pressure loss, 731, 733  
recirculating, 465, 467, 471, 728  
rectangular equivalents of  
round, 439, 737  
resistance, 731  
roughness correction, 738  
sizing, 731, 746  
sound absorbers, 950  
symbols for drawing, 17  
system design, 465, 469, 473, 731, 746  
weight, 758, 759  
Duct sizing, 731, 746, 1048  
equal friction method, 750  
general rules, 466, 478, 748  
static regain method, 751  
velocity method, 748  
Dust, 4, 151  
combustible, 161  
concentrations, 155  
determination, 154  
filters, 781, 790, 798  
precipitators, 785, 798  
removal, 781, 798  
size, 153  
Dust collectors, 781, 792  
application, 781, 790, 794  
centrifugal, 795  
cyclone, 798  
cloth, 796  
degree of dust removal, 793  
electrostatic, 798  
fabric, 796, 798  
factors affecting selection, 793  
inertial separators, 795  
settling chambers, 796  
scrubbers, 795, 797  
testing methods, 785  
types, 794  
wet, 795  
centrifugal, 797  
packed tower, 797  
spray towers, 797  
washers, 797  
wet filters, 797  
Dynamic head, 5, 740  
losses, 740  
E  
EDR (Equivalent direct radiation), 7, 396, 504, 508, 510, 512, 551  
defined, 7, 404, 563  
Effective temperature, 9, 122  
chart, 122, 126  
index, 122  
Efficiency  
boiler, 402  
conversion burner furnace, 414  
Ejector nozzles, 719  
Elbow  
attenuation, 949  
copper equivalents, 537  
friction losses, 537, 742, 743  
iron equivalents, 537, 557, 1112  
sheet metal, equivalent, 740

Electric, electrical  
baseboard, 967  
convactor, 967  
demand control, 978  
dielectric heating, 977  
heat applications, 964  
heating, 963  
calculating capacities, 975  
central, 970, 971  
control, 978  
domestic water, 974  
equipment, 965  
heat pump, 971  
induction, 977  
power problems, 977  
resistors, 8, 963  
systems, 966  
units, 964  
hot water heating, 970  
induction heating, 977  
installation methods, 964  
motor design limits, 924  
panel heating, 575, 968, 969, 970  
precipitators, 785, 798  
radiant convactor, 967  
radiant heating, 574, 967  
resistors, 965, 968  
steam radiators, 968  
systems, 925, 965  
voltage ratings, 924  
Electricity, static, 139, 1030  
Emissivity, 95, 170  
Enclosed radiator, 561  
Enthalpy, 4, 24, 30, 51  
free, 4  
specific, 4, 30  
Entropy, 4, 30, 51  
mixed, 4  
Equivalent evaporation, 4  
Estimating fuel consumption, 445  
Eupatheoscope, 1162  
Evaporative  
condensers, 872  
cooled, unit conditioners, 609  
cooling, 697  
Evaporators, 873  
Excess air, 340, 354, 358, 387  
Exhaust opening, 728, 1042, 1052  
measurement of velocities, 1052, 1156  
Exhaust systems, 1041  
air flow equipment, 1054  
axial velocity formula, 1042  
capture velocities, 1042  
construction, 1043  
conveying velocity, 1052  
corrosion, 1056  
duct construction, 1053  
duct design, 1048, 1053  
duct resistance, 1051  
duct system design, 1048  
duct velocity, 1044  
ducts for, 1046  
air velocities in, 1044-1048  
construction, 1053  
design, 1053  
resistance, 1058  
dust filters, 1055  
elements, 1041  
equipment, 1055  
exhaust requirements, 1048  
general requirements, 1041  
hoods, 1041  
air flow, 1043  
axial velocity formula for, 1042  
canopy, 1044-1047  
capture velocities, 1042  
chemical laboratories, 1045  
design principles, 1041  
kitchen, 1045  
special exhaust requirements, 1043  
spray booths, 1047  
suction, 1055

**Exhaust systems (continued)**  
velocity contours, 1043  
ventilation rates, 1044-1047  
make-up air, 1055  
maintenance, 1055  
materials, 1053, 1056, 1058  
performance, 1055  
pressure loss, 1051  
specifications, 1053  
suction requirements, 1055  
types of fans, 1054  
velocity contours, 1043  
velocity requirements, 1044-1051  
ventilation rates, 1044-1049

**Expansion**  
factor, gases, 81, 82  
of pipe, 532, 644  
tank installation, 551  
tank piping, 548  
tank size, 549  
tanks, 549  
valves, 675  
Explosion hazard, 138  
Extended plenum systems, 472, 473

## F

**Fan fans, 763**  
application, 777  
arrangement of drives, 772  
ratio, 779  
location, 779  
axial flow, 763  
centrifugal, 767  
characteristic curves, 768-771  
control, 774  
designations, 764  
drive position, 774  
efficiency, 767  
exhaust, 778  
furnace system, 475  
hot gas, 780  
installation, 777  
kitchen, 779  
laws, 768  
marine, 778  
mine, 778  
motive power, 775  
noise generated, 946  
performance, 763, 767, 768, 946  
radial flow, 763, 767  
rotation, 773  
selection of, 775  
air conditioning systems, 775  
industrial exhaust systems, 1064  
special application, 779  
speed, 776  
system characteristics, 771  
types, 763  
unitary systems, 778  
velocity, operating, 776  
volume control, 774

**Fanning formula, 69, 556**  
Fever therapy, 142  
equipment for production of, 143  
Film conductance, 93, 167, 168, 177

**Filter, filters, 781**  
air conditioning units, 613  
atmosphere, 781  
charged media, 776  
dry air, 785, 796, 1094  
dust, 785  
installation, 790  
ionizing, 785  
maintenance, 789  
moving curtain, 784  
performance, 787  
selection, 789, 793  
testing, 787  
vapor adsorption, 799  
viscous impingement type, 783

**Fitting allowance**  
pipe, 609, 537, 1112  
sheet metal, 483, 483, 740  
Flash loss, 539  
Flexible mountings, 959  
Float trap, 524  
Floor  
cooling unit, 609  
heat transfer coefficients, 194, 195  
panel design, 630  
unit heater, 595  
Floor slab heat loss, 263

**Flow**  
coefficient, orifices, 77  
compressible fluids, 73  
critical, 76  
measurement  
head meters, 78, 83  
liquids, 78  
orifices, 78  
Pitot tube, 84, 1152  
variable area meters, 85

**Flow meters, 78, 83, 1111**  
Flue gas analysis, 360  
Flue gas dew-point, 364  
Flue gas loss, 361  
Fluids, flow, 67  
theory, 67  
Fluid meters, 78, 1111  
Fog, 4, 162  
Force, 4

**Forced**  
air heating system, 475  
circulation pipe sizes, 542  
convection, 91-93  
Free  
convection, 92, 93  
enthalpy, 4  
Pressing in pipes, 666

**Friction loss**  
air ducts, 489, 731  
circular pipes, 69  
effect of area change, 744  
elbows, 468, 482, 509, 537, 742, 1112  
gas piping, 389  
high temperature, 556  
non-circular pipes, 72  
refrigerant piping, 878, 879  
water heating, 537, 539  
water piping, 537-539, 555, 1108-1110

**Fuel, fuels, 331**  
analysis, 331, 341, 348  
burning equipment, 367  
classification, 332, 334, 340, 349  
consumption, 445  
calculated heat-loss method, 447  
degree-day method, 449  
load factor, 461  
maximum demands, 461  
seasonal efficiency, 440  
unit, 455-459  
firing methods, 335, 336, 337  
gas, 347  
liquid, 340  
solid, 331  
unit consumption, 456, 457  
utilization, 410

**Fuel oil, 340**  
analysis, 341  
carbon residue, 342  
classification of, 340, 343  
combustion of, 344  
flashpoint, 342  
grade of, 343  
maximum carbon dioxide values, 359  
theoretical air requirements, 357  
viscosity, 343  
weight per gallon, 344  
Fumes, 4, 151

**Furnace, furnaces, 4, 409**  
capacity, 413  
casings, 415

**Furnace, furnaces (continued)**  
cast iron, 411  
design, 397, 414  
efficiency, 414  
fan, 410, 411  
filters, 410  
forced warm air, 410  
gas-fired units, 385  
grate area, 413  
gravity warm air, 410, 412  
heating surface, 412  
heavy duty, 411  
humidification equipment, 415  
materials, 411, 418  
mechanical warm air, 410  
controls, 490  
cooling methods, 492, 1132  
dampers, 477  
ducts, 477  
fans, 410  
filters, 410  
method of designing, 414  
motors, 410  
ratings, 412  
oil-fired units, 411  
rating, 406, 412, 413  
steel, 411  
stoker-fired units, 368  
types, 409  
volume, 4, 340, 374, 377  
warm air, 409

## G

**Gage, gages**  
draft, 1149  
pressure, 7, 1149  
Garage ventilation, 246

**Gas, gases, 152, 153, 347**  
appliance rating, 389  
atmospheric, 153, 164  
burner controls, 876  
burners, 385  
calorific value, 348, 349  
chimneys for heating, 436  
classification of, 349  
combustion of, 350  
equipment, commercial, 390  
equipment, industrial, 390  
estimating consumption, 453  
expansion factor, 81, 82  
flammable, 157  
flue, 358  
heaters, 419  
solubility, 685  
space heaters, 386, 419  
specific heat, 5  
wall heaters, 387

**Gaseous fuels, 347**  
calorific value, 348, 349  
classification of, 348, 349  
combustion of, 350, 357  
maximum carbon dioxide values, 359  
products of combustion, 354, 356  
properties of, 348  
specific gravity, 348  
theoretical air requirements, 348, 349  
typical analyses, 348

**Gas-fired appliances, 384**  
boilers, 384  
combustion process, 387  
controls, 406  
conversion burners, 385  
furnaces, 385  
measurement of efficiency of, 387  
pipe size, 389  
ratings for, 388  
sizing heating plants, 389  
space heaters, 388

**Glass**  
coefficient of transmission, 200  
design tables, 299, 306  
heat absorbent, 302

## Index to Technical Data Section

**Glass (continued)**  
shading of, 308  
solar heat transmitted, 297, 304  
window transmittance, 300

**Glass block walls**  
coefficient of transmission, 200  
solar heat gain, 305-307  
Globe thermometer, 1162  
Graphical symbols for drawings, 17  
air conditioning, 17, 21  
duct work, 19  
heating, 17, 19, 19  
piping, 17  
refrigerating, 21  
ventilating, 19, 20  
Grate area, 5, 404, 412

**Greek alphabet, 14**  
Grille, grilles, (see registers), 455, 487, 478, 701, 715, 956  
air supply nozzles, 355  
attenuation, 949  
exhaust, 455, 726  
locations, 455, 720, 726  
door, 727  
floor, 727  
wall, 727  
mechanical furnace systems, 471  
nozzles, 726, 956  
railway car, 1091  
recirculating, 1091  
return, 465, 726, 658  
selection, 956  
velocity, 478, 726, 768  
Ground temperatures, 262

**Guarded hot plate, 1161**  
Gun type oil burners, 376

## H

**Hangers pipe, 643**  
Hartford return connection, 495, 620

**Hay fever symptoms, 144**  
Health, 131, 1031

**Heat, 5**  
area transmitting surface, 1121  
auxiliary sources, 269, 314  
balance, 361  
combustion, 332, 349, 355, 656  
emission of  
appliances, 316  
occupants, 120-122, 314  
pipe coils, 673  
exchange measurements, 114  
flow resistance, 99, 167  
flow through glass, 200, 297  
flow through roofs, 189, 196-199, 292, 296  
flow through walls, 186, 190-199, 294  
gain, 275  
generated by motors, 315  
humid, 6  
infiltration equivalent, 311  
instantaneous load, 283, 310  
introduced by outside air, 311  
lag, 690  
latent, 5, 268, 275, 313, 314, 327  
liquid, 5  
loss, pipe, 653  
mechanical equivalent of, 6, 13  
methods of, transfer, 89  
radiant, 92, 95, 96  
ratio, sensible, 311  
removal, natural ventilation, 235  
sensible, 5, 267, 316  
specific, 5  
transfer, 89, 190-200, 564-569, 759, 1121  
boiler rates, 397  
overall coefficients, 167, 168, 178-200, 841, 1121, 1122

**Heat (continued)**  
surface coils, 638  
symbols, 17, 94, 167  
through building materials, 167  
water coils, 1121, 1122

**Heat gain, 375**  
appliances, 316  
ceilings, 311  
components of, 275  
ducts, 690, 759  
electrical heating equipment, 316  
floors, 311  
gas burning equipment, 318  
glass, 201-202  
glass blocks, 305  
infiltration, 311  
instantaneous, 310  
latent, 284, 312, 314  
lights, 316  
moisture, 319  
occupants, 314  
outside air, 313  
partitions, 307  
people, 120, 314  
roof, 289, 298  
sensible, 283, 312  
shaded windows, 308  
solar, 301  
steam heated equipment, 317  
various sources, 270, 319  
ventilation, 311  
wall, 289, 294

**Heat loss**  
air change, 268  
bare pipe, 566, 653  
basement per  
duct, 759  
floor slab, 264  
infiltration, 266  
insulated pipe, 656  
latent, 268  
residence problems, 270  
sensible, 267  
through ceilings and roofs, 266  
transmission, 167, 265  
Heat pump, 548, 556, 857, 971, 1127  
Heat removal, 237

**Heater, heaters**  
direct-fired unit, 595  
electric, 597, 653  
gas, 419  
design, 420  
efficiency, 419  
materials, 419  
rating, 418  
testing, 418  
oil, 417  
design, 419  
materials, 418  
rating, 418  
testing, 418  
solar water, 1125  
solid fuel, 416  
design, 417  
equivalent, 416  
rating, 416  
testing, 416  
space, 416  
installation, 420  
unit, 595, 664  
vertical blow unit, 596

**Heating**  
air conditioning units, 609  
boilers, 395  
surface, 9, 397  
coil selection, 637  
district, 671  
effect, radiator, 567  
electric, 963  
hot water, 974  
load, 249, 316, 402, 690  
performance of coils, 841, 1121  
reversed cycle refrigeration, 867

**Heating (continued)**  
steam systems, 493  
surface, 9  
square foot of, 8  
symbols for drawing, 17  
the radiator, 569  
vacuum systems, 10, 493, 500  
vapor, 10, 498  
warm air system, 10, 463, 475  
water, 535, 1118  
Heavy duty fan furnace, 411  
High duty humidifiers, 809  
High temperature hazards, 117, 137

**High temperature systems, 553**  
boilers for, 559  
circuits, 556  
control, 558  
design, 558  
economics, 555  
fittings, 558  
fitting pressure loss, 557  
fundamental principles, 553  
general considerations, 553  
insulation, 558  
pipe, 558  
pumps, 558  
storage effect, 560  
Hood, hoods, 1041  
Horsepower, boiler, 2

**Hospital, hospitals**  
air conditioning in, 131, 147  
operating rooms, 138  
air conditions, 139  
reducing explosion hazard, 138  
sterilization of air, 132  
ventilation requirements, 140

**Hot water**  
boiler supply load, 403, 1115  
coil surface, 1121  
demand per  
fixture, 1106, 1107, 1118  
person, 1115, 1116  
electric heating, 974  
heat pump, 1127  
heating surface, 1121  
indirect heater, 1110  
methods of heating, 1118  
panel heating, 571  
safety devices, 1124  
service, 1105  
service piping, 1122  
solar heaters, 1125  
storage tank, 1115  
supply  
boilers, 896, 974, 1118  
piping, 1122  
temperature control, 1123

**Hot water heating systems, 5, 535**  
circulation head, 535, 536, 543  
classification, 539, 542  
direct return system, 542  
expansion tank, 548  
forced circulation, 536, 539, 544  
friction heads, 536  
gravity, 535, 539  
available head, 535  
circulation, 535  
pressure heads, 535  
high temperature, 553  
boilers, 559  
circuits, 558  
control, 558  
design, 558  
economics, 555  
fundamental principles, 553  
insulation, 558  
pipe fittings, 558  
pumps, 558  
storage, 560  
installation details, 551  
mechanical circulators, 546, 548

Hot water heating systems (continued)

one-pipe  
forced circulation, 540, 543, 545  
gravity circulation, 539, 542, 543  
orifice friction heads, 541  
pipe sizes, 537-539, 545  
forced circulation, 535-540  
gravity circulation, 535-540  
piping design, 542, 556  
pressure head, 535  
relief valve, 552  
reversed return system, 542  
safety devices, 552  
two-pipe  
forced, 540, 543, 547  
gravity, 539, 546  
zoning, 552

Human body  
acclimatization, 118  
adaptation, 113, 118  
cold condition, 115  
hot condition, 115, 314  
heat emission, 120, 314  
high temperature hazards, 117  
metabolic rates, 113  
odors, 113  
temperature, 114  
thermal interchanges, 113  
some of evaporative regulation, 115  
Humid heat, 5

Humidification, 613, 805, 807  
control, 490, 914  
direct, 807  
forced furnace systems, 490

Humidifier, humidifiers  
air washer, 807  
atomizing, 809  
high duty, 809  
self-contained, 810  
spray, 809  
unit, 809  
Humidistat, 5

Humidity, 5  
absolute, 5  
control, 488, 914, 1092  
influence of, 122, 141  
measurement of, 1158  
nurseries for premature infants, 140  
ratio, 5, 25  
relative, 5, 25, 699  
Hygrometers, 1159, 1160  
Hygroscopic materials, 1026  
Hygrostat, 5, 901

Ice systems, 865  
Impulse trap, 524-527  
Inch of water, 5  
Induction units, 693  
high pressure types, 693  
low pressure types, 692

Industrial  
air conditioning, 1015  
calculations, 1031  
conditioning and drying, 1027  
contaminant control, 1031  
control of chemical reactions, 1027  
dilution systems, 1032  
general requirements, 1015, 1031  
humidities, 1016-1026, 1030  
laboratory, 1030  
local relief, 1033  
machining tolerance, 1030  
moisture content and regain, 1026  
polished surfaces, 1030  
process, 1015

Industrial (continued)  
safety, 1031  
spot cooling, 1036  
static electricity, 1030  
temperatures, 1016-1026  
exhaust systems, 1041

Infiltration  
causes, 227  
due to wind pressure, 228  
heat losses, 266  
latent, 267  
sensible, 267  
measurement, 1163  
temperature differences, 233  
through outside doors, 229, 231  
through walls, 228  
through windows, 229  
Inflammability, 163  
Inside temperature, 258, 259, 276  
Instruments, 1145

Insulation, 5, 653  
economical pipe thickness, 667  
gravity furnace duct, 463, 464  
low temperature pipe, 663  
pipe, 653  
pipes to prevent freezing, 665  
sound, 950  
thermal conductivity, 657  
underground pipe, 667  
Intermittently heated buildings, 270  
Isobaric, 6  
Isothermal, 6

J

Jets, 703  
expansion, 705  
radial, 710  
velocity, 705  
Joints, duct, 755

K

Kata thermometer, 1157

L

Laboratories, 1030  
Latent heat, 5, 266, 276  
loss, 268  
Laws of thermodynamics, 9  
Leaders, 463  
Leakage of air, 227  
door, 229, 231, 232  
window, 229, 230, 311  
Light heat gain, 315  
Lignite, 338  
Liquid  
absorbents, 890  
heat of, 5  
Lithium bromide, 885  
Lithium chloride, 885

M

Load  
cooling, 275, 689  
design, 6, 269  
factor, 461  
heating, 243, 690  
maximum, 6, 403, 461  
refrigeration, 275  
Machine vibration, 959  
Manometer, 6, 1150  
Marine (see ship heating, ventilation, air conditioning)  
Mass, 6  
Mbb, 538  
Mean radiant temperature, 119, 579, 581, 912  
Meter, meters, 78, 683  
area, 78, 85, 683  
condensate, 683  
flow, 78, 85, 683

N

Natural draft, 421  
towers, 913  
Natural ventilation, 235  
general rules, 241  
heat removal, 237  
Noise, noises, 941, 1133  
absorptive material, 950  
air conditioning system, 942, 1133  
air supply opening, 955  
apparatus for measuring, 942  
attenuation, 949  
average in rooms, 946  
control, 941  
controlling vibration, 959  
cross transmission between rooms, 958  
design room level, 945  
duct sound absorbers, 950, 952  
duct system attenuation, 949  
fans, 948  
general problem, 942  
grille, 956  
intakes, 726  
kinds of, 944  
levels, 717, 943, 945  
loudness, 941

Meter, meters (continued)  
force, 78  
head, 78, 83, 684  
installation, 683  
orifice, 79, 1154  
selection, 684  
velocity, 684  
venturi, 1155  
Metering, liquids, 78, 683  
Micromanometers, 1151  
Micron, 6  
Mist, 162

Moist air, 25  
properties of, 25  
saturation, 26  
specific volume, 32

Moisture, 205, 1026, 1061  
content, 1026, 1028, 1062  
in building construction, 205  
load, 319  
loss per person, 122, 314, 892  
movement in materials, 208  
permeability, 212  
regain, 1026  
transmission, 208  
Mol, 6  
Monofluorotrichloromethane, 849, 853

Motor, motors, 270, 210, 923  
alternating current, 927  
capacitor type, 930  
classification, 926  
control, 934, 937  
control equipment for, 934  
current limitation, 935  
design limits, 924  
drives, 924  
electric, 923  
enclosures, 930  
glossary, 938  
heat generated by, 270  
hermetically enclosed, 932  
increment limitation, 935  
multi-speed, 929, 930  
polyphase, 927  
rating, 938  
regulation induction, 931  
selection, 923  
single phase, 930  
speed characteristics, 926  
speed classification, 939  
speed ranges, 924  
split phase, 931  
squirrel cage, 927, 934  
starting methods, 934  
synchronous, 928, 935  
wound rotor, 928, 935

N

Natural draft, 421  
towers, 913  
Natural ventilation, 235  
general rules, 241  
heat removal, 237

Noise, noises, 941, 1133  
absorptive material, 950  
air conditioning system, 942, 1133  
air supply opening, 955  
apparatus for measuring, 942  
attenuation, 949  
average in rooms, 946  
control, 941  
controlling vibration, 959  
cross transmission between rooms, 958  
design room level, 945  
duct sound absorbers, 950, 952  
duct system attenuation, 949  
fans, 948  
general problem, 942  
grille, 956  
intakes, 726  
kinds of, 944  
levels, 717, 943, 945  
loudness, 941

Index to Technical Data Section

Noise, noises (continued)  
measurement, 942  
openings, 955  
plate cells, 953  
plenum absorption, 955  
through building construction, 958  
transmitted through ducts, 944  
typical sound level, 945  
unit of measurement, 941  
Nozzle flow, 75, 78

Nurseries for premature infants, 140  
air conditioning equipment, 141

O

Odors, 111, 113, 147, 156, 792  
human body, 111

Oil Fuel, 340  
analysis, 341  
calorific value, 344  
classification of, 340, 343  
combustion index, 345  
combustion of, 344, 378  
estimating consumption, 392, 455  
heating of, 383  
piping, 383  
storage, 383

Oil burners, 382  
atomizing, 382  
boiler settings, 381  
classification, 375, 382  
combustion adjustments, 379  
combustion process, 378  
commercial, 382  
controls, 906  
domestic, 375  
furnace design, 381  
gun type, 375  
industrial, 382  
measurement of efficiency of combustion, 380  
mechanical draft, 375  
operating requirements, 378  
rotary type, 376, 382  
vaporizing type, 377

One-pipe system, 494, 540, 545  
gravity air-vent, 496  
hot water, 545  
steam, 6  
supply riser, 6  
unit heater connection, 494  
vapor, 496

Opening, openings  
air supply noises, 955  
stacks, 241  
types of, 240  
doors, 240  
roof ventilators, 240  
skylights, 240  
vertical, 234  
windows, 240

Operating rooms, 133  
conditions, 139  
reducing explosion hazard, 138  
sterilization of air in, 140  
Orifice  
discharge, 75, 504, 541  
flow, 75  
formulas, 77, 1154  
heating systems, 509  
Orsat apparatus, 1162  
Outdoor air, 113, 685, 1090, 1093

Outlet, outlets  
air supply noises, 955  
ceiling, 719  
duct approaches, 723  
location, 465, 475, 476, 720  
performance, 715, 721  
selection, 720  
side outlets, 476

Outlet, outlets (continued)  
sound absorbers, 955  
types, 476, 704  
wall outlets, 718  
Outside temperature, 251, 279  
Overhead distribution, 498, 1123  
Overhead system, 498, 1123  
Oxygen  
chambers, 146  
tents, 146  
therapy, 145  
Ozone, 113

P

Panel heating, 571  
application methods, 571  
calculation principles, 575, 580  
convection transfer, 576  
design of panel, 550, 583  
electric, 572, 968-970  
embedded piping, 572  
hot water, 571  
installation, 584  
output from surface, 575, 578  
piping, 583  
radiation transfer, 575  
starting system, 573  
steam, 571  
warm air, 490, 574  
Panel radiator, 6  
Particle size chart, 153  
Perfect gas relationships, 27  
Perforated ceilings, 720  
Perforated outlets, 711, 720  
Permeability, 206, 213  
Permeance, 209, 212, 213  
pH value, 409, 987, 994  
Physical impurities in air, 113

Physiological principles, 111  
acclimatization, 118  
comfort chart, 126  
effective temperature, 122  
high temperature hazards, 117  
thermal interchanges, 113  
upper limits of heat, 119  
Pipe coils, 566, 591  
heat emission, 565, 654  
wall, 566

Pipe, piping, 623  
application, 650  
capacity, 506, 508-518, 538, 1105  
coatings, 1001  
coil connections, 532  
coil output, 565  
cold water, 1105  
commercial dimensions, 627  
conducts for, 674  
connection to heating units, 520, 532  
corrosion, 981, 993  
covering, 653  
design, hot water system, 542  
dimensions, 624  
economical thickness insulation, 667  
expansion, 644  
fittings, 629, 633  
fitting equivalent, 509, 537, 553, 1106, 1112  
flexibility, 644  
forced circulation, 542  
friction loss, 536, 553, 1109  
hangers, 648  
heat losses, 653, 656  
hot water heating systems, 542  
hot water supply, 1122  
inside dimensions, 624  
insulation, 656, 677  
insulation prevent freezing, 665  
low temperature insulation, 663  
materials, 623, 1001  
one-pipe forced circulation, 545  
one-pipe gravity circulation, 545  
one-pipe vapor, 515

xix

Pipe, piping (continued)  
overhead distribution, 499, 1123  
properties, 624, 646  
sizes, 507, 542  
cooling systems, 1114  
gas, 369  
high pressure steam, 514-516, 554  
high temperature water, 553  
hot water forced circulation, 545, 547  
hot water gravity circulation, 545  
indirect heating units, 518  
low pressure, 529  
one pipe riser, 510, 516  
one pipe vapor, 515  
orifice systems, 502  
pressure drop, 507  
sub-atmospheric systems, 517  
tables for steam, 510-515  
threading data, 628, 629  
two-pipe forced circulation, 547  
two-pipe gravity circulation, 545  
two-pipe low pressure, 516  
two-pipe riser, 510  
two-pipe vapor systems, 516  
vacuum systems, 517  
water supply systems, 1105, 1122  
steam distribution, 510, 675  
steam heating systems, 510-515  
supports, 648  
surface, 626  
symbols for drawings, 17  
tax, 403, 653  
threading practice, 629  
tunnels, 677  
underground insulation, 667  
unit heater connections, 494, 534, 600  
water supply, 1105  
welding, 648  
Pitot tubes, 84, 1152  
Plate cell, 953  
Plenum absorbers, 955  
Plenum chambers, 6, 473  
Pneumatic control systems, 898

Pollution of air, 151  
Polyphase motors, 927  
Ponds, 811  
Potentiometer, 7, 1147  
Power, 7  
Precipitators, 785, 798  
Precooling, 697  
Premature infant nurseries, 140

Pressure  
absolute, 1  
atmospheric, 1  
changes in ducts, 731, 744  
gages, 1149  
loss, elbows, 468, 482, 509, 537, 557, 1112  
loss, water supply piping, 1108-1110  
measurement, 1139  
barometer, 1151  
regulator, 518, 680, 902  
static, 7  
taps, 84  
total, 7  
vapor, 7  
velocity, 7  
Prime surface (see Heating Surface), 9  
Propeller fan, 763, 771  
Protective coatings, 1001  
Psychrometer, 7, 1158  
Psychrometric chart, 51-63, 124

Pump, pumps  
condensate return, 522  
high temperature, 556  
mechanical circulators, 546, 556

**Pump, pumps (continued)**  
vacuum heating, 522  
controls, 523  
piston displacement, 523  
**Pyrometer, 7, 1149**  
optical, 1149  
radiation, 1149

**R**

**Radial flow fan, 763**  
Radiant drying, 1089

**Radiant heating. (see Panel heating)**

**Radiation, 7, 89**  
baseboard, 564, 566  
equation, 92  
finned tube, 565  
load, 403  
ratings, 566  
shape factor, 95, 575

**Radiator, radiators, 7, 561**  
baseboard, 564, 567  
codes, 563, 566, 1172  
concealed, 563  
connections, 531  
correction factor, 568  
direct, 7  
effect of paint, 569  
enclosed, 569  
gas-fired, 387  
heat emission of, 561  
heating, 569  
heating effect, 567  
output of, 561, 568  
panel, 6  
ratings, 566  
recessed, 5, 565  
tube, 563  
types of, 567  
warm air, 387

**Railway air conditioning, 1089**  
air cleaning, 1090  
air distribution, 1090  
heating, 1089  
humidity control, 1092  
refrigeration, 1090  
summer systems, 1090  
temperature control, 1092  
ventilation, 1091  
winter systems, 1089

**Reciprocating compressors, 869**  
Recording equipment, 900  
Rectangular duct equivalents, 737

**Reducing valves, 518, 680**  
Reflective insulation, 170, 178

**Refrigerant, refrigerants, 8, 847, 849**  
dichlorodifluoromethane, 850, 851  
feeds, 834  
monochlorodifluoromethane, 852, 853  
monofluorotrichloromethane, 854  
pipe size, 877  
water, 862

**Refrigeration, 847, 1090, 1094**  
absorption system, 863  
accessories, 880  
air cycle, 861  
basic concepts, 847  
complex cycles, 860  
compressors, 869-873  
condensers (see *Condensers*), 872  
control, 874, 876  
coolers, 873  
definitions, 847  
discharge pressure, 858  
equipment selection, 851  
evaporators, 873  
expansion valves, 875  
float valves, 875

**Refrigeration (continued)**  
heat pump, 866, 867  
ice systems, 866  
load, 275  
mechanical, 847, 855, 1094, 1102  
piping, 877  
reverse cycle, 848, 867  
ship, 1102  
simple cycle, 845  
steam jet, 861  
subcooling, 858  
suction, 857  
superheating, 854  
symbols for drawing, 17  
theory, 847  
ton of, 8, 847  
types of compressors (see *Compressors*), 871  
vapor compression cycle, 854  
volumetric efficiency, 859  
water jacket, 858

**Regain, 1028, 1028**  
control of, 1015  
hygroscopic materials, 885  
static, 751

**Register, registers. (see Grilles)**, 463, 465, 476, 701, 719, 726  
air supply noises, 555  
mechanical furnace systems, 476  
noises, 717, 955  
selection, 463, 476, 720  
Reheat, 680, 695  
Relative humidity, 5, 25, 52, 217  
measurement of, 1153  
Relief valve, 552, 1124

**Residence**  
control systems, 907  
air conditioning, 907, 1129  
domestic hot water supply, 1123  
heating, 907  
cooling methods, 492, 1129  
gravity furnace systems, 953  
heat loss problems, 270  
hot water heating system, 535  
mechanical furnace system, 475  
steam heating system, 493

**Residential Air Conditioning, 1129**  
air distribution, 1133  
application, 1131  
central systems, 1131  
equipment capacity, 1129  
equipment location, 1133  
equipment types, 1130  
noise, 1133  
operating costs, 1134  
Resistance thermometers, 1148  
Resistors, 953

**Return**  
grille, 465, 471, 726, 958  
main, 8, 493, 512-515  
openings, 465, 729  
Reverse cycle refrigeration, 848, 867  
Reversed return system, 8, 542  
Ringelmann chart, 1162

**Roof, roofs**  
heat flow through, 179, 196-199, 289, 292, 298  
time lag of solar radiation, 310  
ventilators, 240

**Room**  
air conditioners, 609, 1131  
air motion, 702, 717  
control, 908  
coolers, 609, 614, 615, 619  
cross transmission noise, 958  
latent heat, 314, 315  
noise level, 945  
operating, 138  
sensible heat, 313

**Rotary dryer, 1082**  
Rotary oil burner, 376, 382

**S**

**Sanitary ventilation, 132**  
Saturated air, 1, 25  
Saturation, 8  
degree of, 8, 25  
pressure, 7

**Scale, 983**  
cause and prevention, 981, 985  
closed systems, 983  
heating systems, 992  
high temperature, 992  
open systems, 990  
temperature, 9

**Schoolhouse Heating and Ventilating**  
design factors, 1138  
classrooms, 1138  
direct radiation, 1142  
economic, 1040  
forced air, 1142  
gravity exhaust, 1141  
mechanical exhaust, 1141  
panel heating, 1143  
unit ventilator, 1143  
general considerations, 1137  
maintenance, 1144  
operation, 1144  
systems, 1141  
Secondary air, 338, 354, 388  
Sectional boiler, 395

**Sensible cooling, 697**  
Sensible heat, 267, 275, 314  
gain, 275, 314  
loss, 267  
Sheet metal gages, 757, 758

**Ship heating, ventilation, air conditioning, 1100**  
air conditioning, 1100, 1102  
design conditions, 1101  
factors affecting design, 1100  
general absorption, 1100  
heating, 1100  
insulation of ducts, 1100  
refrigeration, 1091  
requirements for space, 1101  
cargo, 1102  
living, 1100  
machinery, 1101  
storeroom, 1102  
systems, typical, 1109  
ventilating, 1100

**Silica gel, 587**  
Silicon dioxide, 887  
Single phase motors, 930  
Slime, 983, 992  
cause and prevention, 992  
formers, 981  
Slotted outlets, 711  
Sludge, 981  
cause and prevention, 992  
Smoke, 8, 154  
abatement, 155, 336  
density measurements, 1162  
Smokeless arch, 8  
Smokeless combustion, 338

**Snow melting, 584**  
artificial characteristics, 688  
circulating medium, 591  
effect of viscosity, 589  
design, 584  
draining, 591  
drifting snow, 592  
heat from slab, 587  
heating requirements, 584  
installation, 590  
internal corrosion, 591  
pumping head, 588  
safety, 590  
slab construction, 591  
snowfall, 585  
testing installation, 591  
thermal stresses, 591  
Soil specific heat, 174

Index to Technical Data Section

**Solar constant, 8, 284**

**Solar heat, 284**  
absorbed by glass, 300  
altitude, 285  
calculation tables, 286-288, 292-298  
through shaded windows, 308  
time lag, 310  
transmission of, 284  
through glass, 297, 302  
through glass block, 305  
through roofs, 289  
through walls, 289

**Solar heat gain, 284**  
basic principles, 284  
design for figured rolled glass, 303  
design for flat glass, 299, 302  
design for glass block, 305  
deviation from design, 306  
shading glass, 308

**Solar radiation, 284**  
absorption of, 284  
magnitude, 284  
Solar water heater, 1125  
Sol-air temperature, 289

**Soot, 156, 336, 384**  
Sorbents, 885  
absorbents, 885, 889  
adsorbents, 885

**Sound (see Noise), 941**  
absorbers, 940, 953  
apparatus for measuring, 942  
attenuation, 949  
control, 946, 959  
cross transmission between rooms, 953  
general problem, 943  
duct absorbers, 950, 952, 953  
intensity, 941  
isolation, 913  
levels, 942, 946  
measurement, 942  
outlet absorbers, 955  
pressure, 941  
unit, 941  
Space heaters, 416  
design, 417  
rating, 416  
Split systems, 8  
Splitter dampers, 725

**Spray**  
apparatus, 803  
booths, 1047  
cooling, 809  
cooling ponds, 811  
cooling towers, 813  
dehumidifier, 809, 807  
distribution, 809  
dryer, 1083  
equipment, 803  
generation, 809  
humidifiers, 807-810  
unit air conditioner, 613  
Spread, air distribution, 702, 716  
Square foot of heating surface, 8  
Squirrel-cage induction motor, 924, 926, 927, 934

**Stack, stacks, 227, 241, 421, 463**  
height, 8, 243  
wall, 453, 466  
smoke, 421

**Standard, standards, 1167**  
air distribution, 702  
atmosphere, 63  
Standard air, 1  
Static  
electricity elimination, 1030  
pressure, 7, 731, 764  
regain, 751  
Steady flow, energy equation, 24, 67

**Steam, 8**  
coils, 829, 838  
distribution piping, 603, 674  
estimating consumption, 456, 657, 672  
flow, 505, 506  
flow measurement, 78, 683  
heated equipment, 317, 672  
heating systems, 493  
condensate return, 463, 677  
connections to units, 532  
control valves, 533  
corrosion, 691  
drips, 529  
flash lag, 530  
gravity one-pipe air-vent, 495  
gravity return, 494  
Hartford return, 495  
high pressure steam, 511  
low pressure steam, 511  
mechanical return, 494  
one-pipe, 494  
orifice, 502  
piping for, 503  
sub-atmospheric, 501  
two pipe, 496  
vacuum, 490  
vapor, 498  
jet type system, 861  
meters, 78, 683  
panel heating, 571  
pipe capacities, 506-515  
properties, 32, 49  
reducing valves, 518  
requirements, 468, 672  
runout, 495  
superheated, 8  
tables, 32, 49  
traps, 524  
valves, 533  
velocity, 508, 675  
Steel boilers, 396  
Sterilization of air, 132

**Stoker, stokers, 387**  
classification of, 387  
combustion adjustments, 372  
combustion process, 369  
controls, 375  
furnace design, 373  
mechanical, 367  
overfed flat grate, 371  
overfed inclined grate, 369  
sizing and ratings, 374  
underfeed, 370  
Sub-atmospheric systems, 501  
Summer air conditioning system, 275, 1129  
Summer climatic conditions, 279  
Summer comfort, 126, 127

**Supply mains, 9**  
Supply openings, 476, 701, 718, 720, 955, 1091  
measurement of velocities, 1152, 1156  
Supports, pipe, 648

**Surface**  
condensation, 205, 217, 221, 656  
conductance, 3, 170, 177  
coefficients, 92, 170, 663  
external pipe, 624, 626, 654  
heating, 9  
extended, 9  
temperature, 202, 415, 680, 1148  
Suspended unit heater, 596

**Symbols, 12, 13, 14, 15**  
air conditioning, 31  
for drawings, 17  
heating, 18  
piping, 17  
ventilating, 19

**T**

**Tables**  
air changes, 233  
air conditioning temperatures and humidities, 1016-1026

**Tables (continued)**  
air duct size, 466  
air leakage, 228, 230, 232  
air requirements, 113  
air, volume of, 32  
allowable concentration  
gases, vapors, 158  
dust, fumes, 160, 161  
altitude, pressure and temperature, 63  
aluminum ducts, 758  
analytical solutions for heat conduction, 107  
anthracite size, 533  
anti-freeze, solutions, 583  
atmospheric gas, 985  
atmospheric impurities, 163, 985  
attenuation  
between grille and room, 951  
data, lining board, 953  
in straight ducts, 949  
of branches, 950  
of elbows, 950  
of plate absorber, 954  
attic ventilation, 953  
azimuth angle, 288  
black body radiation, 96  
boiler ratings, 399, 400, 401  
bonnet pressure, 489  
building load factors, 463  
caloric value, 332, 344, 348, 356  
capacity constants, unit heat-ers, 698  
capture velocities, 1042  
carbon dioxide maximum, 362  
cast-iron boiler rating, 402  
ceiling temperature, 289  
chimney draft, 435  
chimney efficiency, 433  
circular equivalents of rectangular ducts, 737, 738, 739  
classification of  
coals, 333  
hot water heating systems, 542  
motors, 928  
water, 852  
climatic conditions, 251, 279  
coal analyses, 332  
coal classification, 333  
codes, 1167  
coil heat emission, 666  
combustible elements and compounds, 356  
combustion rates, 405  
comfort ranges, 123  
condenser design data, 826  
conductance, 63, 170-173, 175, 176, 179  
air space, 170, 178  
conduction problem solution, 101, 107  
conductivity materials, 91, 171-175, 178, 179  
contaminant exhaust, 1042  
convection conductances, 63  
conversion equations, 15  
conveying velocity, 1044-1047  
cooling coil arrangements, 889  
cooling tower performance, 824  
cooling tower pipe size, 1114  
copper elbow equivalents, 537  
copper sheets, 758  
copper tube capacity, 540  
copper tube dimensions, 626  
copper tube surface, 626  
correction factors  
steam radiator, 568  
unit heaters, 568  
water radiator, 568  
corrosion resistance, 1156  
cost of air conditioning, 1006  
decibel scale, 943  
degree-days for cities, 451-454, 460-461  
design dry- and wet-bulb temperatures, 251, 259, 278, 279, 1016, 1101  
design humidity, 1016-1026  
dew-point, fuels, 365

**Tables (continued)**  
 draft in chimneys, 435  
 draft requirements of appliances, 438  
 duct attenuation, 949, 950  
 duct combinations, 458, 479  
 duct gages, 757  
 duct joints, 756  
 duct pressure drop, 489  
 duct sizing, 456, 467, 479, 480, 483, 489, 1044  
 duct velocity, 747  
 duct weight, 758  
 dust concentration, 155  
 elbow attenuation, 950  
 elbow equivalent, 509, 537, 740, 1112  
 electric heating systems, 966  
 electric water heaters, 975  
 emissivity factors, 95, 96, 170  
 end reflection, 954  
 environmental conditions, limits, 118  
 equivalent length of fittings, 489, 497, 509, 1112  
 equivalent temperature differentials, 292, 294  
 exhaust pipes for machines, 1044-1048  
 exhaust velocities, 1042, 1044-1048  
 expansion tank sizes, 550  
 fabric filters, 798  
 fan outlet velocity, 776  
 fan speed, 778  
 fitting allowance, 468, 482, 509  
 fitting dimensions, 633-643  
 fixture flow, 1106  
 fixture units, 1106  
 flammability of gases and vapors, 162  
 flanged fittings surface, 655  
 flue gas dewpoint, 365  
 free convection, 94  
 friction loss, pipe, 389, 606, 510-515, 538, 540  
 friction valves and fittings, 509, 537, 1106  
 fuel combustion, 358  
 fuel consumption, 456, 457  
 fuel oil properties, 342  
 fumes, concentration, 160  
 gas analysis, 348  
 gas piping capacity, 389  
 gaseous fuel properties, 348  
 glass absorbance, 300  
 glass transmittance, 300  
 graphical symbols, 17  
 heat absorbed, cooling water, 821  
 heat conductance, 93, 101, 170-173, 178, 179  
 heat equivalents, 270  
 heat flow walls and roofs, 190-193, 196-199, 292  
 heat gain  
   appliances, 316  
   coil heat emission, 566  
   glass, 301, 302  
   glass blocks, 305-307  
   insulated cold pipes, 665  
 heat loss  
   bare copper pipe, 654  
   bare steel pipe, 506, 654  
   basement, 263  
   floor, 265  
   pipe coils, 566  
   radiation, 96  
   residence, 271, 273  
   room, 271, 581  
 heat pump, 856  
 heat transmission coefficients, 190  
 building construction, 190-200, 292-296  
 doors, 200  
 glass, 200  
 roofs, 196-199, 296  
 walls, 190-193, 296  
 water heaters, 1122  
 hot water demand, 1106, 1115, 1118

**Tables (continued)**  
 hot water pipe sizes, 538, 540  
 humidities, industrial air conditioning, 1016-1026  
 hygroscopic materials, 1023  
 incident angle, 287  
 inertial separator, 796  
 infiltration through outside doors, 222  
 infiltration through walls, 228  
 infiltration through windows, 230  
 inflammability, gases, 162  
 inside temperatures, 259, 279, 1016-1026  
 instantaneous solar heat gain, 301, 302, 304-307  
 insulation conductivity, 657  
 insulation factors, 651  
 insulation thickness, 667, 668  
 insulation to prevent freezing, 666  
 insulation, underground, 668  
 intake velocity, 726  
 iron elbow equivalents, 537  
 life of equipment, 1008  
 limits for contaminants, 163  
 load factors, 462  
 maintenance cost, 1011  
 maximum allowable concentrations  
   dust, fumes, mists, 160  
   dusts, 160, 161  
   flammable gases, 158  
   gases, 158  
   vapors, 158  
 metal gages for ducts, 757, 1053  
 meter performance, 1112  
 minimum outdoor air requirements to remove odors, 113  
 moisture content for materials, 1028  
 moisture regain, 1028  
 moisture transfer, 213  
 motor classification, 926  
 motor current, 927  
 motor design limits, 924  
 motor drive applications, 931  
 motor horsepower, 924  
 motor ratings, 933  
 motor speed range, 924  
 motor starting methods, 934  
 motor torque, 931  
 motor voltage, 924  
 noise levels, 945, 946  
 oil fuel specifications, 344  
 oil heat value, 344  
 operating cost, 1006, 1009, 1010  
 orifice capacities, 504, 541  
 outdoor air requirement, 113  
 outlet velocities, 776  
 outside temperature, 251, 279, 451  
 owning and operating cost, 1006  
 particle size, 153, 154  
 particulate matter, size, 153  
 permeability to vapor, 213  
 physiological response to heat, 117  
 pipe capacity, 389, 506, 509-510, 512-516, 538, 540, 878, 879  
 pipe covering factors, 661  
 pipe dimension, 624  
 pipe fittings, 630  
 dimensions, 633-642  
 pressure ratings, 632  
 pipe freezing prevention, 666  
 pipe insulation, 657  
 pipe roughness, 73  
 pipe surface, 624  
 thermal stress, 645, 646, 648  
 pipe volume, 624  
 pressure loss  
   ducts, 489  
   elbows, 509, 537, 1112  
   fittings, 468, 482, 509, 537, 1112  
   refrigerant line, 878, 879

**Tables (continued)**  
 registers, 467, 488  
 return intake, 726  
 properties of  
   air, 32  
   dichlorodifluoromethane, 551  
   fuel oil, 342  
   gaseous fuels, 348  
   moist air, 32  
   monochlorodifluoromethane, 553  
   monofluorotrifluoromethane, 554  
   steam, 49  
   water, 40  
 radiation, black body, 98  
 radiation factors, 95, 569  
 radiation problem solution, 97  
 radiator heat loss correction factors, 568  
 radiator sizes, 563, 564  
 rating air conditioning units, 617  
 rating steel boilers, 400  
 ratio of specific heats, 73  
 refrigerant properties, 851, 853, 854  
 refrigerant line capacity, 878, 879  
 refrigeration equipment selection, 882  
 regain of hygroscopic materials, 1028  
 requirements for fuel oil, 342  
 return pipe capacities, 507, 512  
 room temperature differential, 280  
 screen mesh, 154  
 shading effect, 309  
 sheet metal gages for ducts, 757, 1053  
 ship design conditions, 1101  
 slime control, 993  
 slime formers, 988  
 smoke chart numbers, 1163  
 snowfall data, 535  
 snow melting systems, 587  
 sodium dichromate, 996  
 soil conductivity, 174  
 soil-air temperature, 290  
 solar altitude, 286, 288  
 solar azimuth, 288  
 solar declination, 288  
 solar heater design, 1127  
 solar heat gain, 292, 297, 300-309  
 solar radiation, 286  
 sound attenuation, 947-951, 953, 954  
 sound level, 945, 946  
 sound pressures and intensities, 943  
 specific gravity factors, 390  
 specific heat of compressible fluids, 73  
 specific heat ratio, 73  
 spray pond design data, 813  
 steady-state conduction problems, 101  
 steam consumption of buildings, 459  
 steam conversion factors, 567  
 steam pipe capacities, 506, 508-510, 512-515  
 steam table, 49  
 steel boiler ratings, 400, 401  
 summer climatic conditions, 279  
 summer design conditions, 276, 279  
 surface conductance, 93, 170  
 temperature differential, 260, 292, 294, 691  
 temperature, industrial air conditioning, 1016-1026  
 temperature, inside, 258, 275, 1016-1026  
 temperature limit for men, 118  
 temperature range, 278  
 temperature, summer, 279  
 temperature, winter, 251

Index to Technical Data Section

**Tables (continued)**  
 thermal conduction problems, 107, 113  
 thermal conductivity, 91, 657  
 thermal convection conductance, 93  
 thermodynamic properties  
   moist air, 32  
   water, 40  
 transmittance, glass, 300, 301  
 unit conditioner rating, 617  
 unit fuel consumption, 456  
 unit heater capacity factors, 598  
 unit ventilator capacities, 606  
 upper temperature limits, 118  
 vanes in elbows, 740  
 vapor transfer, 216  
 velocity, return intake, 726  
 ventilation standards, 285  
 warm air ducts, 466  
 warm air fittings, 468  
 water analyses, 982, 1003  
 water cooling effectiveness, 821  
 water fixture flow, 1106  
 water main temperatures, 806  
 water meter performance, 1112  
 water pipe capacities, 538, 540  
 water requirements, 1115, 1116, 1118  
 weight of air, 32  
 weights of ducts, 758  
 wet collectors, 797  
 winter climatic conditions, 251  
 winter design temperatures, 251

**Tank tanks**  
 expansion, 550  
 Tax, pipe, 403

**Temperature, temperatures**  
 absolute, 9, 30  
 attic, 261  
 automatic control, 895, 907  
 basement, 263  
 control for railway passenger car, 1092  
 control service water, 1123  
 design wet-bulb, 276, 279, 819  
 dew-point, 26  
 dry-bulb, 9  
 drying, 1033  
 effective, 9  
 ground, 263, 264  
 hazard, 117  
 industrial, 1161  
 inside, 258, 270, 1101  
 ceilings, high, 259  
 proper level, 259  
 mean radiant, 120, 578  
 measurement, 1145  
 pyrometers, 1149  
 thermocouple, 1146  
 thermometers, 1145  
 outside, 251, 279  
 scales, 9  
 surface, 292, 414, 1148  
 thermodynamic wet-bulb, 26  
 unheated spaces, 263  
 water main, 806  
 wet-bulb, 9

**Terminology, 1**  
 Test methods, 1145, 1167

**Testing codes, 1167**

**Therapy**  
 cold, 143  
 fever, 142  
 oxygen, 145

**Thermal**  
 conductance, 167, 170, 171  
 conduction equation, 90  
 conductivity, 90, 168  
 convection, 89, 91  
 convection equation, 91  
 expansion of pipe, 644  
 integrator, 1167  
 interchanges of body, 113

**Thermal (continued)**  
 radiation equation, 92  
 resistance, 8, 167, 170  
 resistivity, 8, 170  
 steady-state conduction problems, 101  
 transmittance, 266  
 unit conductances for convection, 93  
 Thermocouples, 1146

**Thermodynamics, 23**  
 air and water mixture, 25, 29, 32  
 laws of, 9, 23  
 wet-bulb temperature, 26

**Thermometers, 1145**  
 alcohol, 1145  
 dry-bulb, 1155  
 globe, 1162  
 Kato, 1157  
 mercurial, 1145  
 resistance, 1148  
 stem correction, 1145  
 wet-bulb, 1158

**Thermostat, 9, 901**  
 room, 908  
 Time lag through walls and roofs, 311, 689  
 Ton of refrigeration, 8  
 Total heat, 5  
 Total pressure, 7

**Tower, towers, 813**  
 cooling, design, 820  
 cooling, performance, 822  
 mechanical draft, 815  
 natural draft, 813  
 selection, 825  
 spray cooling, 813

**Transmission**  
 heat losses, 263-267  
 solar heat, 299, 297  
 Transmittance, thermal, 9  
 Transportation air conditioning, 1089  
 temperature and humidity control, 1092, 1093, 1095

**Trap, traps, 524**  
 alternating receiver, 528  
 automatic return, 499, 528  
 bucket, 526  
 float, 524, 526  
 impulse, 527  
 installation, 528  
 steam, 524  
 thermostatic, 524  
 tilting, 527  
 Traveling-grate stoker, 369, 371  
 Treatment of disease, 131, 137  
 Tropical air cooling, 136  
 Tube radiator, 8  
 Tunnel dryer, 1032  
 Tunnel, pipe, 678  
 Turning vane, 724, 740  
 Two-pipe system, 10, 496, 516, 540

**U**

**Ultra-violet light, 113, 132, 156**

**Underfeed stoker, 369-370**  
 Underground pipe insulation, 667  
 Unheated space temperatures, 263

**Unit, units (continued)**  
 air cleaners, 781, 792  
 air conditioners, 609  
 application, 618  
 cooling, 619  
 dehumidifying, 613  
 humidifying, 613  
 ratings, 616, 617  
 remote units, 610, 614

**Unit, units (continued)**  
 sound isolation, 613  
 types, 609  
 air coolers, 610  
 defrosting, 620  
 design, 619  
 performance, 619  
 ratings, 620  
 types of, 619  
 air filters, 781, 787  
 British thermal, 2  
 dehumidification, 613  
 direct-indirect heating, 3  
 fuel consumption, 445  
 heaters, 595  
 application, 597  
 automatic control, 600  
 boiler capacity, 603  
 capacity factors, 598  
 classification, 595  
 control, 600  
 direct-fired, 595  
 electric, 597  
 maintenance, 602  
 outlet velocity, 597  
 piping connections, 600  
 ratings, 597  
 temperatures, 598, 600  
 types of, 595  
 humidifiers, 810  
 types of, 810  
 induction, 692, 693  
 noise measurement, 941  
 systems, 595  
 ventilators, 604  
 air exhaust vents, 608  
 applications, 606  
 capacity, 605  
 control, 607  
 location, 607  
 ratings, 604  
 selection, 607  
 window, 608  
 Unitary equipment, 595  
 definitions, 595

**V**

**Vacuum**  
 cooling units, 861  
 heating pumps, 522  
 control, 523  
 piston displacement, 523  
 heating system, 10, 500  
 down-feed, 500  
 unit heater connection, 601

**Valve, valves, 533, 635, 902**  
 automatic, 902  
 check, 641  
 control, 533  
 expansion, 875  
 gate, 533, 638  
 globe, 638  
 reducing pressure, 518, 641  
 relief, 552, 641

**Vane, vanes, 702, 715, 724, 740**  
 Vaned outlets, 724

**Vapor, vapors, 151**  
 adsorption, 799  
 barrier, 208, 213, 221  
 heating systems, 10, 498  
 pressure, 7  
 transfer, 208  
 transmission, 208  
 unit heater connection, 601  
 Vaporizing oil burner, 377

**Velocity, 10**  
 capture, 1042  
 coil, 336, 841  
 conveying, 1044-1048  
 duct, 747, 1044  
 exhaust intakes, 726, 1044-1048  
 hood, 1044  
 operating, 747, 776, 1042, 1044-1048  
 pressure, 7  
 reduction method, 748

**Velocity (continued)**  
return grilles, 726  
unit heater, 535

**Ventilation**, 10, 278  
animal shelters, 242-246  
dairy stables, 243  
garages, 240  
living space, 223, 278  
natural, 235  
general rules, 241  
passenger bus in summer, 1094  
railway passenger car, 1091  
rules, 241  
ship, 1100  
symbols for drawings, 17  
systems, 677  
walls and attics, 224  
wind forces, 236

**Ventilator, ventilators**, 240  
control, 241  
roof, 240  
unit, 604  
control, 607, 917  
window, 608

**Vertical blow unit heater**, 595

**Vertical openings**, 234  
sealing of, 228

**Vibration**, machine, 959

**Viscous filters**, 783

**Impingement**, 783

**Vitiation of air**, 111

**Volume**  
control, 725  
furnace, 374, 381  
specific, 10

# W

**Wall, walls**  
heat flow through, 190-193, 289  
heat transfer coefficients, 89,  
190-193  
infiltration through, 228  
time lag of solar radiation, 310

**Warm air**  
gravity heating system, 463  
combination carrying capacity, 469, 470  
design procedure, 465, 469,  
473  
extended plenum, 473  
furnace capacity, 412  
installation practice, 463,  
464, 466  
standardized combinations,  
469-470  
mechanical heating systems,  
475  
air distribution, 467  
automatic control, 415, 490,  
895  
ceiling panel system, 490

**Warm air (continued)**  
combination of parts, 478  
cooling methods, 1129  
continuous circulation, 490  
dampers, 477  
design procedure, 472, 481  
ducts, 477  
fans, 410  
filters, 410  
furnace, 409  
heavy duty, 411  
selection, 473, 484  
humidification, 415  
large systems, 481  
perimeter system, 491  
pressure drop, 489  
registers and grilles, 476  
standard combinations, 466,  
478  
panel heating, 490  
radiators, 387

**Washer, washers**, 803  
air, 1, 799, 801  
cooling, 807  
dehumidification, 807  
humidification, 805

**Water**  
analysis, 982  
atmospheric cooling equip-  
ment, 811, 813  
characteristics, 982  
classification, 982  
coils, 832, 1121  
content of radiators, 550  
control temperature service,  
1123  
cooled  
condenser, 872  
cooling tower, 813  
corrosion treatment, 997  
demand, 1106, 1115-1118  
faucets, 1108  
fittings, loss, 1108, 1111  
fixtures, 1106  
fixture units, 1106  
formed deposits, 981  
heater  
coal-fired, 1118  
solar, 1125  
heating, 1118  
in building material, 207  
load, 1105  
make-up, 827, 990  
maximum main temperature,  
806  
meters, 1111  
mineralized, 982  
properties of, 40, 982  
services, 1105  
storage capacity, 1115  
supply piping, 1122  
arrangement, 1122  
temperature control, 1123

**Water (continued)**  
thermodynamic properties of,  
40  
treating chemicals, 981, 1002  
well temperatures, 808  
Water vapor, 25, 32-39, 205  
condensation in buildings, 205  
saturation pressure, 25, 40  
specific enthalpy, 4  
specific volume, 10, 40  
surface condensation, 217

**Welding**, 623

**Wet-bulb temperature** (see  
Temperature), 9, 26, 819  
Wet cup, 212  
Wet return, 8, 493

**Wind, winds**  
forces, 228, 235  
due to stack effect, 228  
natural draft equipment, 421  
selection of, velocity, 250, 251,  
278

**Window, windows**  
coefficients of transmission,  
200  
leakage, 229  
solar radiation through, 297  
ventilators, 607

**Winter**  
air conditioning system, 685,  
1129  
comfort zone, 124  
freezing equipment, 828  
Wound rotor motor, 928  
Wrought-iron pipe, 823  
Wrought-steel pipe, 823

# Y

**Year-round air conditioning**  
system, 685, 1129  
air flow in, 687, 1133  
control methods, 687, 912  
design procedure, 685, 781  
equipment arrangement, 700  
installation, 685, 1129  
location of apparatus, 700, 1132  
residential, 908  
selection, 688, 1129

# Z

**Zone control**, 587  
Zone of evaporative regulation,  
1115

**Zoning**, 552, 637, 908  
control, 637, 908  
hot water system, 552  
reheat, 638  
volume control, 637

## CHAPTER 1 TERMINOLOGY

Glossary of Physical and Heating, Ventilating, Refrigerating  
and Air Conditioning Terms Used in the Text



**Absolute Zero**: The zero from which absolute temperature is reckoned. Approximately -273.15 Cor -459.67 F. These values were established by the Tenth General Conference on Weights and Measures, 1954.

**Absorbent**: A sorbent which changes physically or chemically, or both, during the sorption process.

**Absorption**: The action of a material in extracting one or more substances present in an atmosphere or mixture of gases or liquids; accompanied by physical change, chemical change, or both, of the sorbent.

**Acceleration**: The time rate of change of velocity, i.e., the derivative of velocity with respect to time. In the cgs system the unit of acceleration is the centimeter per (second) (second); in the fps system the unit is the foot per (second) (second),  $a = \frac{dv}{dt}$ .

**Acceleration Due to Gravity**: The rate of gain in velocity of a freely falling body the value of which varies with latitude and elevation. The international gravity standard has the value of 980.665 cm per (sec) (sec) or 32.174 ft per (sec) (sec) which is the actual value of this acceleration at sea level and about 45 deg latitude.

**Adiabatic**: An adjective descriptive of a process such that no heat is added to, or taken from, a substance or system undergoing the process.

**Adsorbent**: A sorbent which does not change physically or chemically during the sorption process.

**Adsorption**: The action, associated with surface adherence, of a material in extracting one or more substances present in an atmosphere or mixture of gases and liquids, unaccompanied by physical or chemical change. Commercial adsorbent materials have enormous internal surfaces.

**Aerosol**: An assemblage of small particles, solid or liquid, suspended in air. The diameters of the particles may vary from 100 microns down to 0.01 micron or less, e.g., dust, fog, smoke.

**Air Cleaner**: A device designed for the purpose of removing airborne impurities such as dusts, gases, vapors, fumes and smokes. (Air cleaners include air washers, air filters, electrostatic precipitators and charcoal filters.)

**Air Conditioning**: The simultaneous control of all, or at least the first three, of the following factors affecting both the physical and chemical conditions of the atmosphere within a structure: temperature, humidity, motion, distribution, pressure, dust, bacteria, odors, toxic gases, and ionization.

**Air, Dry**: In psychrometry; air unmixed with, or containing no, water vapor.

**Air, Saturated**: A mixture of dry air and saturated water vapor, all at the same dry-bulb temperature.

**Air, Standard**: Air with a density of 0.075 lb per cu ft and an absolute viscosity of  $1.22 \times 10^{-4}$  lb mass per (ft) (sec). This is substantially equivalent to dry air at 70 F and 29.92 in. (Hg) barometer.

**Air Washer**: An enclosure in which air is drawn or forced through a spray of water in order to cleanse, humidify, or dehumidify the air.

**Anemometer**: An instrument for measuring the velocity of a fluid.

**Aspect Ratio**: In air distribution outlets, the ratio of the length of the core of a grille, face or register to the width.

In rectangular ducts, the ratio of the width to the depth.

**Atmospheric Pressure**: The pressure of the atmosphere to be measured by means of the barometer. *Standard Atmospheric Pressure* or *Standard Atmosphere* is exactly 1,013,250 dynes per square centimeter by recent action of the Tenth General Conference on Weights and Measures (1954). It is approximately the pressure exerted by a column of mercury 76 cm high at standard gravitational acceleration, 980.665

cm per (sec) (sec), the mercury having a density of 13.5951 grams per cubic centimeter. It is equivalent to 14.696 psi or 29.921 in. of mercury at 32 F.

**Baffle:** A surface used for deflecting fluids, usually in the form of a plate or wall.

**Blast Heater:** A set of heat transfer coils or sections used to heat air which is drawn or forced through it by a fan.

**Blow (throw):** In air distribution, the distance an air stream travels from an outlet to a position at which air motion along the axis reduces to a velocity of 50 fpm.

For unit heaters, the distance an air stream travels from a heater without a perceptible rise due to temperature difference and loss of velocity.

**Boiler Heating Surface:** That portion of the surface of the heat-transfer apparatus in contact with the fluid being heated on one side and the gas or refractory being cooled on the other, in which the fluid being heated forms part of the circulating system; this surface shall be measured on the side receiving heat. This includes the boiler, water walls, water screens, and water floor. (ASME Power Test Codes, Series 1929.)

**Direct Heating Surface** is generally understood to be the boiler heating surface subject to direct radiation from the surface of the grate, or from the surfaces of oil or gas burners.

**Indirect Heating Surface** is the boiler heating surface within the flues.

**Boiler Horsepower:** The equivalent evaporation of 34.5 lb of water per hr from and at 212 F. This is equal to a heat output of  $970.3 \times 34.5 = 33,475$  Btu per hr.

**British Thermal Unit (Btu):** The Btu is defined as 778.177 foot-pounds if it is related to the IT calorie in such a way that 1 IT calorie per (kg) (C deg) = 1 Btu per (lb) (F deg), with 1 lb = 453.5924 grams. The Ninth General Conference on Weights and Measures (1948) recommended the absolute joule as the fundamental unit of energy thereby, in effect, liquidating the old international electrical units. This calls for a redefinition of the International Tables calorie (IT cal) according to the following conversion factor: 4.18684 joule per IT calorie.

**Calorie (Gram Calorie):** The IT gram calorie is equivalent to 0.003968 Btu. (See definition of Btu.)

**Central Fan System:** A mechanical indirect system of heating, ventilating, or air conditioning, in which the air is treated or handled by equipment located outside the rooms served, usually at a central location, and is conveyed to and from the rooms by means of a fan and a system of distributing ducts. (See Chapter 30.)

**Chimney Effect:** The tendency of air or gas in a duct or other vertical passage to rise when heated due to its lower density compared with that of the surrounding air or gas. In buildings, the tendency toward displacement (caused by the difference in temperature) of internal heated air by unheated outside air due to the difference in density of outside and inside air.

**Comfort Air Conditioning:** The process by which simultaneously the temperature, moisture content, movement and quality of the air in enclosed spaces intended for human occupancy may be maintained within required limits. (See also general definition of *Air Conditioning* on page 1 of this chapter.)

**Comfort Line:** A line on the comfort chart showing relation between the effective temperature and the percentage of adults feeling comfortable.

**Comfort Zone (Average):** The range of effective temperatures over which the majority (50 percent or more) of adults feel comfortable. (See Chapter 6.)

**Condensate:** The liquid formed by condensation of a vapor. In steam heating, water condensed from steam; in air conditioning, water extracted from air, as by condensation on the cooling coil of a refrigeration machine.

**Condensation:** The process of changing a vapor into liquid by the extraction of heat. Condensation of steam or water vapor is effected in either steam condensers or in dehumidifying coils and the resulting water is called *condensate*.

**Conductance, Surface (Unit):** The amount of heat transferred by radiation, conduction, and convection from unit area of a surface to the air or other fluid in contact with it, or vice versa, in unit time for a unit difference in temperature between the surface and the fluid. The common unit is: Btu per (hour) (square foot) (Fahrenheit degree). Symbol  $f$ . The temperature of the fluid should be taken in a plane sufficiently far from the surface that it will not be affected by the temperature of the surface.

**Conductance, Thermal:** The time rate of heat flow through unit area of a body, of given size and shape, per unit temperature difference. Common unit is: Btu per (hour) (square foot) (Fahrenheit degree). Symbol  $C$ .

**Conduction, Thermal:** The process of heat transfer through a material medium in

which kinetic energy is transmitted by the particles of the material from particle to particle without gross displacement of the particles.

**Conductivity, Thermal:** The time rate of heat flow through unit area of a homogeneous substance under the influence of a unit temperature gradient. Common units are: Btu per (hour) (square foot) (Fahrenheit degree per inch). Symbol  $k$ .

**Conductor, Thermal:** A material which readily transmits heat by means of conduction.

**Convection:** The motion resulting in a fluid from the differences in density and the action of gravity. In heat transmission this meaning has been extended to include both forced and natural motion or circulation.

**Convective Heat Transfer:** The transmission of heat by either natural or forced motion of a fluid (liquid or gas).

**Convactor:** An agency of convection. In heat transfer, a surface designed to transfer its heat to a surrounding fluid largely or wholly by convection. The heated fluid may be removed mechanically or by gravity (Gravity Convactor). Such a surface may or may not be enclosed or concealed. When concealed and enclosed the resulting device is sometimes referred to as a concealed radiator. (See also definition of *Radiator*.) (See also Chapter 23.)

**Decibel:** A unit used to express the relation between two amounts of power. By definition the difference in decibels between two powers  $P_1$  and  $P_2$ ,  $P_1$  being the larger, is: db difference =  $10 \log_{10} P_2/P_1$ .

In acoustics the threshold of hearing at 1,000 cycles per sec has been standardized at  $10^{-16}$  watts per sq cm. If  $P_2$  is the power in watts per square centimeter of a measured sound, then  $10 \log_{10} P_2/10^{-16}$  is the db difference above the threshold and is known as the *intensity level*. This is a definite recognized way of describing the intensity of a sound.

**Declination of Sun:** The angle above or below equatorial plane. It is plus if north of the plane, and minus if below. Celestial objects are located by declination.

**Degree-Day:** A unit, based upon temperature difference and time, used in estimating fuel consumption and specifying nominal heating load of a building in winter. For any one day, when the mean temperature is less than 65 F, there exists as many degree-days as there are Fahrenheit degrees difference in temperature between the mean temperature for the day and 65 F.

**Dehumidify:** To reduce by any process, the quantity of water vapor within a given space.

**Dehydrate:** To remove water in all forms from matter. Liquid water, hygroscopic water, and water of crystallization or water of hydration are included.

**Density:** The ratio of the mass of a specimen of a substance to the volume of the specimen. The mass of a unit volume of a substance. When weight can be used without confusion, as synonymous with mass, density is the weight per unit volume.

**Dew-Point:** See *Temperature, Dew-Point*.

**Diffusivity, Thermal:** Thermal conductivity divided by product of density and specific heat =  $k/\rho c$ . Expressed in units of square feet per hour.

**Direct-Indirect Heating Unit:** A heating unit located in the room or space to be heated and partially enclosed; the enclosed portion being used to heat air which enters from outside the room.

**Direct-Return System (Hot Water):** A hot water system in which the water, after it has passed through a heating unit is returned to the boiler along a direct path so that the total distance traveled by the water is the shortest feasible, and so that there are considerable differences in the lengths of the several circuits composing the system.

**Down-Feed One-Pipe Riser (Steam):** A pipe which carries steam downward to the heating units and into which the condensate from the heating units drains.

**Down-Feed System (Steam):** A steam heating system in which the supply mains are above the level of the heating units which they serve.

**Draft:** A current of air. Usually refers to the pressure difference which causes a current of air or gases to flow through a flue, chimney, heater or space.

**Draft Head (Side Outlet Enclosure):** The height of a gravity convactor between the bottom of the heating unit and the bottom of the air outlet opening. (*Top Outlet Enclosure*): The height of a gravity convactor between the bottom of the heating unit and the top of the enclosure.

**Drip:** A pipe, or a steam trap and a pipe considered as a unit, which conducts condensation from the steam side of a piping system to the water or return side of the system.



**Dry:** To separate or remove a liquid or vapor from another substance. The liquid may be water, but the term is also used for the removal of liquid or vapor forms of other substances.

**Dust:** An air suspension (aerosol) of solid particles of any material. (See also Chapter 8.)

**Enthalpy:** A term used in lieu of *total heat* or *heat content*. Expressible in Btu per pound. Mathematically defined as  $h = u + pv/J$ . When a change occurs at constant pressure, as when water is boiled, the change in enthalpy is equal to the heat added; in this case latent heat.

**Enthalpy, Free:** A thermodynamic property which serves as a measure of the available energy of a system with respect to surroundings at the same temperature and same pressure as that of the system. No process involving an increase in available energy can occur spontaneously.

**Enthalpy, Specific:** A term sometimes applied to enthalpy per unit weight, the English unit being Btu per pound.

**Entropy:** The ratio of the heat added to a substance to the absolute temperature at which it is added. Mathematically, for a reversible process,  $dS = dq/T$  or  $S = \int dq/T$ .

These formulas are applicable when temperature is not constant. During a reversible adiabatic change, entropy is constant. During a reversible isothermal change, the heat absorbed by the substance is equal to the product of the absolute temperature of the substance and its change of entropy.

**Entropy, Specific:** A term sometimes applied to entropy per unit weight, the English unit being Btu per (Fahrenheit degree, absolute) (pound).

**Equivalent Evaporation:** The amount of water a boiler would evaporate, in pounds per hour, if it received feed water at 212 F and vaporized it at the same temperature and corresponding atmospheric pressure.

**Fan Furnace System:** See *Warm Air Heating System*.

**Fog:** Suspended liquid droplets generated by condensation from the gaseous to the liquid state, or by breaking up a liquid into a dispersed state, such as by splashing, foaming, and atomizing. (See also Chapter 8.)

**Force:** The action on a body which tends to change its relative condition as to rest or motion.

**Fumes:** Smoke; aromatic smoke; odor emitted, as of flowers; a smoky or vaporous exhalation, usually odorless, as that from concentrated nitric acid. The word *fumes* is so broad and inclusive that its usefulness as a technical term is very limited. Its principal definitive characteristic is that it implies an odor. The terms vapor, smoke, fog, etc., which can be more strictly defined, should be used whenever possible.

Also defined as solid particles generated by condensation from the gaseous state, generally, after volatilization from molten metals, etc., and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce. (See also Chapter 8.)

**Furnace:** That part of a boiler or warm air heating plant in which combustion takes place. Also a complete heating unit for transferring heat from fuel being burned to the air supplied to a heating system.

**Furnace Volume (Total):** The total furnace volume for horizontal-return tubular boilers and water-tube boilers is the cubical contents of the furnace between the grate and the first plane of entry into or between tubes. It therefore includes the volume behind the bridge wall as in ordinary horizontal-return tubular boiler settings, unless manifestly ineffective (i.e., no gas flow taking place through it), as in the case of waste-heat boilers with auxiliary coal furnaces, where one part of the furnace is out of action when the other is being used. For Scotch or other internally-fired boilers, it is the cubical contents of the furnace, flues and combustion chamber, up to the plane of first entry into the tubes. (ASME Power Test Codes, Series 1929.)

**Grate Area:** The area of the grate surface, measured in square feet, to be used in estimating the rate of burning fuel. This area is construed to mean the area measured in the plane of the top surface of the grate, except that with special furnaces, such as those having magazine feed, or special shapes, the grate area shall be the mean area of the active part of the fuel bed taken perpendicular to the path of the gases through it. For furnaces having a secondary grate, such as those in double-grate down-draft boilers, the effective area shall be taken as the area of the upper grate plus one-eighth of the area of the lower grate, both areas being estimated as previously defined.

**Gravity, Specific:** The ratio of the mass of a unit volume of a substance to the mass of the same volume of a standard substance at a standard temperature. Water

at 39.2 F is the standard substance usually referred to. For gases, dry air at the same temperature and pressure as the gas, is often taken as the standard substance.

**Gravity Warm Air Heating System:** See *Warm Air Heating System*.

**Head, Dynamic:** Same as Total Pressure expressed in height of liquid.

**Heat:** That form of energy which transfers from one system to another, by virtue of the temperature difference which exists between the two systems, when they are placed in communication.

**Heat, Humid:** Ratio of increase of enthalpy per pound of dry air to rise of temperature under conditions of constant pressure and constant humidity ratio.

**Heat, Latent:** A term used to express the energy involved in a change of state.

**Heat, Sensible:** A term used in heating and cooling to indicate any portion of heat which changes only the temperature of the substances involved.

**Heat of the Liquid:** The increase in enthalpy per unit weight of a saturated liquid as its temperature increases from a chosen base temperature. For water, the base temperature is usually taken as 32 F.

**Heat, Specific:** The heat absorbed (or given up) by a unit mass of a substance when its temperature is increased (or decreased) by 1 deg. Common Units: Btu per (pound) (Fahrenheit degree), calories per (gram) (Centigrade degree). For gases, both specific heat at constant pressure ( $c_p$ ) and specific heat at constant volume ( $c_v$ ) are frequently used. In air conditioning,  $c_p$  is usually used.

**Heat, Total:** See *Enthalpy*.

**Heat Transmission, Coefficient:** Any one of a number of coefficients used in the calculation of heat transmission by conduction, convection, and radiation, through various materials and structures. (See thermal conductance, thermal conductivity, thermal resistance, thermal resistivity, thermal transmittance, etc.)

**Heating Element, Electric:** A unit assembly consisting of a resistor, insulated supports, and terminals for connecting the resistor to electric power.

**Heating Unit, Electric:** A structure containing one or more heating elements, electrical terminals or leads, electric insulation, and a frame or casing, all assembled together in one unit.

**Hot Water Heating System:** A heating system in which water is used as the medium by which heat is carried from the boiler to the heating units.

**Humidify:** To increase, by any process, the density of water vapor within a given space.

**Humidistat:** A regulatory device, actuated by changes in humidity, used for the automatic control of relative humidity.

**Humidity:** Water vapor within a given space.

**Humidity, Absolute:** The weight of water vapor per unit volume, pounds per cubic foot or grams per cubic centimeter.

**Humidity, Relative:** The ratio of the mol fraction of water vapor in a mixture to the mol fraction of water vapor in saturated air at the same dry-bulb temperature and barometric pressure. (See discussion in Chapter 3.) Also defined in various texts as the ratio of the actual partial pressure of the water vapor in a space to the saturation pressure of pure water at the same temperature.

**Humidity Ratio:** In a mixture of water vapor and air, the weight of water vapor per pound of dry air. Symbol,  $W$ . Also called *Specific Humidity*.

**Humidity, Specific:** See *Humidity Ratio*.

**Hygostat:** Same as *Humidistat*.

**Inch of Water:** A unit of pressure equal to the pressure exerted by a column of liquid water 1 in. high at a standard temperature. The standard temperature is sometimes taken as 0 C and sometimes as 62 F. One inch of water at 62 F = 5.197 lb per sq ft.

**Insulation (Thermal):** A material having a relatively high resistance to heat flow, and used principally to retard the flow of heat.

**Isobaric:** An adjective used to indicate a change taking place at constant pressure.

**Isothermal:** An adjective used to indicate a change taking place at constant temperature.

**Load, Estimated Design:** In a heating or cooling system, the sum of the useful heat transfer, plus heat transfer from or to the connected piping, plus heat transfer occurring in any auxiliary apparatus connected to the system. The units are Btu per hour or, in heating, equivalent direct radiation (EDR).

**Load, Estimated Maximum:** In a heating or cooling system, the calculated maximum heat transfer that the system will be called upon to provide.



**Manometer:** An instrument for measuring pressures; essentially a U-tube partially filled with a liquid, usually water, mercury, or a light oil; so constructed that the amount of displacement of the liquid indicates the pressure being exerted on the instrument.

**Mass:** A measure of the inertia of a body. It also measures the quantity of matter in a body. Since the only general property of a given portion of matter that cannot be changed is its inertia, it is this property by which quantities of matter are defined. Two bodies which have equal inertias are said to have equal masses, or to contain equal quantities of matter. (This definition fails at velocities approaching the velocity of light.) The mass of a body is numerically equal to the ratio of the force required to give the body a given acceleration, to the acceleration:  $m = F/a$ . The common units of mass are the gram and the pound.

**Mechanical Equivalent of Heat:** The quantity of mechanical energy equal to one unit of heat.  $J = 778.177 \text{ ft-lb per Btu} = 4.1858 \times 10^7 \text{ ergs per gram-calorie}$ .

**Medium, Heating:** A substance such as water, steam, air or furnace gas used to convey heat from the boiler, furnace or other source of heat or energy to the heating unit from which the heat is dissipated.

**Micron:** A unit of length, the thousandth part of 1 mm or the millionth of a meter.

**Millimeter of Mercury:** A unit of pressure equal to the pressure exerted by a column of mercury 1 mm high at a temperature of 0 C. One millimeter of mercury at 0 C =  $1.934 \times 10^{-2} \text{ psi}$ .

**Mol:** A weight of a substance numerically equal to its molecular weight. If the weight is in pounds the unit is a *Pound Mol*, in grams the unit is a *Gram Mol*. For perfect gases the volume of 1 mol is constant for all gases at the same temperature and pressure. For real gases this is approximately true at moderate pressures. At 32 F and zero-pressure the value of the product, pressure times specific volume, is  $359.045 \pm 0.006$  atmosphere cubic feet (atm ft<sup>3</sup>), for 1 mol of any gas. For dry air at 32 F and standard atmospheric pressure, the specific volume is 358.83 cu ft per mol (ft<sup>3</sup> per mol).

**One-Pipe Supply Riser—(Steam):** A pipe which carries steam vertically to a heating unit, and which also carries the condensate from the heating unit. In an up-feed system, steam and condensate flow in opposite directions; in an overhead or down-feed system, they flow in the same direction.

**One-Pipe System—(Steam):** A steam heating system in which a single main serves the dual purpose of supplying steam to the heating unit and conveying condensate from it. Ordinarily to each heating unit there is but one connection which must serve as both the supply and the return, although separate supply and return connections may be used. (Hot Water)—A hot water system in which the cooled water from the heating units is returned to the supply main. Consequently, the heating units farthest from the boiler are supplied with cooler water than those near the boiler in the same circuit.

**Overhead System:** Any steam or hot water system in which the supply main is above the heating unit. In a steam system the return must be below the heating units; in a water system the return may be above or below the heating units.

**Panel Heating:** A heating system in which heat is transmitted by both radiation and convection from panel surfaces to both air and surrounding surfaces.

**Panel Radiator:** A heating unit placed on or flush with a flat wall surface, and intended to function essentially as a radiator.

**Perimeter System:** See *Warm Air Heating System*.

**Plenum Chamber:** An air compartment maintained under pressure, and connected to one or more distributing ducts.

**Potentiometer:** An instrument for comparing small electromotive forces, or for measuring small electromotive forces by comparison with a known electromotive force. Its principal advantage is that during the measurement, no current flows through the source of electromotive force.

**Power:** The rate of performing work. Common units are horsepower, Btu per hour, and watts.

**Pressure:** Force per unit area. Common units are pounds per square inch, gram per square centimeter, inch of water, millimeter of mercury.

**Pressure, Absolute:** The sum of the gage pressure and the barometric pressure.

**Pressure, Dynamic:** Same as *Total Pressure*.

**Pressure, Gage:** Pressure measured from atmospheric pressure as a base. Gage pressure may be indicated by a manometer which has one leg connected to the pressure source and the other exposed to atmospheric pressure.

**Pressure, Saturation:** The saturation pressure for a pure substance for any given temperature is that pressure at which vapor and liquid, or vapor and solid, can co-exist in stable equilibrium.

**Pressure, Static:** The normal force per unit area that would be exerted by a moving fluid on a small body immersed in it if the body were carried along with the fluid. Practically, it is the normal force per unit area at a small hole in a wall of the duct through which the fluid flows (piezometer) or on the surface of a stationary tube at a point where the disturbances, created by inserting the tube, cancel. It is supposed that the thermo-dynamic properties of a moving fluid depend on static pressure in exactly the same manner as those of the same fluid at rest depend upon its uniform hydrostatic pressure.

**Pressure, Total:** In the theory of the flow of fluids; the sum of the static pressure and the velocity pressure at the point of measurement.

**Pressure, Vapor:** The pressure exerted by a vapor. If a vapor is kept in confinement over its liquid so that the vapor can accumulate above the liquid, the temperature being held constant, the vapor pressure approaches a fixed limit called the maximum, or saturated, vapor pressure, dependent only on the temperature and the liquid. The term *vapor pressure* is sometimes used as synonymous with *saturated vapor pressure*.

**Pressure, Velocity:** In a moving fluid, the pressure capable of causing an equivalent velocity, if applied to move the same fluid through an orifice such that all pressure energy expended is converted into kinetic energy.

**Psychrometer:** An instrument for ascertaining the humidity or hygrometric state of the atmosphere.

**Psychrometric:** Pertaining to psychrometry or the state of the atmosphere with reference to moisture.

**Psychrometric Chart:** A graphical representation of the thermodynamic properties of moist air.

**Psychrometry:** The branch of physics relating to the measurement or determination of atmospheric conditions, particularly regarding the moisture mixed with the air.

**Pyrometer:** An instrument for measuring high temperatures.

**Radiant Heating:** A heating system in which only the heat radiated from panels is effective in providing the heating requirements. The term *Radiant Heating* is frequently used to include both *Panel* and *Radiant Heating*.

**Radiation:** The transmission of energy by means of electromagnetic waves.

**Radiation, Thermal (Heat) Radiation:** The transmission of energy by means of electromagnetic waves of very long wave length. Radiant energy of any wave length may, when absorbed, become thermal energy and result in an increase in the temperature of the absorbing body.

**Radiation, Equivalent Direct (EDR):** A unit of heat delivery of 240 Btu per hr. It does not imply 144 sq. in. of surface.

**Radiator:** A heating unit exposed to view within the room or space to be heated. A radiator transfers heat by radiation to objects within visible range, and by conduction to the surrounding air which in turn is circulated by natural convection; a so-called radiator is also a convector, but the term radiator has been established by long usage.

**Radiator, Concealed:** A heating device located within, adjacent to, or exterior to the room being heated, but so covered or enclosed or concealed that the heat transfer surface of the device, which may be either a radiator or a convector, is not visible from the room. Such a device transfers its heat to the room largely by convection air currents.

**Radiator, Direct:** Same as *Radiator*.

**Radiator, Recessed:** A heating unit set back into a wall recess, but not enclosed.

**Radiator, Tube or Tubular:** A heating unit used as a radiator in which the heat transfer surfaces are principally tubes.

**Refrigerant:** A substance which produces a refrigerating effect by its absorption of heat while expanding or vaporizing.

**Refrigeration, Ton of:** The removal of heat at a rate of 200 Btu per min, 12,000 Btu per hr, or 288,000 Btu per 24 hr.

**Resistance, Thermal:** The reciprocal of thermal conductance. Symbol  $R$ .

**Resistivity, Thermal:** The reciprocal of thermal conductivity. Symbol  $r$ .

**Resistor, Electric:** A material used to produce heat by passing an electric current through it.

**Return, Dry:** A return pipe in a steam heating system which carries both water of condensation and air. The dry return is above the level of the water line in the boiler in a gravity system. (See *Return, Wet*.)

**Return, Wet:** That part of a return main of a steam heating system which is filled with water of condensation. The wet return usually is below the level of the water line in the boiler, although not necessarily so. (See *Return, Dry*.)

**Return Mains:** Pipes or conduits which return the heating or cooling medium from the heat transfer unit to the source of heat or refrigeration.

**Reversed-Return System:** A system in which the heating or cooling medium from several heat transfer units is returned along paths arranged so that all circuits composing the system or composing a major sub-division of it are of practically equal length.

**Sabin:** A unit of equivalent sound absorption equal to the equivalent absorption of one square foot of a surface of unit absorptivity (i.e., of one square foot of surface which absorbs all incident sound energy).

**Saturation:** The condition for co-existence in stable equilibrium of a vapor and liquid or a vapor and solid phase of the same substance. Example: Steam over the water from which it is being generated.

**Saturation, Degree of:** The ratio of the weight of water vapor associated with a pound of dry air to the weight of water vapor associated with a pound of dry air saturated at the same temperature.

**Smoke:** An air suspension (aerosol) of particles, usually but not necessarily solid, often originating in a solid nucleus, formed from combustion or sublimation. Also defined as carbon or soot particles less than 0.1 micron in size which result from the incomplete combustion of carbonaceous materials such as coal, oil, tar, and tobacco.

**Smokeless Arch:** An inverted baffle placed in an up-draft furnace toward the rear to aid in mixing the gases of combustion, and thereby to reduce the smoke produced.

**Solar Constant:** The solar intensity incident on a normal surface located outside the earth's atmosphere at a distance from the sun equal to the mean distance between the earth and the sun. Its value is 415, 445, or 430 Btu per (hr)<sup>2</sup> (sq ft) as the July, January, or mean value, respectively. At sea level in July the solar intensity value is about 300 Btu per (sq ft) (hr) since about 28 percent is absorbed in the earth's atmosphere.

**Sorbent:** A material which extracts one or more substances present in an atmosphere or mixture of gases or liquids with which it is in contact, due to an affinity for such substances.

**Sorption:** Adsorption or absorption.

**Split System:** A system in which the heating is accomplished by means of radiators or convectors supplemented by mechanical circulation of air (heated or unheated) from a central point. Ventilation may be provided by the same system.

**Square Foot of Heating Surface (Equivalent):** This term is synonymous with Equivalent Direct Radiation (EDR).

**Stack Height:** The height of a gravity convector between the bottom of the heating unit and the top of the outlet opening.

**Steam:** Water in the vapor phase. *Dry Saturated Steam* is steam at the saturation temperature corresponding to the pressure, and containing no water in suspension. *Wet Saturated Steam* is steam at the saturation temperature corresponding to the pressure, and containing water particles in suspension. *Superheated Steam* is steam at a temperature higher than the saturation temperature corresponding to the pressure.

**Steam Heating System:** A heating system in which heat is transferred from the boiler or other source of heat to the heating units by means of steam at, above, or below atmospheric pressure.

**Steam Trap:** A device for allowing the passage of condensate, or air and condensate, and preventing the passage of steam.

**Supply Mains:** The pipes through which the heating medium flows from the boiler or source of supply to the run-outs and risers leading to the heating units.

**Surface, Heating:** The exterior surface of a heating unit. *Extended heating surface (or extended surface):* Heating surface consisting of fins, pins or ribs which receive heat by conduction from the prime surface. *Prime Surface:* Heating surface having the heating medium on one side and air (or extended surface) on the other. (See also *Boiler Heating Surface*.)

## Terminology

**Temperature:** The thermal state of matter with reference to its tendency to communicate heat to matter in contact with it. If no heat flows upon contact, there is no difference in temperature.

**Temperature, Absolute:** Temperature expressed in degrees above absolute zero.

**Temperature, Dew-Point:** The temperature at which the condensation of water vapor in a space begins for a given state of humidity and pressure as the temperature of the vapor is reduced. The temperature corresponding to saturation (100 percent relative humidity) for a given absolute humidity at constant pressure.

**Temperature, Dry-Bulb:** The temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

**Temperature, Effective:** An arbitrary index which combines into a single value the effect of temperature, humidity, and air movement on the sensation of warmth or cold felt by the human body. The numerical value is that of the temperature of still, saturated air which would induce an identical sensation.

**Temperature, Mean Radiant (MRT):** The temperature of a uniform black enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the existing nonuniform environment.

**Temperature Scales.** Three temperature scales, Centigrade, Fahrenheit, and Reaumur, derive their degree values by dividing the difference between the ice point and steam points of water as follows: Centigrade 100, Fahrenheit 180, and Reaumur 80. Only the first two are important in the United States. The value of a Fahrenheit degree is therefore 5/9 of a Centigrade degree.

The Kelvin scale, sometimes called Centigrade absolute, has its zero point at the lowest attainable temperature 273.15 Centigrade degrees below the triple-point temperature of water and exactly 273.15 below the zero of the Centigrade scale.

The Rankine scale, sometimes called Fahrenheit absolute, has its zero at the lowest attainable temperature 459.688 Fahrenheit degrees below the triple-point temperature of water and exactly 459.67 F deg below the zero of the Fahrenheit scale.

To convert Centigrade to Kelvin temperature (generally designated K) add 273.15 deg.

To convert Fahrenheit to Rankine temperature (generally designated R) add 459.67 deg.

**Temperature, Wet-Bulb:** Thermodynamic wet-bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicated by a wet-bulb psychrometer constructed and used according to specifications. (ASME Power Test Codes, Series 1932, Instruments and Apparatus, Part 18.)

**Therm:** A quantity of heat equivalent to 100,000 Btu.

**Thermodynamics, Laws of:** Two laws upon which rest the classical theory of thermodynamics. These laws have been stated in many different, but equivalent ways. *The First Law:* (1) When work is expended in generating heat, the quantity of heat produced is proportional to the work expended; and conversely, when heat is employed in the performance of work, the quantity of heat which disappears is proportional to the work done. (Joule) (G.P.); (2) If a system is caused to change from an initial state to a final state by adiabatic means only, the work done is the same for all adiabatic paths connecting the two states. (Zemansky); (3) In any power cycle or refrigeration cycle the net heat absorbed by the working substance is exactly equal to the net work done. *The Second Law:* (1) It is impossible for a self-acting machine, unaided by any external agency, to convey heat from a body of lower to one of higher temperature. (Clausius) (G.P.); (2) It is impossible to derive mechanical work from heat taken from a body unless there is available a body of lower temperature into which the residue not so used may be discharged (Kelvin) (G.P.); (3) It is impossible to construct an engine that, operating in a cycle, will produce no effect other than the extraction of heat from a reservoir and the performance of an equivalent amount of work (Zemansky).

**Thermostat:** An instrument which responds to changes in temperature, and which directly or indirectly controls temperature.

**Transmittance, Thermal:** The time rate of heat flow, from the fluid on the warm side to the fluid on the cold side, per (square foot) (degree temperature difference between the two fluids). Sometimes called *Overall Coefficient of Heat Transfer*.

Common unit is Btu per (hour) (square foot) (Fahrenheit degree). Symbol *U*.

\* Names of authors who first stated laws are given in parentheses.

† From *Glossary of Physics*, by LeRoy Dougherty Weld (McGraw-Hill, 1937).

**Two-Pipe System (Steam or Water):** A heating system in which one pipe is used for the supply of the heating medium to the heating unit, and another for the return of the heating medium to the source of heat supply. The essential feature of a two-pipe system is that each heating unit receives a direct supply of the heating medium, which medium cannot have served a preceding heating unit.

**Up-Feed System:** A heating system in which the supply mains are below the level of the heating units which they serve.

**Vacuum Heating System:** A two-pipe steam heating system equipped with the necessary accessory apparatus which will permit operating the system below atmospheric pressure when desired.

**Vane Ratio:** In air distributing devices the ratio of depth of vane to shortest opening width between two adjacent grille bars.

**Vapor:** The gaseous form of substances which are normally in the solid or liquid state, and which can be changed to these states either by increasing the pressure or decreasing the temperature. Vapors diffuse. (ASA definition.)

**Vapor Heating System:** A steam heating system which operates under pressures at or near atmospheric and which returns the condensate to the boiler or receiver by gravity. Vapor systems have thermostatic traps or other means of resistance on the return ends of the heating units for preventing steam from entering the return mains; they also have a pressure-equalizing and air-eliminating device at the end of the dry-return.

**Velocity:** A vector quantity which denotes at once the time rate and the direction of a linear motion.  $V = \frac{ds}{dt}$ . For uniform linear motion  $V = \frac{s}{t}$ . Common units are: feet per second.

**Ventilation:** The process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned. (See *Air Conditioning*.)

**Viscosity:** That property of semi-fluids, fluids and gases by virtue of which they resist an instantaneous change of shape or arrangement of parts. It is the cause of fluid friction whenever adjacent layers of fluid move with relation to each other.

The coefficient of viscosity is the resistance offered by a layer of the fluid of unit area to the motion parallel to this area of another layer of the fluid at unit distance moving with unit velocity relative to the first layer. This coefficient is known as the *absolute viscosity*, and in cgs units is the force in dynes per square centimeter at a velocity of 1 cm per second at a distance of 1 cm. This unit of absolute viscosity is the *poise*. Values of absolute viscosity are frequently listed in centipoises, a centipoise being 1/100 of 1 poise.

In many formulas *absolute viscosity* is expressed in pounds per foot second or pounds per foot hour. Conversion from centipoises may be made as follows: viscosity in centipoises  $\times 0.000672$  = viscosity in pounds per foot second, or viscosity in centipoises  $\times 2.42$  = viscosity in pounds per foot hour.

**Kinematic viscosity** is the ratio of *absolute viscosity* to the density of a fluid. The unit is the stoke which equals one poise per cu cm per gram, or 1 sq cm per sec. For conversion to English units: kinematic viscosity in stokes  $\times 0.001076$  = kinematic viscosity in square feet per second.

**Volume, Specific:** The volume of a substance per unit mass; the reciprocal of density. Units: cubic feet per pound, cubic centimeters per gram, etc.

**Warm Air Heating System:** A warm air heating plant consists of a heating unit (fuel-burning furnace) enclosed in a casing, from which the heated air is distributed to various rooms of the building through ducts.

**Warm Air Heating System, Forced:** A warm air heating system in which circulation of air is effected by a fan. Such a system may include air cleaning devices.

**Warm Air Heating System, Gravity:** A warm air heating system in which the motive head producing flow depends on the difference in weight between the heated air leaving the casing and the cooler air entering the bottom of the casing.

**Warm Air Heating System, Perimeter:** A warm air heating system of the combination panel and convection type. Warm air ducts embedded in the concrete slab of a basementless house, around the perimeter, receive heated air from a furnace and deliver it to the heated space through registers placed in or near the floor. Air is returned to the furnace from registers near the ceiling.

## CHAPTER 2

ABBREVIATIONS, SYMBOLS,  
CONVERSION FACTORS

Standard Abbreviations; Standard Symbols; Greek Alphabet; Conversion Equations; Graphical Symbols for Piping, Ductwork, Heating and Ventilating, Refrigerating; Identification of Piping by Color

THIS chapter contains information regarding abbreviations, symbols, and conversion equations, which are of particular interest to the engineer engaged in heating, ventilating, and air conditioning.

## ABBREVIATIONS

Abbreviations are shortened forms of names and expressions employed in texts and tabulations, and should not generally be used as symbols in equations. Most of the following abbreviations have been compiled from a list of approved standards.<sup>1</sup> In general, the period has been omitted in all abbreviations, except where the omission results in the formation of an English word. Additional abbreviations applying to individual chapters will be found at the end of Chapters 3, 4, 13, 32, and 47.

Absolute.....abs  
Air horsepower.....air hp  
Alternating-current (as adjective).....a-c  
Ampere.....amp  
Ampere-hour.....amp-hr

Atmosphere.....atm  
Average.....avg  
Avoirdupois.....avdp  
Barometer.....bar  
Boiling point.....bp

Brake horsepower.....bhp  
Brake horsepower-hour.....bhp-hr  
British thermal unit.....Btu  
British thermal units per hour.....Btuh  
Calorie.....cal

Centigram.....cg  
Centimeter.....cm  
Centimeter-gram-second (system).....cgs  
Cubic.....cu  
Cubic centimeter.....cu cm or cc

Cubic foot.....cu ft  
Cubic feet per minute.....cfm  
Cubic feet per second.....cfs  
Decibel.....db  
Degree.....deg or °

Degree, Centigrade.....C  
Degree, Fahrenheit.....F  
Degree, Kelvin.....K  
Degree, Rankine.....R  
Diameter.....diam

<sup>1</sup> Abbreviations for Scientific and Engineering Terms, Z10.1-1941 (American Standards Association).

<sup>2</sup> It is recommended that the abbreviation for the temperature scale, F, C, K, R, be included in expressions for numerical temperatures but, wherever feasible, the abbreviation for degrees be omitted e.g., 68 F.

|                                       |        |
|---------------------------------------|--------|
| Direct-current (as adjective).....    | d-c    |
| Electromotive Force.....              | emf    |
| Feet per minute.....                  | fpm    |
| Feet per second.....                  | fps    |
| Foot.....                             | ft     |
| Foot-pound.....                       | ft-lb  |
| Foot-pound-second (system).....       | fps    |
| Freezing point.....                   | fp     |
| Gallon.....                           | gal    |
| Gallons per minute.....               | gpm    |
| Gallons per second.....               | gps    |
| Gram.....                             | g      |
| Gram-calorie.....                     | g-cal  |
| Horsepower.....                       | hp     |
| Horsepower-hour.....                  | hp-hr  |
| Hour.....                             | hr     |
| Inch.....                             | in.    |
| Inch-pound.....                       | in.-lb |
| Indicated horsepower.....             | ihp    |
| Indicated horsepower-hour.....        | ihp-hr |
| Kilogram.....                         | kg     |
| Kilowatt.....                         | kw     |
| Kilowatt-hour.....                    | kwhr   |
| Mass.....                             | mass   |
| Melting point.....                    | mp     |
| Meter.....                            | m      |
| Micron.....                           | μ (mu) |
| Miles per hour.....                   | mph    |
| Millimeter.....                       | mm     |
| Minute.....                           | min    |
| Molecular weight.....                 | mol wt |
| Mol.....                              | mol    |
| Ounce.....                            | oz     |
| Pound.....                            | lb     |
| Pounds per square inch.....           | psi    |
| Pounds per square inch, gage.....     | psig   |
| Pounds per square inch, absolute..... | psia   |
| Revolutions per minute.....           | rpm    |
| Revolutions per second.....           | rps    |
| Second.....                           | sec    |
| Specific gravity.....                 | sp gr  |
| Specific heat.....                    | sp ht  |
| Square foot.....                      | sq ft  |
| Square inch.....                      | sq in. |
| Watt.....                             | w      |
| Watt-hour.....                        | whr    |

## SYMBOLS

A letter symbol is a single character, with subscript or superscript if required, used to designate a physical magnitude in mathematical equations and expressions. Two or more symbols together always represent a product. The following have been compiled from a selected list of approved standards.<sup>1</sup> Additional symbols and variations in the standard symbols

<sup>1</sup> Letter Symbols for Mechanics of Solid Bodies, Z10.3-1943, and Letter Symbols for Heat and Thermodynamics, Z10.4-1943 (American Standards Association).

found necessary in the individual chapters will be found in a list at the end of Chapters 3, 4, 13, 32, and 47.

|                                                       |                 |
|-------------------------------------------------------|-----------------|
| Acceleration, due to gravity.....                     | g               |
| Acceleration, linear.....                             | a               |
| Area.....                                             | A               |
| Change in specific volume during vaporization.....    | v <sub>12</sub> |
| Density, Weight per unit volume, Specific weight..... | d or ρ (rho)    |

$$d = \frac{1}{v}$$

|                                                                                                                                          |                        |
|------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| Distance, linear.....                                                                                                                    | s                      |
| Dry saturated vapor, Dry saturated gas at saturation pressure and temperature, vapor in contact with liquid.....                         | Subscript g            |
| Efficiency.....                                                                                                                          | η                      |
| Elevation above some datum.....                                                                                                          | z, Z                   |
| Emissivity.....                                                                                                                          | ε                      |
| Energy in general; work, total; work, molal.....                                                                                         | E                      |
| Entropy. (The capital should be used for any weight, and the small letter for unit weight).....                                          | S or s                 |
| Force, total load.....                                                                                                                   | F                      |
| Gas Constant, in equation $pV = nRT$ .....                                                                                               | R                      |
| Head.....                                                                                                                                | H or h                 |
| Heat content, Total heat, Enthalpy. (The capital should be used for any weight and the small letter for unit weight).....                | H or h                 |
| Heat content of saturated liquid, Total heat of saturated liquid, Enthalpy of saturated liquid, sometimes called heat of the liquid..... | h <sub>l</sub>         |
| Heat content of dry saturated vapor, Total heat of dry saturated vapor, Enthalpy of dry saturated vapor.....                             | h <sub>g</sub>         |
| Heat of vaporization at constant pressure.....                                                                                           | L or h <sub>fg</sub>   |
| Hydraulic radius.....                                                                                                                    | R <sub>a</sub>         |
| Internal energy, Intrinsic energy. (The capital should be used for any weight and the small letter for unit weight).....                 | U or u                 |
| Length of path of heat flow, thickness.....                                                                                              | L                      |
| Load, total.....                                                                                                                         | W                      |
| Mechanical efficiency.....                                                                                                               | e <sub>m</sub>         |
| Mechanical equivalent of heat.....                                                                                                       | J                      |
| Power, Horsepower, Work per unit time.....                                                                                               | P                      |
| Pressure, Absolute pressure, Gage pressure, Force per unit area.....                                                                     | p                      |
| Quantity (total) of fluid, water, gas, heat; Quantity by volume; Total quantity of heat transferred.....                                 | Q                      |
| Quality of steam, Pounds of dry steam per pound of mixture.....                                                                          | x                      |
| Reynolds Number.....                                                                                                                     | Re                     |
| Saturated liquid at saturation pressure and temperature, Liquid in contact with vapor.....                                               | Subscript f            |
| Specific heat.....                                                                                                                       | c                      |
| Specific heat at constant pressure.....                                                                                                  | c <sub>p</sub>         |
| Specific heat at constant volume.....                                                                                                    | c <sub>v</sub>         |
| Specific volume, Volume per unit weight, Volume per unit mass.....                                                                       | v                      |
| Temperature (ordinary) F or C. (Theta is used preferably only when t is used for Time in the same discussion).....                       | t or θ (theta)         |
| Temperature (absolute) F abs or K. (Capital theta is used preferably only when small theta is used for ordinary temperature).....        | T or Θ (capital theta) |
| Thermal conductance: heat transferred per (unit time) (degree).....                                                                      | C                      |

$$C = \frac{1}{R} = \frac{kA}{L} = \frac{q}{t_1 - t_2}$$

<sup>4</sup> Terms ending *totally* designate properties independent of size or shape, sometimes called *specific properties*. Examples: conductivity, resistivity. Terms ending *once* designate quantities depending not only on the material, but also upon size and shape, sometimes called *total quantities*. Examples: conductance, transmittance. Terms ending *ton* designate rate of heat transfer. Examples: conduction, transmission.

Thermal conductance per unit area, Unit conductance: heat transferred per (unit time) (unit area) (degree).....  $C_s$

$$C_s = \frac{C}{A} = \frac{1}{RA} = \frac{q}{A(t_1 - t_2)} = \frac{k}{L}$$

Thermal conductivity: heat transferred per (unit time) (unit area) (degree per unit length).....  $k$

$$k = \frac{\frac{q}{A}}{\frac{(t_1 - t_2)}{L}}$$

Surface coefficient of heat transfer, Film coefficient of heat transfer, Individual coefficient of heat transfer: heat transferred per (unit time) (unit area) (degree).....  $f$

$$f = \frac{\frac{q}{A}}{t_1 - t_2}$$

(In general  $f$  is not equal to  $k/L$ , where  $L$  is the actual thickness of the fluid film.)

Overall coefficient of heat transfer, Thermal transmittance per unit area: heat transferred per (unit time) (unit area) (degree overall).....  $U$

$$U = \frac{\frac{q}{A}}{t_1 - t_2}$$

Thermal transmission (heat transferred per unit time).....  $q$

$$q = \frac{Q}{t}$$

Thermal resistance (degree per unit of heat transferred per unit time).....  $R$

$$R = \frac{t_1 - t_2}{q} = \frac{L}{kA}$$

Thermal resistivity.....  $1/k$

Vaporization values at constant pressure, Differences between values for saturated vapor and saturated liquid at the same pressure..... *Subscript fg*

Velocity.....  $V$

Viscosity, absolute.....  $\mu$

Viscosity, kinematic.....  $\mu/\rho$

Volume (total).....  $V$

Volume per unit time, Rate at which quantity of material passes through a machine, Quantity of heat per unit time, Quantity of heat per unit weight.....  $q$

Weight of a major item, Total weight.....  $W$

Weight rate, Weight per unit of power, Weight per unit of time.....  $W$

Work (total).....  $W$

### THE GREEK ALPHABET

|                         |                           |                         |
|-------------------------|---------------------------|-------------------------|
| A $\alpha$ Alpha        | I $\iota$ Iota            | P $\rho$ Rho            |
| B $\beta$ Beta          | K $\kappa$ Kappa          | $\Sigma$ $\sigma$ Sigma |
| $\Gamma$ $\gamma$ Gamma | $\Delta$ $\lambda$ Lambda | T $\tau$ Tau            |
| $\Delta$ $\delta$ Delta | M $\mu$ Mu                | T $\upsilon$ Upsilon    |
| E $\epsilon$ Epsilon    | N $\nu$ Nu                | $\Phi$ $\phi$ Phi       |
| Z $\zeta$ Zeta          | $\Xi$ $\xi$ Xi            | X $\chi$ Chi            |
| H $\eta$ Eta            | O $\omicron$ Omicron      | $\Psi$ $\psi$ Psi       |
| $\Theta$ $\theta$ Theta | $\Pi$ $\pi$ Pi            | $\Omega$ $\omega$ Omega |

### CONVERSION EQUATIONS<sup>1</sup>

#### Heat, Power and Work

|                              |                                                                                               |
|------------------------------|-----------------------------------------------------------------------------------------------|
| 1 ton refrigeration          | = { 12,000 Btu per hour<br>200 Btu per minute                                                 |
| Latent heat of ice           | = 143.4 Btu per pound                                                                         |
| 1 Btu                        | = { 778.3 ft-lb<br>0.2930 Int. whr<br>252.0 I.T. calorie                                      |
| 1 Int. watthour              | = { 2656 ft-lb<br>3.413 Btu<br>3600 Int. joules<br>860 I.T. calories                          |
| 1 Int. kilowatthour          | = { 3,413 Btu<br>3,517 lb water evaporated from<br>and at 212 F                               |
| 1 Int. kilowatt (1000 watts) | = { 1.341 hp<br>56.88 Btu per minute<br>44,267 ft-lb per minute                               |
| 1000 I.T. calories           | = { 3.968 Btu<br>3088 ft-lb                                                                   |
| 1 I.T. Kilocalorie           | = 1.1628 Int. whr                                                                             |
| 1 horsepower                 | = { 0.7455 Int. kw<br>42.40 Btu per minute<br>33,000 ft-lb per minute<br>550 ft-lb per second |
| 1 boiler horsepower          | = { 33,475 Btu per hour<br>9.809 Int. kw                                                      |

#### Weight and Volume

|                                   |                                |
|-----------------------------------|--------------------------------|
| 1 gal (U. S.)                     | = { 231 cu in.<br>0.1337 cu ft |
| 1 British or Imperial gallon      | = 277.42 cu in.                |
| 1 cu ft                           | = { 7.481 gal<br>1728 cu in.   |
| 1 cu ft water at 60 F. (in vacuo) | = 62.37 lb                     |
| 1 cu ft water at 212 F. { " " }   | = 59.83 lb                     |
| 1 gal water at 60 F. { " " }      | = 8.338 lb                     |
| 1 gal water at 212 F. { " " }     | = 7.998 lb                     |
| 1 lb (avdp)                       | = { 16 oz<br>7000 grains       |
| 1 bushel                          | = 1.244 cu ft                  |
| 1 short ton                       | = 2000 lb                      |

#### Pressure

|                      |                                                                                                                                             |
|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1 lb per square inch | = { 144 lb per square foot<br>2.0360 in. mercury at 32 F<br>2.0422 in. mercury at 62 F<br>2.309 ft water at 62 F<br>27.71 in. water at 62 F |
| 1 oz per square inch | = { 0.1276 in. mercury at 62 F<br>1.732 in. water at 62 F                                                                                   |

<sup>1</sup>Checked in 1944 by National Bureau of Standards. Abbreviations Int. and I.T. refer to International and International (Steam) Table, respectively.

|                                  |   |                                                                                                                                                                                                                                                      |
|----------------------------------|---|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 atmosphere                     | = | $\begin{cases} 14.696 \text{ lb per square inch} \\ 2116 \text{ lb per square foot} \\ 33.94 \text{ ft water at } 62^\circ\text{F} \\ 30.01 \text{ in. mercury at } 62^\circ\text{F} \\ 29.921 \text{ in. mercury at } 32^\circ\text{F} \end{cases}$ |
| 1 in. water at 62 F (in vacuo)   | = | $\begin{cases} 0.03609 \text{ lb per square inch} \\ 0.5774 \text{ oz per square inch} \\ 5.197 \text{ lb per square foot} \end{cases}$                                                                                                              |
| 1 ft. water at 62 F (in vacuo)   | = | $\begin{cases} 0.4330 \text{ lb per square inch} \\ 62.37 \text{ lb per square foot} \end{cases}$                                                                                                                                                    |
| 1 in. mercury at 62 F (in vacuo) | = | $\begin{cases} 0.4897 \text{ lb per square inch} \\ 7.835 \text{ oz per square inch} \\ 1.131 \text{ ft water at } 62^\circ\text{F} \\ 13.57 \text{ in. water at } 62^\circ\text{F} \end{cases}$                                                     |
| 1 in. mercury at 32 F (in vacuo) | = | 0.49115 lb per square inch                                                                                                                                                                                                                           |

## Metric Units

|                                                                                                      |   |                                                                                                                                                                     |
|------------------------------------------------------------------------------------------------------|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 cm                                                                                                 | = | 0.3937 in. = 0.0328 ft                                                                                                                                              |
| 1 in.                                                                                                | = | 2.540 cm                                                                                                                                                            |
| 1 m                                                                                                  | = | 3.281 ft                                                                                                                                                            |
| 1 ft                                                                                                 | = | 0.3048 m                                                                                                                                                            |
| 1 sq cm                                                                                              | = | 0.1550 sq in.                                                                                                                                                       |
| 1 sq in.                                                                                             | = | 6.452 sq cm                                                                                                                                                         |
| 1 sq m                                                                                               | = | 10.76 sq ft                                                                                                                                                         |
| 1 sq ft                                                                                              | = | 0.09290 sq m                                                                                                                                                        |
| 1 cu cm                                                                                              | = | 0.06102 cu in.                                                                                                                                                      |
| 1 cu in.                                                                                             | = | 16.39 cu cm                                                                                                                                                         |
| 1 cu m                                                                                               | = | 35.31 cu ft                                                                                                                                                         |
| 1 cu ft                                                                                              | = | 0.02832 cu m                                                                                                                                                        |
| 1 liter                                                                                              | = | 1000 cu cm = 0.2642 gal                                                                                                                                             |
| 1 kg                                                                                                 | = | 2.205 lb (avdp)                                                                                                                                                     |
| 1 lb                                                                                                 | = | 0.4536 kg                                                                                                                                                           |
| 1 metric ton                                                                                         | = | 2205 lb (avdp)                                                                                                                                                      |
| 1 gram                                                                                               | = | 0.002205 lb (avdp)                                                                                                                                                  |
| 1 kilometer per hour                                                                                 | = | 0.6214 mph                                                                                                                                                          |
| 1 gram per square centimeter                                                                         | = | $\begin{cases} 0.02905 \text{ in. mercury at } 62^\circ\text{F} \\ 0.3942 \text{ in. water at } 62^\circ\text{F} \end{cases}$                                       |
| 1 kg per sq cm (metric atmosphere)                                                                   | = | 14.22 lb per square inch                                                                                                                                            |
| 1 gram per cubic centimeter                                                                          | = | $\begin{cases} 0.03613 \text{ lb per cubic inch} \\ 62.43 \text{ lb per cubic foot} \end{cases}$                                                                    |
| 1 dyne                                                                                               | = | 0.00007233 poundals                                                                                                                                                 |
| 1 absolute joule                                                                                     | = | $\begin{cases} 10,000,000 \text{ ergs} \\ 0.7376 \text{ ft-lb} \end{cases}$                                                                                         |
| 1 Int. joule                                                                                         | = | 0.7378 ft-lb                                                                                                                                                        |
| 1 metric horsepower                                                                                  | = | $\begin{cases} 75 \text{ kg-m per second} \\ 0.986 \text{ hp (U. S.)} \end{cases}$                                                                                  |
| 1 I.T. kilocalorie per kilogram                                                                      | = | 1.8 Btu per pound                                                                                                                                                   |
| 1 I.T. calorie per square centimeter                                                                 | = | 3.687 Btu per square foot                                                                                                                                           |
| 1 I.T. calorie per (second) (square centimeter) for a temperature gradient of 1 C deg per centimeter | = | $\begin{cases} 2903 \text{ BTU per (hour) (square foot)} \\ \text{for a temperature gradient of } 1^\circ\text{F} \\ \text{deg per inch of thickness.} \end{cases}$ |

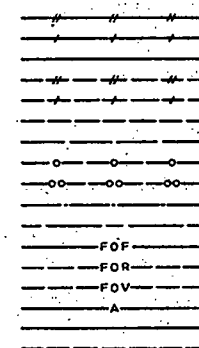
## GRAPHICAL SYMBOLS FOR DRAWINGS\*

## Graphical Symbols for Drawings

## Piping

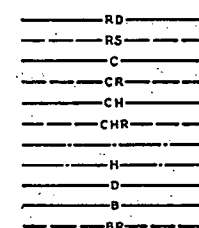
## HEATING

1. High Pressure Steam
2. Medium Pressure Steam
3. Low Pressure Steam
4. High Pressure Return
5. Medium Pressure Return
6. Low Pressure Return
7. Boiler Blow Off
8. Condensate or Vacuum Pump Discharge
9. Feedwater Pump Discharge
10. Make-Up Water
11. Air Relief Line
12. Fuel Oil Flow
13. Fuel Oil Return
14. Fuel Oil Tank Vent
15. Compressed Air
16. Hot Water Heating Supply
17. Hot Water Heating Return



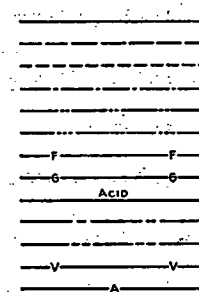
## AIR CONDITIONING

18. Refrigerant Discharge
19. Refrigerant Suction
20. Condenser Water Flow
21. Condenser Water Return
22. Circulating Chilled or Hot Water Flow
23. Circulating Chilled or Hot Water Return
24. Make-Up Water
25. Humidification Line
26. Drain
27. Brine Supply
28. Brine Return



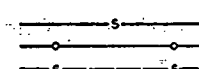
## PLUMBING

29. Soil, Waste or Leader (Above Grade)
30. Soil, Waste or Leader (Below Grade)
31. Vent
32. Cold Water
33. Hot Water
34. Hot Water Return
35. Fire Line
36. Gas
37. Acid Waste
38. Drinking Water Flow
39. Drinking Water Return
40. Vacuum Cleaning
41. Compressed Air



## SPRINKLERS

42. Main Supplies
43. Branch and Head
44. Drain

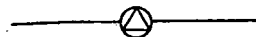


\* Extracted from: American Standard Graphical Symbols for Pipe Fittings, Valves, and Piping (ASA Z33.2.3-1949) and American Standard Graphical Symbols for Heating, Ventilating, and Air Conditioning (ASA Z33.2.4-1949) with the permission of the publisher, The American Society of Mechanical Engineers, 29 West 39th St., New York 18, N. Y.

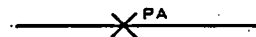
## Graphical Symbols for Drawings

Heating

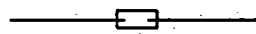
1. Air Eliminator



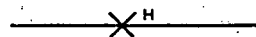
2. Anchor



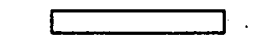
3. Expansion Joint



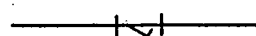
4. Hanger or Support



5. Heat Exchanger

6. Heat Transfer Surface, Plan  
(Indicate Type Such as Convector)7. Pump  
(Indicate Type Such as Vacuum)

8. Strainer



9. Tank (Designate Type)



10. Thermometer

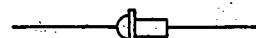


11. Thermostat

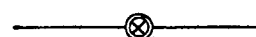


12. Traps

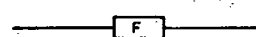
12.1 Boiler Return



12.2 Blast Thermostatic



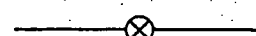
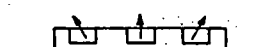
12.3 Float



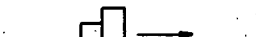
12.4 Float and Thermostatic



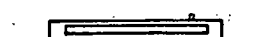
12.5 Thermostatic

13. Unit Heater  
(Centrifugal Fan), Plan

14. Unit Heater (Propeller), Plan



15. Unit Ventilator, Plan

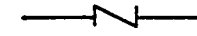


## Graphical Symbols for Drawings

Heating

16. Valves

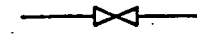
16.1 Check



16.2 Diaphragm



16.3 Gate



16.4 Globe



16.5 Lock and Shield



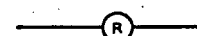
16.6 Motor Operated



16.7 Reducing Pressure



16.8 Relief (Either Pressure or Vacuum)



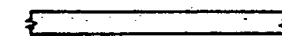
17. Vent Point



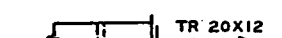
## Graphical Symbols for Drawings

Ventilating

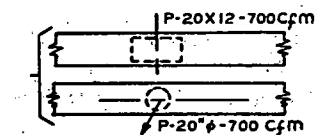
18. Access Door



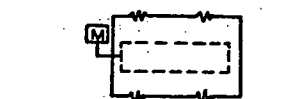
19. Adjustable Blank Off



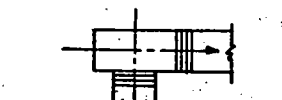
20. Adjustable Plaque



21. Automatic Dampers



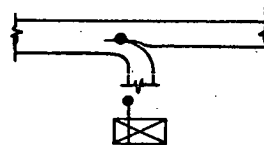
22. Canvas Connections



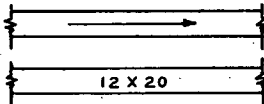
## Graphical Symbols for Drawings

## Ventilating

23. Deflecting Damper



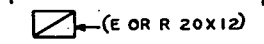
24. Direction of Flow



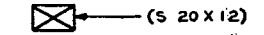
25. Duct (1st Figure, Side Shown; 2nd Side not Shown)



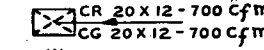
26. Duct Section (Exhaust or Return)



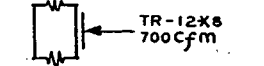
27. Duct Section (Supply)



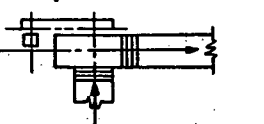
28. Exhaust Inlet Ceiling (Indicate Type)



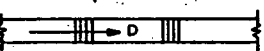
29. Exhaust Inlet Wall (Indicate Type)



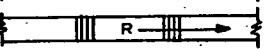
30. Fan and Motor With Belt Guard



31. Inclined Drop in Respect to Air Flow



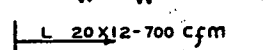
32. Inclined Rise in Respect to Air Flow



33. Intake Louvers on Screen



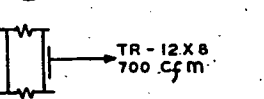
34. Louver Opening



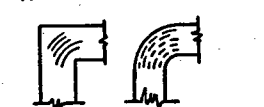
35. Supply Outlet Ceiling (Indicate Type)



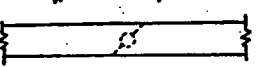
36. Supply Outlet Wall (Indicate Type)



37. Vanes



38. Volume Damper



## Abbreviations, Symbols, Conversion Factors

## Graphical Symbols for Drawings

## Air Conditioning

39. Capillary Tube
40. Compressor
41. Compressor, Enclosed, Crankcase, Rotary, Belted
42. Compressor, Open Crankcase, Reciprocating, Belted
43. Compressor, Open Crankcase, Reciprocating, Direct Drive
44. Condenser, Air Cooled, Finned, Forced Air
45. Condenser, Air Cooled, Finned, Static
46. Condenser, Water Cooled, Concentric Tube in a Tube
47. Condenser, Water Cooled, Shell and Coil
48. Condenser, Water Cooled, Shell and Tube
49. Condensing Unit, Air Cooled
50. Condensing Unit, Water Cooled
51. Cooling Tower
52. Dryer
53. Evaporative Condenser
54. Evaporator, Circular, Ceiling Type, Finned
55. Evaporator, Manifolded, Bare Tube, Gravity Air
56. Evaporator Manifolded, Finned, Forced Air

57. Evaporator Manifolded, Finned, Gravity Air
58. Evaporator, Plate Coils, Headered or Manifold
59. Filter, Line
60. Filter & Strainer, Line
61. Finned Type Cooling Unit, Natural Convection
62. Forced Convection Cooling Unit
63. Gage
64. High Side Float
65. Immersion Cooling Unit
66. Low Side Float
67. Motor-Compressor, Enclosed Crankcase, Reciprocating, Direct Connected
68. Motor-Compressor, Enclosed Crankcase, Rotary, Direct Connected
69. Motor-Compressor, Sealed Crankcase, Reciprocating
70. Motor-Compressor, Sealed Crankcase, Rotary
71. Pressurestat
72. Pressure Switch
73. Pressure Switch With High Pressure Cut-Out
74. Receiver, Horizontal
75. Receiver, Vertical



|                                                                              |  |                                                                        |  |
|------------------------------------------------------------------------------|--|------------------------------------------------------------------------|--|
| 76. Scale Trap                                                               |  | 80.6 Evaporator Pressure Regulating, Throttling Type (Evaporator Side) |  |
| 77. Spray Pond                                                               |  | 80.7 Hand Expansion                                                    |  |
| 78. Thermal Bulb                                                             |  | 80.8 Magnetic Stop                                                     |  |
| 79. Thermostat (Remote Bulb)                                                 |  | 80.9 Snap Action                                                       |  |
| 80. Valves                                                                   |  | 80.10 Suction Vapor Regulating                                         |  |
| 80.1 Automatic Expansion                                                     |  | 80.11 Thermo Suction                                                   |  |
| 80.2 Compressor Suction Pressure Limiting, Throttling Type (Compressor Side) |  | 80.12 Thermostatic Expansion                                           |  |
| 80.3 Constant Pressure, Suction                                              |  | 80.13 Water                                                            |  |
| 80.4 Evaporator Pressure Regulating, Snap Action                             |  | 81. Vibration Absorber, Line                                           |  |
| 80.5 Evaporator Pressure Regulating, Thermostatic Throttling Type            |  |                                                                        |  |

### IDENTIFICATION OF PIPING SYSTEMS BY COLOR

The color scheme for identification of piping systems, based on material carried, as listed in the following table and shown in Fig. 1, is reprinted from Part V, Fourth Edition, of the Engineering Standards of the Heating, Piping and Air Conditioning Contractors National Association.<sup>1</sup>

| CLASS                      | COLOR                                                            |
|----------------------------|------------------------------------------------------------------|
| F—Fire-protection          | Red                                                              |
| D—Dangerous materials      | Yellow or Orange                                                 |
| S—Safe Materials           | Green (or the achromatic colors, white, black, gray or aluminum) |
| and, when required         |                                                                  |
| P—Protective materials     | Bright blue                                                      |
| V—Extra valuable materials | Deep purple                                                      |

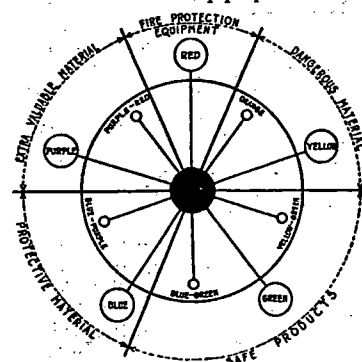


FIG. 1. MAIN CLASSIFICATION BY COLOR

<sup>1</sup> See Scheme for Identification of Piping Systems, A13-1928, American Standards Association

### CHAPTER 3

## THERMODYNAMICS

Mass and Energy Balances; Thermodynamic Properties of Moist Air; Formulas and Tables; Thermodynamic Properties of Water, Formulas and Tables; Degree of Saturation; A.S.H.V.E. Psychrometric Chart; Solution of Air Conditioning Problems by Use of Tables and Psychrometric Chart; U. S. Standard Atmosphere

**T**HERMODYNAMICS is that branch of natural science which deals with energy and its transformations into various forms. In this chapter the discussion will be limited to thermodynamics as it affects the arts of heating and air conditioning. This will necessarily presume some knowledge of the fundamentals of the science on the part of the reader who may also find it desirable to refer to a standard text on the subject, preferably one published after 1930.

### MASS AND ENERGY BALANCES

The First Law of Thermodynamics is a statement of the Principle of Conservation of Energy. It may be stated as follows: *The energy added to a system is equal to the increase or decrease of the energy stored in the system, plus the energy which leaves the system.* For a completely contained, or non-flow system, this may be restated as: The heat added to a non-flow system is equal to the change in the internal energy of the system, plus the work done by the system.

$$q_2 = U_2 - U_1 + w \quad (1)$$

For a constant pressure process

$$q_2 = H_2 - H_1 \quad (2)$$

where

$q_2$  = energy added between points 1 and 2.

$U$  = internal energy of system.

$w$  = work done by system.

$H$  = enthalpy of system.

Subscripts 1 and 2 refer to sections of the system between which a change takes place.

For engineering problems, a more important application of the First Law is its use in cases in which, in addition to energy, one or more fluids are crossing the boundaries of the system. The most simple of these is the steady flow system, in which the rates of energy and mass flow across the boundaries of the system are constant, and no mass or energy is stored or released by the system.

Consider a system as illustrated in Fig. 1. The fluid crossing the boundaries of the system carries with it potential energy by reason of its elevation above some convenient datum, kinetic energy by reason of its

velocity, and energy in the form of enthalpy. Additional energy may cross the boundaries of the system in the forms of heat or work. The various forms of energy crossing the boundaries between the sections under consideration may be equated by applying the First Law of Thermodynamics:

$$PE_1 + KE_1 + H_1 + {}_1q_2 = PE_2 + KE_2 + H_2 + w \quad (3)$$

where

$PE$  = potential energy, Btu per pound dry air.

$KE$  = kinetic energy, Btu per pound dry air.

$H$  = enthalpy, Btu per pound dry air.

${}_1q_2$  = heat added between sections 1 and 2, Btu per pound dry air.

$w$  = shaft work withdrawn between sections 1 and 2, Btu per pound of dry air.

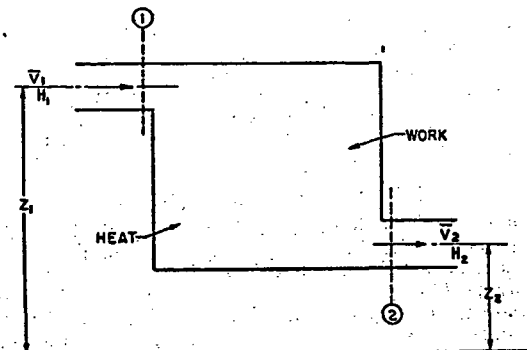


FIG. 1. ENERGY CHANGE BETWEEN TWO SECTIONS OF A SYSTEM

For most psychrometric problems, since the change in the potential energy and kinetic energy terms is negligible compared to the enthalpy change, Equation 3 may be simplified to

$$H_1 + {}_1q_2 = H_2 + w \quad (4)$$

where

$H$  = enthalpy of the flowing medium, Btu per pound of dry air.

The enthalpy of the entire system may be broken down into constituent parts, thus:

$$GH = Gh + Lh_{w1} + Sh_{w2} \quad (5)$$

where

$h$  = enthalpy of moist air, Btu per pound of dry air.

$h_{w1}$  = enthalpy of liquid water, Btu per pound.

$h_{w2}$  = enthalpy of solid water, Btu per pound.

$L$  = flow rate of liquid water, pounds per hour.

$S$  = flow rate of solid water, pounds per hour.

$G$  = flow rate of dry air, pounds per hour.

Similarly, an equation expressing the conservation of mass may be written thus:

$$\sum_{in} [G(1 + W) + L + S] = \sum_{out} [G(1 + W) + L + S] \quad (6)$$

where

$W$  = humidity ratio, pounds of water vapor per pound of dry air.

### THERMODYNAMIC PROPERTIES OF MOIST AIR

The working substance of the air conditioning engineer is moist air. Air is actually a mixture of oxygen, nitrogen, carbon dioxide, water vapor, and traces of other gases.

The mixture consisting of the components other than water vapor is known as *dry air*. Its composition remains essentially constant under all conditions. In moist air the amount of water vapor varies considerably. To allow for this variation the specific properties of moist air are developed in terms of the relative amounts of water vapor and dry air. Accepted air conditioning practice is to express this in terms of the amount of water vapor per pound of dry air.

Terms frequently used in describing the condition of a mixture of air and water vapor are *humidity ratio*, *relative humidity*, *degree of saturation*, *dry-bulb temperature*, *thermodynamic wet-bulb temperature*, and *dew-point temperature*. These terms are defined in following paragraphs.

**Humidity Ratio.** Weight of water vapor associated with unit weight of dry air, pounds of water vapor per pound of dry air. Humidity ratio has also been called *specific humidity*, and this term is still used in many places.

**Relative Humidity.** Ratio of the mol fraction of water vapor in the actual mixture to the mol fraction of water vapor in saturated air at the same dry-bulb temperature and barometric pressure.

**Degree of Saturation.** Ratio of the actual humidity ratio to the humidity ratio of saturated air at the same dry-bulb temperature and barometric pressure.

Relative humidity and degree of saturation are related according to the identity:

$$\phi = \frac{\mu}{1 - (1 - \mu)f_s \frac{P_s}{P_a}} \quad (7)$$

where

$\phi$  = relative humidity, expressed as a decimal.

$\mu$  = degree of saturation, expressed as a decimal.

$P_a$  = observed (or barometric) pressure of the moist air.

$P_s$  = saturation pressure of pure water at the prevailing temperature, expressed in the same units as  $P_a$ .

$f_s$  = a dimensionless factor which may be regarded as accounting for influences arising when air and water are intermixed. Magnitudes of  $f_s$  have been reported by Goff and Gratch<sup>1</sup> and by Goff.<sup>2</sup> Table 1 gives values of  $f_s$  for a limited range of conditions.

**Dry-Bulb Temperature.** The temperature indicated by any type of thermometer or thermocouple not affected by the water vapor content of the air, or by radiation.

**Thermodynamic Wet-Bulb Temperature.** The temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature.

Consider an adiabatic system as shown in Fig. 2. Unsaturated air at the state  $h_1, W_1$ , enters the system at section 1, and saturated air at the state  $h^*, W^*$ , leaves the system at section 2. Liquid water at the state  $h_w^*$ , corresponding to the temperature of the saturated air leaving the system is supplied. Then, since no work is done and the system is strictly adiabatic, the energy equation becomes

$$h_1 + (W^* - W_1)h_w^* = h^* \quad (8)$$

where

\* indicates condition at thermodynamic wet-bulb temperature.

TABLE 1. MAGNITUDES OF  $f_s$  FOR THE RANGE 0 TO 125 F  
(Standard Barometric Pressure, 29.921 in. Hg)

| TEMP. F | $f_s$  | TEMP. F | $f_s$  |
|---------|--------|---------|--------|
| 0       | 1.0048 | 70      | 1.0045 |
| 10      | 1.0046 | 80      | 1.0047 |
| 20      | 1.0046 | 90      | 1.0048 |
| 30      | 1.0045 | 100     | 1.0050 |
| 40      | 1.0044 | 110     | 1.0053 |
| 50      | 1.0044 | 120     | 1.0055 |
| 60      | 1.0044 | 125     | 1.0057 |

Note: The original source gives  $f_s$  to seven significant figures over the temperature range -203 F to +202 F and over the pressure range 20 to 35 in. Hg.

The temperature corresponding to  $h^*$  for given values of  $h_1$  and  $W_1$  is called the thermodynamic wet-bulb temperature, or the temperature of adiabatic saturation.

The temperature indicated by an ordinary wet-bulb thermometer is affected by a number of factors not accounted for in Equation 8, and hence, may be quite different from the theoretical temperature obtained from its use. The measured wet-bulb temperature is influenced by (a) radiation from the surroundings to the wick; (b) conduction of heat along the stem of the thermometer; and (c) impact of the air on the wick or bulb of the thermometer. Arnold<sup>2</sup> has developed a theory which makes possible the calculation of the true thermodynamic wet-bulb temperature from observed data through the use of suitable corrections to be applied to the readings of the wet-bulb thermometer. However, unless extreme precision is required, the observed temperature may be taken equal to the theoretical temperature for most engineering problems, if no attempt is made to shield the wick from radiation and the air velocity past the wick is about 1000 fpm.

**Dew-Point Temperature.** The saturation temperature corresponding to a given combination of humidity ratio  $W$  and barometric pressure is called the dew-point temperature. It is the lowest temperature at which the

given humidity ratio can exist at the corresponding barometric pressure. At this temperature condensation will first start to form when moist air is cooled.

### Perfect Gas Relationships

Hypotheses, based on experimental observation of the physical behavior of gases, which were advanced by Boyle, Charles, Gay-Lussac, Dalton, Gibbs, Joule, Kelvin and others, were reduced to reasonably simple mathematical expressions and came to be regarded as physical laws. However, as scientific knowledge increased, and as more precise methods of measurement were developed, it became apparent that these simple equations did not describe the behavior of the mixtures of actual gases and vapors accurately.

The original statements have been found to be useful tools, nevertheless, in many cases. For example, the behavior of common diatomic and tria-

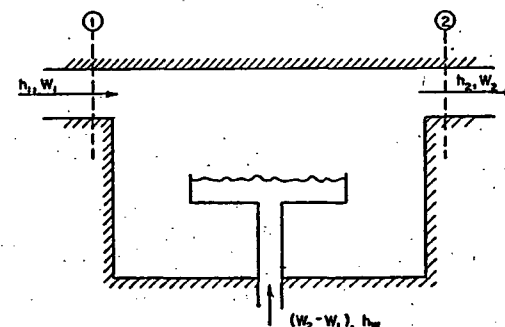


FIG. 2. ILLUSTRATION OF ADIABATIC SATURATION

tomic gases at low pressures follows these equations closely enough so that they may be used for some types of engineering problems. Many useful engineering works have been constructed through the use of approximations. The degree of approximation, however, which may be tolerated in engineering design must be decided by the engineer, based upon his study and experience in the field.

**Boyle's Law.** One of the original observations of the physical behavior of gases was made by Robert Boyle who noted that, if a constant weight of gas is compressed with the temperature held constant, the volume  $V$  varied inversely as the absolute pressure  $P$ . Stated mathematically,

$$PV = \text{constant} \quad (\text{temperature constant}) \quad (9)$$

**Charles' Law.** Experiments made independently by Charles and Gay-Lussac led to the formulation of what is now known as Charles' Law: If a constant weight of gas is heated or cooled at constant volume, the absolute pressure  $P$  varies as the absolute temperature  $T$ ; if a constant weight of

gas is heated or cooled at constant pressure, the volume  $V$  varies as the absolute temperature  $T$ . Stated mathematically,

$$\frac{P}{T} = \text{constant} \quad (\text{volume constant}) \quad (10)$$

$$\frac{V}{T} = \text{constant} \quad (\text{pressure constant}) \quad (11)$$

Boyle's Law and Charles' Law may be combined to form the equation of state for the ideal or perfect gas,

$$PV = RT \quad (12)$$

where

$R$  is a constant whose value depends on the units selected for  $P$ ,  $V$ , and  $T$ .

**Dalton's Rule.** Dalton stated that each gas in a mixture occupies the total volume of the mixture just as though the other gases were not present. Gibbs later expanded this statement for perfect gases into the following principles:

1. The pressure of a mixture of gases is the sum of the partial pressures of the individual gases when they exist at the total volume and temperature of the mixture.
2. The internal energy, enthalpy, and entropy of a mixture of gases are respectively equal to the sums of the individual internal energies, enthalpies, and entropies of the components when they exist at the total volume and temperature of the mixture.

While these relationships do not hold exactly for all systems of real gases, they may be used with a good degree of precision for many engineering applications at low pressures. Moreover, since water vapor very closely follows the perfect gas relationships in the range usually encountered in air conditioning, the Gibbs-Dalton Rule may frequently be applied to mixtures of dry air and water vapor.

Thus,

$$V_m = V_a = V_w \quad (13)$$

$$T_m = T_a = T_w \quad (14)$$

$$p_m = p_a + p_w \quad (15)$$

$$m_m h = m_a h_a + m_w h_w \quad (16)$$

where

Subscript  $m$  denotes mixture; subscript  $a$  denotes dry air; subscript  $w$  denotes water vapor.

Symbol  $m$  = weight of dry air crossing any duct section, pounds per minute.

Using Equations 12, 13, 14, and 15, the relation is obtained as follows:

$$v_r = \frac{n_a RT}{p_a} = \frac{n_w RT}{p_w} = \frac{(n_a + n_w) RT}{p} \quad (17)$$

where

$v_r$  = total volume, cubic feet.

$n_a$  = number of mols of dry air.

## Thermodynamics

$n_w$  = number of mols of water vapor.

$R$  = universal gas constant, 1545 foot-pounds per (Fahrenheit degree) (mol).

$p_a$  = partial pressure of dry air.

$p_w$  = partial pressure of water vapor.

$T$  = absolute temperature, Fahrenheit degrees.

The partial pressure of water vapor in the mixture is then

$$p_w = \frac{n_w}{n_a + n_w} p \quad (18)$$

or, the partial pressure of the water vapor in moist air is equal to the product of the mol fraction of the water vapor and the observed pressure of the mixture. A similar expression is obtained for the dry air.

Assuming that the perfect gas laws can be applied to water vapor at saturation at low pressures, the partial pressure of water vapor in a saturated mixture may be written as

$$p_w = \frac{n_s}{n_a + n_s} p \quad (19)$$

where

$n_s$  = number of mols of water vapor at saturation.

The relative humidity may be obtained by combining Equations 18 and 19 and solving for the ratio of mol fractions. Thus, using perfect gas relationships,

$$\phi = \frac{p_w}{p_s} \quad (20)$$

The humidity ratio  $W$  may be obtained from Equation 17:

$$W = \frac{18.016}{28.966} \frac{p_w}{p_a} = 0.622 \frac{p_w}{p - p_w} \quad (21)$$

where 18.016 and 28.966 are the molecular weights of water and dry air, respectively.

Equation 16 may be rewritten as

$$h = h_a + W h_w \quad (22)$$

where

$h$  = enthalpy, Btu per pound of dry air.

In relating the enthalpy to the state of the moist air, the fact that in all applications only differences in enthalpy are involved, allows the arbitrary selection of a datum or zero enthalpy point. Accordingly, from perfect gas relationships, it is possible to write for any temperature of  $t$ , Fahrenheit greater than 0 F

$$h_a = 0.24 t \quad (23)$$

where it is assumed that the same arbitrary datum of 0 F is used as in determining the properties of moist air in Table 2.

## Tables of Thermodynamic Properties of Moist Air

Research work conducted at the *University of Pennsylvania* and at other institutions has shown that the Gibbs-Dalton Rule is inaccurate in varying degrees, depending on temperature, pressure and the amount of water

vapor present. The probable reasons for this inaccuracy are due to the effect of:

1. Chemical solution of gas molecules in the water vapor.
2. The finite size of the molecules causing interference with the free passage of other molecules toward the boundaries of the system.
3. Intermolecular forces of attraction and repulsion.

Many attempts have been made to develop an equation of state which would predict the true states of real gases and vapors. The Van der Waal, Maxwell, and Beattie-Bridgman equations are probably the best known. Unfortunately, these expressions rapidly become much too complicated to be used in everyday calculations and, therefore, engineers find it more convenient to use tables of thermodynamic properties for specific working substances, as these can be prepared by physicists using the best laboratory equipment and all the refinements of mathematics.

Mechanical engineers have long been familiar with such tables for the properties of steam. Tables of the properties of moist air, as prepared by Goodenough and others, have been available for some time, but the latest and most precise of such tables are those which have resulted from a co-operative research agreement between the AMERICAN SOCIETY OF HEATING AND AIR-CONDITIONING ENGINEERS and the *Towne Scientific School of the University of Pennsylvania*. These properties are published herein as Table 2, and are taken from a research report by Goff and Gratch.<sup>4</sup> Table 2, which experimentally and mathematically takes into account deviations from perfect gas behavior, such as those listed above, makes the application of the Gibbs-Dalton Rule a less frequent necessity.

In Table 2 there are 15 columns of figures, each column being headed by a suitable symbol. In the following sub-paragraphs brief explanations are given of the data in Table 2 under the appropriate column headings.

$t(F)$  = Fahrenheit temperature defined in terms of absolute temperature  $T$  by the relation,

$$T = t + 459.67 \quad (24)$$

$W_s$  = humidity ratio at saturation. Saturation is the condition at which the vapor phase (moist air) may exist in equilibrium with a condensed phase (liquid or solid) at the given temperature and pressure (standard atmospheric pressure in the case of Table 2). At given values of temperature and pressure, the humidity ratio  $W$  can have any value from zero to  $W_s$ .

$v_a$  = specific volume of dry air, cubic feet per pound.

$v_{sa} = v_s - v_a$ , the difference between the volume of moist air at saturation, per pound of dry air, and the specific volume of the dry air itself, cubic feet per pound of dry air.

$v_s$  = specific volume of moist air at saturation per pound of dry air, cubic feet per pound of dry air.

$h_a$  = specific enthalpy of dry air, Btu per pound of dry air. The specific enthalpy of dry air has been assigned the value zero at 0 F, standard atmospheric pressure. The energy unit Btu is related to the foot-pound by definition, as follows: 1 Btu = 778.3 ft-lb.

$h_{sa} = h_s - h_a$ , the difference between the enthalpy of moist air at saturation, per pound of dry air, and the specific enthalpy of the dry air itself, Btu per pound of dry air.

$h_s$  = enthalpy of moist air at saturation per pound of dry air, Btu per pound of dry air.

$s_a$  = specific entropy of dry air, Btu per (pound) (Fahrenheit degree). It will be

noticed that the specific entropy of dry air has been assigned the value zero at 0 F and standard atmospheric pressure.

$s_{sa} = s_s - s_a$ , the difference between the entropy of moist air at saturation, per pound of dry air, and the specific entropy of the dry air itself, Btu per (pound of dry air) (Fahrenheit degree).

$s_s$  = entropy of moist air at saturation per pound of dry air, Btu per (pound of dry air) (Fahrenheit degree).

$h_w$  = specific enthalpy of condensed water (liquid or solid) at standard atmospheric pressure, Btu per pound of water. The specific enthalpy of liquid water has been assigned the value zero at 32 F, saturation pressure (0.088586 psia).

$s_w$  = specific entropy of condensed water (liquid or solid) at standard atmospheric pressure, Btu per (pound of water) (Fahrenheit degree). The specific entropy of liquid water has been assigned the value zero at 32 F, saturation pressure (0.088586 psia).

$p_s$  = saturation pressure of pure water vapor, pounds per square inch or inches of Hg (absolute pressure). At a given pressure, moist air can be saturated at any temperature, though this requires that it have a definite humidity ratio  $W_s$ , and that the coexisting condensed phase contain a definite, but very small, quantity of dissolved air. On the other hand, pure water vapor (steam) below the critical temperature, can be saturated at only one temperature for a given pressure. The values of saturation pressure listed in Table 2 have been computed from the formulas of Goff and Gratch.

### THERMODYNAMIC PROPERTIES OF WATER AT SATURATION

Since water vapor at low pressures acts almost as a perfect gas, the enthalpy of water vapor should also be a function only of the temperature within these limits. Therefore, the enthalpy of the water vapor may be expressed as being approximately equal to the enthalpy of saturated vapor at the dry-bulb temperature of the mixture. Substituting these values in Equation 22, the enthalpy of the mixture becomes

$$h = 0.24 t + Wh_s \quad (25)$$

where  $h_s$  is the value of the enthalpy of saturated vapor at the temperature  $t$ , and is obtained from Table 3.

Table 3 offers revisions to existing steam table data with extensions downward to -160 F. These revisions and extensions were a necessary preliminary to the construction of Table 2. A detailed explanation of the methods employed in the construction of Table 3 is given in a paper by John A. Goff and S. Gratch.<sup>5</sup>

As in Table 2, the temperature scale used as argument in Table 3 is the Fahrenheit scale defined in terms of absolute temperature  $T$  by Equation 24. The symbols used as column headings in Table 3 are the same as those used in steam tables, and have the same meanings.

Properties of water above 212 F from Keenan and Keyes<sup>6</sup> are given in Table 4.

### DEGREE OF SATURATION

Degree of saturation has previously been defined as the ratio of the actual humidity ratio to the humidity ratio of saturated air at the same dry-bulb temperature and barometric pressure. This may be stated mathematically as

$$\mu = \frac{W}{W_s} \quad (26)$$

Obviously the degree of saturation  $\mu$  can have any value from zero (dry air) to unity (moist air at saturation). The degree of saturation is con-

TABLE 2. THERMODYNAMIC PROPERTIES OF MOIST AIR\* (STANDARD ATMOSPHERIC PRESSURE, 29.921 IN. Hg)

| FAHR.<br>TEMP.<br>(°F) | HUMIDITY<br>RATIO<br>$W \times 10^3$ | VOLUME<br>CU FT/LB DRY AIR |          |        | ENTHALPY<br>BTU/LB DRY AIR |          |       | ENTROPY<br>BTU PER (°F) (LB DRY AIR) |          |         | CONDENSED WATER             |                            |                                           | FAHR.<br>TEMP.<br>(°F) |
|------------------------|--------------------------------------|----------------------------|----------|--------|----------------------------|----------|-------|--------------------------------------|----------|---------|-----------------------------|----------------------------|-------------------------------------------|------------------------|
|                        |                                      | $v_a$                      | $v_{sa}$ | $v_g$  | $h_a$                      | $h_{sa}$ | $h_g$ | $s_a$                                | $s_{sa}$ | $s_g$   | Enthalpy<br>Btu/Lb<br>$h_w$ | Entropy<br>Btu/Lb<br>$s_w$ | Vap. Press<br>In. Hg<br>$p_a \times 10^3$ |                        |
|                        |                                      |                            |          |        |                            |          |       |                                      |          |         |                             |                            |                                           |                        |
| -80                    | 0.000120                             | 7.520                      | 0.000    | 7.520  | -35.504                    | 0.000    | 0.000 | -0.10300                             | 0.00000  | 0.00000 | -223.00                     | -0.4007                    | 0.000109                                  | -80                    |
| -75                    | 0.000369                             | 7.547                      | 0.000    | 7.547  | -37.295                    | 0.000    | 0.000 | -0.09901                             | 0.00000  | 0.00000 | -223.40                     | -0.4053                    | 0.000134                                  | -75                    |
| -70                    | 0.000932                             | 7.775                      | 0.000    | 7.775  | -38.088                    | 0.000    | 0.000 | -0.09508                             | 0.00000  | 0.00000 | -223.77                     | -0.4100                    | 0.000301                                  | -70                    |
| -65                    | 0.002119                             | 7.902                      | 0.000    | 7.902  | -38.881                    | 0.000    | 0.000 | -0.09121                             | 0.00000  | 0.00000 | -224.12                     | -0.4147                    | 0.0008307                                 | -65                    |
| -60                    | 0.004608                             | 8.029                      | 0.000    | 8.029  | -39.674                    | 0.000    | 0.000 | -0.08740                             | 0.00000  | 0.00000 | -224.46                     | -0.4195                    | 0.001904                                  | -60                    |
| -55                    | 0.008353                             | 8.156                      | 0.000    | 8.156  | -40.468                    | 0.000    | 0.000 | -0.08358                             | 0.00000  | 0.00000 | -224.80                     | -0.4243                    | 0.004355                                  | -55                    |
| -50                    | 0.014987                             | 8.283                      | 0.000    | 8.283  | -41.262                    | 0.000    | 0.000 | -0.07977                             | 0.00000  | 0.00000 | -225.13                     | -0.4291                    | 0.010235                                  | -50                    |
| -45                    | 0.025009                             | 8.411                      | 0.000    | 8.411  | -42.057                    | 0.000    | 0.000 | -0.07604                             | 0.00000  | 0.00000 | -225.46                     | -0.4338                    | 0.024110                                  | -45                    |
| -40                    | 0.038608                             | 8.537                      | 0.000    | 8.537  | -42.852                    | 0.000    | 0.000 | -0.07237                             | 0.00000  | 0.00000 | -225.79                     | -0.4385                    | 0.056763                                  | -40                    |
| -35                    | 0.056172                             | 8.664                      | 0.000    | 8.664  | -43.646                    | 0.000    | 0.000 | -0.06877                             | 0.00000  | 0.00000 | -226.12                     | -0.4432                    | 0.13111                                   | -35                    |
| -30                    | 0.078211                             | 8.792                      | 0.000    | 8.792  | -44.440                    | 0.000    | 0.000 | -0.06524                             | 0.00000  | 0.00000 | -226.45                     | -0.4479                    | 0.30035                                   | -30                    |
| -25                    | 0.104340                             | 8.919                      | 0.000    | 8.919  | -45.234                    | 0.001    | 0.001 | -0.06177                             | 0.00000  | 0.00000 | -226.78                     | -0.4526                    | 0.68038                                   | -25                    |
| -20                    | 0.134972                             | 9.046                      | 0.000    | 9.046  | -46.028                    | 0.001    | 0.001 | -0.05837                             | 0.00000  | 0.00000 | -227.11                     | -0.4573                    | 1.587                                     | -20                    |
| -15                    | 0.170599                             | 9.173                      | 0.000    | 9.173  | -46.822                    | 0.002    | 0.002 | -0.05507                             | 0.00000  | 0.00000 | -227.44                     | -0.4620                    | 3.691                                     | -15                    |
| -10                    | 0.21162                              | 9.300                      | 0.000    | 9.300  | -47.616                    | 0.002    | 0.002 | -0.05187                             | 0.00000  | 0.00000 | -227.77                     | -0.4667                    | 8.551                                     | -10                    |
| -5                     | 0.25854                              | 9.427                      | 0.000    | 9.427  | -48.410                    | 0.003    | 0.003 | -0.04877                             | 0.00000  | 0.00000 | -228.10                     | -0.4714                    | 19.70                                     | -5                     |
| 0                      | 0.31184                              | 9.554                      | 0.000    | 9.553  | -49.203                    | 0.003    | 0.003 | -0.04577                             | 0.00000  | 0.00000 | -228.43                     | -0.4761                    | 45.89                                     | 0                      |
| 5                      | 0.37114                              | 9.681                      | 0.000    | 9.680  | -50.000                    | 0.004    | 0.004 | -0.04287                             | 0.00000  | 0.00000 | -228.76                     | -0.4808                    | 107.9                                     | 5                      |
| 10                     | 0.43694                              | 9.808                      | 0.000    | 9.806  | -50.800                    | 0.004    | 0.004 | -0.04007                             | 0.00000  | 0.00000 | -229.09                     | -0.4855                    | 247.8                                     | 10                     |
| 15                     | 0.50874                              | 9.935                      | 0.000    | 9.932  | -51.600                    | 0.005    | 0.005 | -0.03737                             | 0.00000  | 0.00000 | -229.42                     | -0.4902                    | 569.8                                     | 15                     |
| 20                     | 0.58704                              | 10.062                     | 0.000    | 10.059 | -52.400                    | 0.005    | 0.005 | -0.03477                             | 0.00000  | 0.00000 | -229.75                     | -0.4949                    | 1300                                      | 20                     |
| 25                     | 0.67154                              | 10.189                     | 0.000    | 10.186 | -53.200                    | 0.006    | 0.006 | -0.03227                             | 0.00000  | 0.00000 | -230.08                     | -0.4996                    | 2970                                      | 25                     |
| 30                     | 0.76204                              | 10.316                     | 0.000    | 10.314 | -54.000                    | 0.006    | 0.006 | -0.02987                             | 0.00000  | 0.00000 | -230.41                     | -0.5043                    | 6700                                      | 30                     |
| 35                     | 0.85854                              | 10.443                     | 0.000    | 10.441 | -54.800                    | 0.007    | 0.007 | -0.02757                             | 0.00000  | 0.00000 | -230.74                     | -0.5090                    | 15200                                     | 35                     |
| 40                     | 0.96104                              | 10.570                     | 0.000    | 10.567 | -55.600                    | 0.007    | 0.007 | -0.02537                             | 0.00000  | 0.00000 | -231.07                     | -0.5137                    | 34700                                     | 40                     |
| 45                     | 1.06954                              | 10.697                     | 0.000    | 10.694 | -56.400                    | 0.008    | 0.008 | -0.02327                             | 0.00000  | 0.00000 | -231.40                     | -0.5184                    | 78000                                     | 45                     |
| 50                     | 1.18404                              | 10.824                     | 0.000    | 10.821 | -57.200                    | 0.008    | 0.008 | -0.02127                             | 0.00000  | 0.00000 | -231.73                     | -0.5231                    | 175000                                    | 50                     |
| 55                     | 1.30454                              | 10.951                     | 0.000    | 10.947 | -58.000                    | 0.009    | 0.009 | -0.01937                             | 0.00000  | 0.00000 | -232.06                     | -0.5278                    | 400000                                    | 55                     |
| 60                     | 1.43104                              | 11.078                     | 0.000    | 11.074 | -58.800                    | 0.009    | 0.009 | -0.01757                             | 0.00000  | 0.00000 | -232.39                     | -0.5325                    | 900000                                    | 60                     |
| 65                     | 1.56354                              | 11.205                     | 0.000    | 11.201 | -59.600                    | 0.010    | 0.010 | -0.01587                             | 0.00000  | 0.00000 | -232.72                     | -0.5372                    | 2000000                                   | 65                     |
| 70                     | 1.70204                              | 11.332                     | 0.000    | 11.328 | -60.400                    | 0.010    | 0.010 | -0.01427                             | 0.00000  | 0.00000 | -233.05                     | -0.5419                    | 4500000                                   | 70                     |
| 75                     | 1.84654                              | 11.459                     | 0.000    | 11.455 | -61.200                    | 0.011    | 0.011 | -0.01277                             | 0.00000  | 0.00000 | -233.38                     | -0.5466                    | 10000000                                  | 75                     |
| 80                     | 2.00704                              | 11.586                     | 0.000    | 11.582 | -62.000                    | 0.011    | 0.011 | -0.01137                             | 0.00000  | 0.00000 | -233.71                     | -0.5513                    | 22000000                                  | 80                     |
| 85                     | 2.18354                              | 11.713                     | 0.000    | 11.709 | -62.800                    | 0.012    | 0.012 | -0.01007                             | 0.00000  | 0.00000 | -234.04                     | -0.5560                    | 50000000                                  | 85                     |
| 90                     | 2.37704                              | 11.840                     | 0.000    | 11.836 | -63.600                    | 0.012    | 0.012 | -0.00887                             | 0.00000  | 0.00000 | -234.37                     | -0.5607                    | 110000000                                 | 90                     |
| 95                     | 2.58754                              | 11.967                     | 0.000    | 11.963 | -64.400                    | 0.013    | 0.013 | -0.00777                             | 0.00000  | 0.00000 | -234.70                     | -0.5654                    | 250000000                                 | 95                     |
| 100                    | 2.81404                              | 12.094                     | 0.000    | 12.090 | -65.200                    | 0.013    | 0.013 | -0.00677                             | 0.00000  | 0.00000 | -235.03                     | -0.5701                    | 550000000                                 | 100                    |

\* Compiled by John A. Goff and E. Gratch.

TABLE 2. THERMODYNAMIC PROPERTIES OF MOIST AIR\* (STANDARD ATMOSPHERIC PRESSURE, 29.921 IN. Hg) (Continued)

| FAHR.<br>TEMP.<br>(°F) | HUMIDITY<br>RATIO<br>$W \times 10^3$ | VOLUME<br>CU FT/LB DRY AIR |          |        | ENTHALPY<br>BTU/LB DRY AIR |          |          | ENTROPY<br>BTU PER (°F) (LB DRY AIR) |          |         | CONDENSED WATER             |                            |                                           | FAHR.<br>TEMP.<br>(°F) |
|------------------------|--------------------------------------|----------------------------|----------|--------|----------------------------|----------|----------|--------------------------------------|----------|---------|-----------------------------|----------------------------|-------------------------------------------|------------------------|
|                        |                                      | $v_a$                      | $v_{sa}$ | $v_g$  | $h_a$                      | $h_{sa}$ | $h_g$    | $s_a$                                | $s_{sa}$ | $s_g$   | Enthalpy<br>Btu/Lb<br>$h_w$ | Entropy<br>Btu/Lb<br>$s_w$ | Vap. Press<br>In. Hg<br>$p_s \times 10^3$ |                        |
|                        |                                      |                            |          |        |                            |          |          |                                      |          |         |                             |                            |                                           |                        |
| -30                    | 1.464                                | 10.820                     | 0.002    | 10.822 | -7.053                     | 0.154    | -0.01631 | 0.00038                              | -0.01631 | 0.00038 | -172.64                     | -0.3652                    | 0.70046                                   | -30                    |
| -25                    | 1.640                                | 10.870                     | 0.003    | 10.873 | -6.726                     | 0.173    | -0.01599 | 0.00043                              | -0.01599 | 0.00043 | -171.56                     | -0.3531                    | 0.78928                                   | -25                    |
| -20                    | 1.836                                | 10.921                     | 0.004    | 10.924 | -6.400                     | 0.192    | -0.01567 | 0.00048                              | -0.01567 | 0.00048 | -170.48                     | -0.3410                    | 0.88085                                   | -20                    |
| -15                    | 2.057                                | 10.972                     | 0.005    | 10.975 | -6.075                     | 0.211    | -0.01535 | 0.00053                              | -0.01535 | 0.00053 | -169.40                     | -0.3289                    | 0.98685                                   | -15                    |
| -10                    | 2.304                                | 11.022                     | 0.006    | 11.025 | -5.750                     | 0.230    | -0.01503 | 0.00058                              | -0.01503 | 0.00058 | -168.32                     | -0.3168                    | 1.1077                                    | -10                    |
| -5                     | 2.576                                | 11.073                     | 0.007    | 11.076 | -5.425                     | 0.249    | -0.01471 | 0.00063                              | -0.01471 | 0.00063 | -167.24                     | -0.3047                    | 1.2437                                    | -5                     |
| 0                      | 2.874                                | 11.124                     | 0.008    | 11.127 | -5.100                     | 0.268    | -0.01439 | 0.00068                              | -0.01439 | 0.00068 | -166.16                     | -0.2926                    | 1.3957                                    | 0                      |
| 5                      | 3.198                                | 11.175                     | 0.009    | 11.178 | -4.775                     | 0.287    | -0.01407 | 0.00073                              | -0.01407 | 0.00073 | -165.08                     | -0.2805                    | 1.5637                                    | 5                      |
| 10                     | 3.548                                | 11.226                     | 0.010    | 11.229 | -4.450                     | 0.306    | -0.01375 | 0.00078                              | -0.01375 | 0.00078 | -164.00                     | -0.2684                    | 1.7477                                    | 10                     |
| 15                     | 3.924                                | 11.277                     | 0.011    | 11.280 | -4.125                     | 0.325    | -0.01343 | 0.00083                              | -0.01343 | 0.00083 | -162.92                     | -0.2563                    | 1.9477                                    | 15                     |
| 20                     | 4.326                                | 11.328                     | 0.012    | 11.331 | -3.800                     | 0.344    | -0.01311 | 0.00088                              | -0.01311 | 0.00088 | -161.84                     | -0.2442                    | 2.1637                                    | 20                     |
| 25                     | 4.754                                | 11.379                     | 0.013    | 11.382 | -3.475                     | 0.363    | -0.01279 | 0.00093                              | -0.01279 | 0.00093 | -160.76                     | -0.2321                    | 2.3957                                    | 25                     |
| 30                     | 5.208                                | 11.430                     | 0.014    | 11.433 | -3.150                     | 0.382    | -0.01247 | 0.00098                              | -0.01247 | 0.00098 | -159.68                     | -0.2200                    | 2.6437                                    | 30                     |
| 35                     | 5.688                                | 11.481                     | 0.015    | 11.484 | -2.825                     | 0.401    | -0.01215 | 0.00103                              | -0.01215 | 0.00103 | -158.60                     | -0.2079                    | 2.9077                                    | 35                     |
| 40                     | 6.194                                | 11.532                     | 0.016    | 11.535 | -2.500                     | 0.420    | -0.01183 | 0.00108                              | -0.01183 | 0.00108 | -157.52                     | -0.1958                    | 3.1877                                    | 40                     |
| 45                     | 6.726                                | 11.583                     | 0.017    | 11.586 | -2.175                     | 0.439    | -0.01151 | 0.00113                              | -0.01151 | 0.00113 | -156.44                     | -0.1837                    | 3.4837                                    | 45                     |
| 50                     | 7.284                                | 11.634                     | 0.018    | 11.637 | -1.850                     | 0.458    | -0.01119 | 0.00118                              | -0.01119 | 0.00118 | -155.36                     | -0.1716                    | 3.7957                                    | 50                     |
| 55                     | 7.868                                | 11.685                     | 0.019    | 11.688 | -1.525                     | 0.477    | -0.01087 | 0.00123                              | -0.01087 | 0.00123 | -154.28                     | -0.1595                    | 4.1237                                    | 55                     |
| 60                     | 8.478                                | 11.736                     | 0.020    | 11.739 | -1.200                     | 0.496    | -0.01055 | 0.00128                              | -0.01055 | 0.00128 | -153.20                     | -0.1474                    | 4.4677                                    | 60                     |
| 65                     | 9.114                                | 11.787                     | 0.021    | 11.790 | -0.875                     | 0.515    | -0.01023 | 0.00133                              | -0.01023 | 0.00133 | -152.12                     | -0.1353                    | 4.8277                                    | 65                     |
| 70                     | 9.776                                | 11.838                     | 0.022    | 11.841 | -0.550                     | 0.534    | -0.00991 | 0.00138                              | -0.00991 | 0.00138 | -151.04                     | -0.1232                    | 5.2037                                    | 70                     |
| 75                     | 10.464                               | 11.889                     | 0.023    | 11.892 | -0.225                     | 0.553    | -0.00959 | 0.00143                              | -0.00959 | 0.00143 | -150.00                     | -0.1111                    | 5.5957                                    | 75                     |
| 80                     | 11.188                               | 11.940                     | 0.024    | 11.943 | 0.100                      | 0.572    | -0.00927 | 0.00148                              | -0.00927 | 0.00148 | -148.92                     | -0.0990                    | 6.0037                                    | 80                     |
| 85                     | 11.948                               | 12.000                     | 0.025    | 12.003 | 0.425                      | 0.591    | -0.00895 | 0.00153                              | -0.00895 | 0.00153 | -147.84                     | -0.0869                    | 6.4277                                    | 85                     |
| 90                     | 12.744                               | 12.060                     | 0.026    | 12.063 | 0.750                      | 0.610    | -0.00863 | 0.00158                              | -0.00863 | 0.00158 | -146.76                     | -0.0748                    | 6.8677                                    | 90                     |
| 95                     | 13.576                               | 12.120                     | 0.027    | 12.123 | 1.075                      | 0.629    | -0.00831 | 0.00163                              | -0.00831 | 0.00163 | -145.68                     | -0.0627                    | 7.3237                                    | 95                     |
| 100                    | 14.444                               | 12.180                     | 0.028    | 12.183 | 1.400                      | 0.648    | -0.00800 | 0.00168                              | -0.00800 | 0.00168 | -144.60                     | -0.0506                    | 7.7957                                    | 100                    |

\* Compiled by John A. Goff and E. Gratch.

TABLE 2. THERMODYNAMIC PROPERTIES OF MOIST AIR\* (STANDARD ATMOSPHERIC PRESSURE, 29.921 IN. Hg) (Continued)

| FAHR.<br>TEMP.<br>(°F) | HUMIDITY<br>RATIO<br>W x 10 <sup>3</sup> | VOLUME<br>CU FT/LB DRY AIR |                 |                | ENTHALPY<br>BTU/LB DRY AIR |                 |                | ENTROPY<br>BTU PER (°F) (LB DRY AIR) |                 |                | CONDENSED WATER |                              |                             | FAHR.<br>TEMP.<br>(°F) |                                           |
|------------------------|------------------------------------------|----------------------------|-----------------|----------------|----------------------------|-----------------|----------------|--------------------------------------|-----------------|----------------|-----------------|------------------------------|-----------------------------|------------------------|-------------------------------------------|
|                        |                                          | v <sub>g</sub>             | v <sub>sa</sub> | v <sub>s</sub> | h <sub>g</sub>             | h <sub>sa</sub> | h <sub>s</sub> | s <sub>g</sub>                       | s <sub>sa</sub> | s <sub>s</sub> | h <sub>lv</sub> | Enthalpy<br>Btu/(Lb)<br>(°F) | Entropy<br>Btu/(Lb)<br>(°F) |                        | Vap. Press<br>In. Hg<br>x 10 <sup>3</sup> |
|                        |                                          |                            |                 |                |                            |                 |                |                                      |                 |                |                 |                              |                             |                        |                                           |
| 7                      | 1.130                                    | 11.756                     | 0.021           | 11.777         | 1.081                      | 1.202           | 2.883          | 0.00364                              | 0.00271         | 0.00855        | -155.61         | -0.3172                      | 5.4022                      | 7                      |                                           |
| 8                      | 1.189                                    | 11.781                     | 0.032           | 11.803         | 1.022                      | 1.266           | 3.188          | 0.00415                              | 0.00285         | 0.00700        | -154.13         | -0.3182                      | 5.3512                      | 8                      |                                           |
| 9                      | 1.251                                    | 11.806                     | 0.044           | 11.830         | 1.002                      | 1.332           | 3.484          | 0.00466                              | 0.00296         | 0.00541        | -152.65         | -0.3192                      | 5.2992                      | 9                      |                                           |
| 10                     | 1.315                                    | 11.831                     | 0.055           | 11.856         | 1.002                      | 1.401           | 3.803          | 0.00516                              | 0.00307         | 0.00382        | -151.17         | -0.3202                      | 5.2468                      | 10                     |                                           |
| 11                     | 1.383                                    | 11.857                     | 0.066           | 11.883         | 2.942                      | 1.474           | 4.116          | 0.00566                              | 0.00318         | 0.00227        | -149.70         | -0.3212                      | 5.1944                      | 11                     |                                           |
| 12                     | 1.454                                    | 11.882                     | 0.078           | 11.910         | 3.252                      | 1.550           | 4.432          | 0.00618                              | 0.00329         | 0.00069        | -148.22         | -0.3222                      | 5.1420                      | 12                     |                                           |
| 13                     | 1.528                                    | 11.907                     | 0.089           | 11.936         | 3.123                      | 1.628           | 4.753          | 0.00671                              | 0.00340         | 0.00009        | -146.75         | -0.3232                      | 5.0896                      | 13                     |                                           |
| 14                     | 1.606                                    | 11.933                     | 0.100           | 11.963         | 3.393                      | 1.713           | 5.076          | 0.00721                              | 0.00351         | 0.00000        | -145.27         | -0.3242                      | 5.0372                      | 14                     |                                           |
| 15                     | 1.687                                    | 11.958                     | 0.111           | 11.990         | 3.903                      | 1.800           | 5.403          | 0.00772                              | 0.00362         | 0.00000        | -143.80         | -0.3252                      | 4.9848                      | 15                     |                                           |
| 16                     | 1.772                                    | 11.983                     | 0.122           | 12.017         | 3.443                      | 1.892           | 5.735          | 0.00822                              | 0.00373         | 0.00000        | -142.32         | -0.3262                      | 4.9324                      | 16                     |                                           |
| 17                     | 1.861                                    | 12.009                     | 0.133           | 12.044         | 4.083                      | 1.988           | 6.071          | 0.00873                              | 0.00384         | 0.00000        | -140.85         | -0.3272                      | 4.8800                      | 17                     |                                           |
| 18                     | 1.953                                    | 12.034                     | 0.144           | 12.072         | 4.324                      | 2.086           | 6.412          | 0.00923                              | 0.00395         | 0.00000        | -139.37         | -0.3282                      | 4.8276                      | 18                     |                                           |
| 19                     | 2.051                                    | 12.059                     | 0.155           | 12.099         | 4.684                      | 2.186           | 6.756          | 0.00973                              | 0.00406         | 0.00000        | -137.90         | -0.3292                      | 4.7752                      | 19                     |                                           |
| 20                     | 2.152                                    | 12.084                     | 0.166           | 12.124         | 4.904                      | 2.289           | 7.103          | 0.01023                              | 0.00417         | 0.00000        | -136.42         | -0.3302                      | 4.7228                      | 20                     |                                           |
| 21                     | 2.258                                    | 12.110                     | 0.177           | 12.154         | 5.084                      | 2.415           | 7.453          | 0.01073                              | 0.00428         | 0.00000        | -134.95         | -0.3312                      | 4.6704                      | 21                     |                                           |
| 22                     | 2.369                                    | 12.135                     | 0.188           | 12.181         | 5.284                      | 2.636           | 7.806          | 0.01123                              | 0.00439         | 0.00000        | -133.47         | -0.3322                      | 4.6180                      | 22                     |                                           |
| 23                     | 2.485                                    | 12.160                     | 0.199           | 12.209         | 5.629                      | 2.861           | 8.165          | 0.01173                              | 0.00450         | 0.00000        | -132.00         | -0.3332                      | 4.5656                      | 23                     |                                           |
| 24                     | 2.606                                    | 12.186                     | 0.210           | 12.237         | 5.705                      | 2.992           | 8.537          | 0.01223                              | 0.00461         | 0.00000        | -130.52         | -0.3342                      | 4.5132                      | 24                     |                                           |
| 25                     | 2.733                                    | 12.211                     | 0.221           | 12.262         | 5.924                      | 3.121           | 8.924          | 0.01273                              | 0.00472         | 0.00000        | -129.05         | -0.3352                      | 4.4608                      | 25                     |                                           |
| 26                     | 2.866                                    | 12.236                     | 0.232           | 12.293         | 6.246                      | 3.072           | 9.317          | 0.01323                              | 0.00483         | 0.00000        | -127.57         | -0.3362                      | 4.4084                      | 26                     |                                           |
| 27                     | 3.003                                    | 12.262                     | 0.243           | 12.321         | 6.465                      | 3.221           | 9.706          | 0.01373                              | 0.00494         | 0.00000        | -126.10         | -0.3372                      | 4.3560                      | 27                     |                                           |
| 28                     | 3.147                                    | 12.287                     | 0.254           | 12.349         | 6.728                      | 3.377           | 10.103         | 0.01423                              | 0.00505         | 0.00000        | -124.62         | -0.3382                      | 4.3036                      | 28                     |                                           |
| 29                     | 3.297                                    | 12.312                     | 0.265           | 12.377         | 6.906                      | 3.540           | 10.500         | 0.01473                              | 0.00516         | 0.00000        | -123.15         | -0.3392                      | 4.2512                      | 29                     |                                           |
| 30                     | 3.454                                    | 12.338                     | 0.276           | 12.406         | 7.200                      | 3.709           | 10.919         | 0.01523                              | 0.00527         | 0.00000        | -121.67         | -0.3402                      | 4.1988                      | 30                     |                                           |
| 31                     | 3.617                                    | 12.363                     | 0.287           | 12.434         | 7.446                      | 3.887           | 11.353         | 0.01573                              | 0.00538         | 0.00000        | -120.20         | -0.3412                      | 4.1464                      | 31                     |                                           |
| 32                     | 3.786                                    | 12.389                     | 0.298           | 12.463         | 7.686                      | 4.072           | 11.788         | 0.01623                              | 0.00549         | 0.00000        | -118.72         | -0.3422                      | 4.0940                      | 32                     |                                           |
| 33                     | 3.964                                    | 12.388                     | 0.298           | 12.463         | 7.686                      | 4.072           | 11.788         | 0.01617                              | 0.00549         | 0.00000        | -118.72         | -0.3422                      | 4.0940                      | 33                     |                                           |
| 34                     | 4.150                                    | 12.413                     | 0.298           | 12.463         | 7.686                      | 4.072           | 11.788         | 0.01617                              | 0.00549         | 0.00000        | -118.72         | -0.3422                      | 4.0940                      | 34                     |                                           |
| 35                     | 4.343                                    | 12.413                     | 0.298           | 12.463         | 7.686                      | 4.072           | 11.788         | 0.01617                              | 0.00549         | 0.00000        | -118.72         | -0.3422                      | 4.0940                      | 35                     |                                           |
| 36                     | 4.543                                    | 12.468                     | 0.298           | 12.468         | 7.686                      | 4.072           | 11.788         | 0.01617                              | 0.00549         | 0.00000        | -118.72         | -0.3422                      | 4.0940                      | 36                     |                                           |
| 37                     | 4.750                                    | 12.468                     | 0.298           | 12.468         | 7.686                      | 4.072           | 11.788         | 0.01617                              | 0.00549         | 0.00000        | -118.72         | -0.3422                      | 4.0940                      | 37                     |                                           |

\* Compiled by John A. Goff and S. Gratch.

\* Extrapolated to represent metastable equilibrium with undercooled liquid.

TABLE 2. THERMODYNAMIC PROPERTIES OF MOIST AIR\* (STANDARD ATMOSPHERIC PRESSURE, 29.921 IN. Hg) (Continued)

| FAHR.<br>TEMP.<br>(°F) | HUMIDITY<br>RATIO<br>W <sub>g</sub> × 10 <sup>3</sup> | VOLUME<br>CU FT/LB DRY AIR |                                  |                                   | ENTHALPY<br>BTU/LB DRY AIR |                                  |                                   | ENTROPY<br>BTU PER (°F) (LB DRY AIR) |                                  |                                   | CONDENSED WATER |                             |                                           | FAHR.<br>TEMP.<br>(°F) |    |
|------------------------|-------------------------------------------------------|----------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------------|-----------------------------------|--------------------------------------|----------------------------------|-----------------------------------|-----------------|-----------------------------|-------------------------------------------|------------------------|----|
|                        |                                                       | v <sub>g</sub>             | v <sub>g</sub> × 10 <sup>3</sup> |                                   | h <sub>g</sub>             | h <sub>g</sub> × 10 <sup>3</sup> |                                   | s <sub>g</sub>                       | s <sub>g</sub> × 10 <sup>3</sup> |                                   | h <sub>l</sub>  | Entropy<br>BTU/(Lb)<br>(°F) | Vap. Press<br>In. Hg<br>× 10 <sup>3</sup> |                        |    |
|                        |                                                       |                            | v <sub>sa</sub>                  | v <sub>sa</sub> × 10 <sup>3</sup> |                            | h <sub>sa</sub>                  | h <sub>sa</sub> × 10 <sup>3</sup> |                                      | s <sub>sa</sub>                  | s <sub>sa</sub> × 10 <sup>3</sup> |                 |                             |                                           |                        |    |
| 38                     | 4.818                                                 | 12.540                     | 0.097                            | 0.097                             | 12.637                     | 9.128                            | 5.101                             | 14.319                               | 0.01909                          | 0.01097                           | 0.03006         | 6.08                        | 0.0122                                    | 0.22604                | 38 |
| 39                     | 5.012                                                 | 12.565                     | 0.101                            | 0.101                             | 12.666                     | 9.268                            | 5.403                             | 14.771                               | 0.01937                          | 0.01139                           | 0.03056         | 7.08                        | 0.0142                                    | 0.23096                | 39 |
| 40                     | 5.213                                                 | 12.591                     | 0.105                            | 0.105                             | 12.696                     | 9.408                            | 5.692                             | 15.230                               | 0.01965                          | 0.01181                           | 0.03108         | 8.09                        | 0.0162                                    | 0.23597                | 40 |
| 41                     | 5.421                                                 | 12.616                     | 0.109                            | 0.109                             | 12.725                     | 9.548                            | 5.949                             | 15.697                               | 0.02003                          | 0.01225                           | 0.03161         | 9.06                        | 0.0182                                    | 0.24106                | 41 |
| 42                     | 5.638                                                 | 12.641                     | 0.114                            | 0.114                             | 12.755                     | 10.088                           | 6.084                             | 16.172                               | 0.02041                          | 0.01275                           | 0.03216         | 10.09                       | 0.0202                                    | 0.24633                | 42 |
| 43                     | 5.860                                                 | 12.666                     | 0.119                            | 0.119                             | 12.785                     | 10.329                           | 6.328                             | 16.657                               | 0.02079                          | 0.01323                           | 0.03272         | 11.10                       | 0.0222                                    | 0.25173                | 43 |
| 44                     | 6.091                                                 | 12.691                     | 0.124                            | 0.124                             | 12.815                     | 10.569                           | 6.580                             | 17.149                               | 0.02117                          | 0.01373                           | 0.03327         | 12.10                       | 0.0242                                    | 0.25698                | 44 |
| 45                     | 6.331                                                 | 12.717                     | 0.129                            | 0.129                             | 12.846                     | 10.809                           | 6.841                             | 17.650                               | 0.02155                          | 0.01425                           | 0.03379         | 13.10                       | 0.0262                                    | 0.26203                | 45 |
| 46                     | 6.578                                                 | 12.742                     | 0.134                            | 0.134                             | 12.876                     | 11.049                           | 7.102                             | 18.151                               | 0.02193                          | 0.01478                           | 0.03431         | 14.16                       | 0.0282                                    | 0.26735                | 46 |
| 47                     | 6.835                                                 | 12.767                     | 0.140                            | 0.140                             | 12.907                     | 11.289                           | 7.361                             | 18.650                               | 0.02231                          | 0.01534                           | 0.03484         | 15.11                       | 0.0302                                    | 0.27288                | 47 |
| 48                     | 7.100                                                 | 12.792                     | 0.146                            | 0.146                             | 12.938                     | 11.530                           | 7.631                             | 19.211                               | 0.02267                          | 0.01594                           | 0.03537         | 16.11                       | 0.0321                                    | 0.27859                | 48 |
| 49                     | 7.374                                                 | 12.818                     | 0.151                            | 0.151                             | 12.968                     | 11.770                           | 7.931                             | 19.751                               | 0.02304                          | 0.01650                           | 0.03591         | 17.11                       | 0.0341                                    | 0.28433                | 49 |
| 50                     | 7.658                                                 | 12.843                     | 0.156                            | 0.156                             | 13.001                     | 12.010                           | 8.231                             | 20.291                               | 0.02341                          | 0.01711                           | 0.03645         | 18.11                       | 0.0361                                    | 0.29016                | 50 |
| 51                     | 7.950                                                 | 12.869                     | 0.161                            | 0.161                             | 13.033                     | 12.250                           | 8.532                             | 20.832                               | 0.02378                          | 0.01771                           | 0.03699         | 19.11                       | 0.0381                                    | 0.29609                | 51 |
| 52                     | 8.250                                                 | 12.894                     | 0.167                            | 0.167                             | 13.064                     | 12.491                           | 8.843                             | 21.375                               | 0.02415                          | 0.01839                           | 0.03754         | 20.11                       | 0.0400                                    | 0.30203                | 52 |
| 53                     | 8.559                                                 | 12.919                     | 0.173                            | 0.173                             | 13.097                     | 12.731                           | 9.156                             | 21.920                               | 0.02452                          | 0.01906                           | 0.03809         | 21.12                       | 0.0420                                    | 0.30802                | 53 |
| 54                     | 8.874                                                 | 12.944                     | 0.185                            | 0.185                             | 13.129                     | 12.971                           | 9.444                             | 22.465                               | 0.02489                          | 0.01976                           | 0.03865         | 22.12                       | 0.0439                                    | 0.31404                | 54 |
| 55                     | 9.197                                                 | 12.969                     | 0.202                            | 0.202                             | 13.162                     | 13.212                           | 9.733                             | 23.014                               | 0.02526                          | 0.02043                           | 0.03921         | 23.12                       | 0.0459                                    | 0.32008                | 55 |
| 56                     | 9.527                                                 | 12.994                     | 0.207                            | 0.207                             | 13.195                     | 13.452                           | 10.022                            | 23.564                               | 0.02563                          | 0.02112                           | 0.03977         | 24.12                       | 0.0478                                    | 0.32613                | 56 |
| 57                     | 9.864                                                 | 13.020                     | 0.208                            | 0.208                             | 13.228                     | 13.692                           | 10.310                            | 24.116                               | 0.02600                          | 0.02181                           | 0.04033         | 25.12                       | 0.0497                                    | 0.33219                | 57 |
| 58                     | 10.209                                                | 13.045                     | 0.216                            | 0.216                             | 13.261                     | 13.932                           | 11.119                            | 24.672                               | 0.02635                          | 0.02250                           | 0.04090         | 26.12                       | 0.0517                                    | 0.33826                | 58 |
| 59                     | 10.560                                                | 13.071                     | 0.224                            | 0.224                             | 13.295                     | 14.172                           | 11.611                            | 25.238                               | 0.02670                          | 0.02327                           | 0.04150         | 27.12                       | 0.0536                                    | 0.34433                | 59 |
| 60                     | 10.918                                                | 13.096                     | 0.233                            | 0.233                             | 13.329                     | 14.413                           | 12.065                            | 25.806                               | 0.02705                          | 0.02404                           | 0.04211         | 28.12                       | 0.0555                                    | 0.35041                | 60 |
| 61                     | 11.180                                                | 13.122                     | 0.242                            | 0.242                             | 13.363                     | 14.653                           | 12.500                            | 26.375                               | 0.02740                          | 0.02482                           | 0.04271         | 29.12                       | 0.0574                                    | 0.35649                | 61 |
| 62                     | 11.447                                                | 13.147                     | 0.251                            | 0.251                             | 13.398                     | 14.893                           | 12.966                            | 27.85                                | 0.02780                          | 0.02561                           | 0.04331         | 30.12                       | 0.0594                                    | 0.36258                | 62 |
| 63                     | 11.720                                                | 13.172                     | 0.261                            | 0.261                             | 13.433                     | 15.134                           | 13.444                            | 28.57                                | 0.02826                          | 0.02640                           | 0.04394         | 31.12                       | 0.0613                                    | 0.36867                | 63 |
| 64                     | 12.000                                                | 13.197                     | 0.271                            | 0.271                             | 13.468                     | 15.374                           | 13.941                            | 29.31                                | 0.02871                          | 0.02720                           | 0.04457         | 32.12                       | 0.0632                                    | 0.37477                | 64 |
| 65                     | 12.285                                                | 13.222                     | 0.282                            | 0.282                             | 13.504                     | 15.614                           | 14.445                            | 30.06                                | 0.02917                          | 0.02801                           | 0.04521         | 33.11                       | 0.0651                                    | 0.38087                | 65 |
| 66                     | 12.574                                                | 13.247                     | 0.292                            | 0.292                             | 13.539                     | 15.855                           | 14.963                            | 30.83                                | 0.02963                          | 0.02882                           | 0.04586         | 34.11                       | 0.0670                                    | 0.38697                | 66 |
| 67                     | 12.868                                                | 13.273                     | 0.303                            | 0.303                             | 13.576                     | 16.095                           | 15.533                            | 31.62                                | 0.03009                          | 0.02963                           | 0.04651         | 35.11                       | 0.0689                                    | 0.39307                | 67 |
| 68                     | 13.167                                                | 13.298                     | 0.315                            | 0.315                             | 13.613                     | 16.335                           | 16.099                            | 32.42                                | 0.03054                          | 0.03044                           | 0.04717         | 36.11                       | 0.0708                                    | 0.39917                | 68 |
| 69                     | 13.470                                                | 13.323                     | 0.327                            | 0.327                             | 13.650                     | 16.576                           | 16.67                             | 33.25                                | 0.03100                          | 0.03123                           | 0.04782         | 37.11                       | 0.0727                                    | 0.40527                | 69 |

\* Compiled by John A. Goff and S. Gratch.

TABLE 2. THERMODYNAMIC PROPERTIES OF MOIST AIR\* (STANDARD ATMOSPHERIC PRESSURE, 29.921 IN. Hg) (Continued)

| FAHR.<br>TEMP.<br>(°F) | HUMIDITY<br>RATIO<br>$W \times 10^3$ | VOLUME<br>CU FT/LB DRY AIR |          |        | ENTHALPY<br>BTU/LB DRY AIR |          |       | ENTROPY<br>BTU PER (°F) (LB DRY AIR) |          |         | CONDENSED WATER             |                              |                               |
|------------------------|--------------------------------------|----------------------------|----------|--------|----------------------------|----------|-------|--------------------------------------|----------|---------|-----------------------------|------------------------------|-------------------------------|
|                        |                                      | CU FT/LB DRY AIR           |          |        | BTU/LB DRY AIR             |          |       | BTU PER (°F) (LB DRY AIR)            |          |         | CONDENSED WATER             |                              |                               |
|                        |                                      | $v_a$                      | $v_{as}$ | $v_s$  | $h_a$                      | $h_{as}$ | $h_s$ | $s_a$                                | $s_{as}$ | $s_s$   | Enthalpy<br>Btu/Lb<br>$h_w$ | Entropy<br>Btu/(°F)<br>$s_w$ | Vap. Press<br>In. Hg<br>$p_s$ |
| 70                     | 1.593                                | 13.246                     | 0.339    | 13.687 | 16.816                     | 17.27    | 34.09 | 0.03405                              | 0.03437  | 0.06842 | 39.11                       | 0.0746                       | 0.73015                       |
| 71                     | 1.439                                | 13.273                     | 0.331    | 13.724 | 17.065                     | 17.37    | 34.95 | 0.03404                              | 0.03354  | 0.07004 | 39.11                       | 0.0745                       | 0.74475                       |
| 72                     | 1.697                                | 13.308                     | 0.364    | 13.762 | 17.397                     | 17.63    | 35.83 | 0.03495                              | 0.03376  | 0.07170 | 40.11                       | 0.0784                       | 0.79112                       |
| 73                     | 1.757                                | 13.424                     | 0.377    | 13.801 | 17.537                     | 17.89    | 36.74 | 0.03540                              | 0.03390  | 0.07340 | 41.11                       | 0.0833                       | 0.81823                       |
| 74                     | 1.819                                | 13.446                     | 0.392    | 13.841 | 17.778                     | 18.15    | 37.66 | 0.03585                              | 0.03428  | 0.07513 | 42.10                       | 0.0891                       | 0.84624                       |
| 75                     | 1.883                                | 13.474                     | 0.407    | 13.881 | 18.018                     | 18.41    | 38.61 | 0.03630                              | 0.03466  | 0.07680 | 43.10                       | 0.0940                       | 0.87504                       |
| 76                     | 1.948                                | 13.499                     | 0.422    | 13.921 | 18.259                     | 18.67    | 39.57 | 0.03675                              | 0.03504  | 0.07852 | 44.10                       | 0.0989                       | 0.90470                       |
| 77                     | 2.016                                | 13.524                     | 0.437    | 13.962 | 18.499                     | 18.93    | 40.57 | 0.03720                              | 0.03542  | 0.08027 | 45.10                       | 0.1037                       | 0.93523                       |
| 78                     | 2.086                                | 13.550                     | 0.453    | 14.003 | 18.740                     | 19.19    | 41.58 | 0.03765                              | 0.03580  | 0.08207 | 46.10                       | 0.1086                       | 0.96653                       |
| 79                     | 2.158                                | 13.576                     | 0.470    | 14.045 | 18.980                     | 19.45    | 42.62 | 0.03810                              | 0.03618  | 0.08384 | 47.10                       | 0.1135                       | 0.99899                       |
| 80                     | 2.233                                | 13.601                     | 0.486    | 14.087 | 19.221                     | 19.71    | 43.69 | 0.03855                              | 0.03656  | 0.08568 | 48.10                       | 0.1184                       | 1.0323                        |
| 81                     | 2.310                                | 13.626                     | 0.504    | 14.130 | 19.461                     | 19.97    | 44.78 | 0.03900                              | 0.03694  | 0.08751 | 49.09                       | 0.1233                       | 1.0665                        |
| 82                     | 2.389                                | 13.651                     | 0.523    | 14.174 | 19.702                     | 20.23    | 45.89 | 0.03945                              | 0.03732  | 0.08934 | 50.09                       | 0.1282                       | 1.1017                        |
| 83                     | 2.471                                | 13.676                     | 0.542    | 14.218 | 19.943                     | 20.49    | 47.00 | 0.03990                              | 0.03770  | 0.09117 | 51.09                       | 0.1331                       | 1.1379                        |
| 84                     | 2.555                                | 13.702                     | 0.560    | 14.262 | 20.183                     | 20.75    | 48.12 | 0.04035                              | 0.03808  | 0.09300 | 52.09                       | 0.1380                       | 1.1752                        |
| 85                     | 2.642                                | 13.727                     | 0.581    | 14.305 | 20.423                     | 21.01    | 49.25 | 0.04080                              | 0.03846  | 0.09483 | 53.09                       | 0.1429                       | 1.2135                        |
| 86                     | 2.731                                | 13.752                     | 0.602    | 14.349 | 20.663                     | 21.27    | 50.38 | 0.04125                              | 0.03884  | 0.09666 | 54.09                       | 0.1478                       | 1.2529                        |
| 87                     | 2.824                                | 13.777                     | 0.624    | 14.393 | 20.904                     | 21.53    | 51.53 | 0.04170                              | 0.03922  | 0.09849 | 55.09                       | 0.1527                       | 1.2934                        |
| 88                     | 2.919                                | 13.803                     | 0.645    | 14.438 | 21.144                     | 21.79    | 52.68 | 0.04215                              | 0.03960  | 0.10032 | 56.09                       | 0.1576                       | 1.3351                        |
| 89                     | 3.017                                | 13.828                     | 0.668    | 14.483 | 21.385                     | 22.05    | 53.83 | 0.04260                              | 0.04000  | 0.10215 | 57.09                       | 0.1625                       | 1.3779                        |
| 90                     | 3.118                                | 13.853                     | 0.692    | 14.528 | 21.625                     | 22.31    | 55.00 | 0.04305                              | 0.04040  | 0.10398 | 58.09                       | 0.1674                       | 1.4219                        |
| 91                     | 3.223                                | 13.878                     | 0.716    | 14.573 | 21.865                     | 22.57    | 56.18 | 0.04350                              | 0.04080  | 0.10581 | 59.09                       | 0.1723                       | 1.4671                        |
| 92                     | 3.330                                | 13.904                     | 0.741    | 14.618 | 22.106                     | 22.83    | 57.36 | 0.04395                              | 0.04120  | 0.10764 | 60.09                       | 0.1772                       | 1.5136                        |
| 93                     | 3.441                                | 13.929                     | 0.768    | 14.663 | 22.346                     | 23.09    | 58.55 | 0.04440                              | 0.04160  | 0.10947 | 61.09                       | 0.1821                       | 1.5602                        |
| 94                     | 3.556                                | 13.954                     | 0.796    | 14.708 | 22.587                     | 23.35    | 59.74 | 0.04485                              | 0.04200  | 0.11130 | 62.09                       | 0.1870                       | 1.6079                        |
| 95                     | 3.673                                | 13.980                     | 0.822    | 14.753 | 22.827                     | 23.61    | 60.94 | 0.04530                              | 0.04240  | 0.11313 | 63.09                       | 0.1919                       | 1.6562                        |
| 96                     | 3.795                                | 14.005                     | 0.851    | 14.798 | 23.068                     | 23.87    | 62.15 | 0.04575                              | 0.04280  | 0.11496 | 64.09                       | 0.1968                       | 1.7051                        |
| 97                     | 3.920                                | 14.030                     | 0.881    | 14.843 | 23.308                     | 24.13    | 63.36 | 0.04620                              | 0.04320  | 0.11679 | 65.09                       | 0.2017                       | 1.7546                        |
| 98                     | 4.049                                | 14.055                     | 0.912    | 14.888 | 23.548                     | 24.39    | 64.58 | 0.04665                              | 0.04360  | 0.11862 | 66.09                       | 0.2066                       | 1.8047                        |
| 99                     | 4.182                                | 14.081                     | 0.942    | 14.933 | 23.788                     | 24.65    | 65.80 | 0.04710                              | 0.04400  | 0.12045 | 67.09                       | 0.2115                       | 1.8554                        |
| 100                    | 4.319                                | 14.106                     | 0.975    | 14.978 | 24.029                     | 24.91    | 67.03 | 0.04755                              | 0.04440  | 0.12228 | 68.09                       | 0.2164                       | 1.9067                        |
| 101                    | 4.460                                | 14.131                     | 1.009    | 15.023 | 24.270                     | 25.17    | 68.26 | 0.04800                              | 0.04480  | 0.12411 | 69.09                       | 0.2213                       | 1.9586                        |
| 102                    | 4.606                                | 14.157                     | 1.043    | 15.068 | 24.510                     | 25.43    | 69.49 | 0.04845                              | 0.04520  | 0.12594 | 70.09                       | 0.2262                       | 2.0111                        |
| 103                    | 4.757                                | 14.182                     | 1.078    | 15.113 | 24.750                     | 25.69    | 70.72 | 0.04890                              | 0.04560  | 0.12777 | 71.09                       | 0.2311                       | 2.0642                        |
| 104                    | 4.911                                | 14.207                     | 1.117    | 15.158 | 24.991                     | 25.95    | 71.95 | 0.04935                              | 0.04600  | 0.12960 | 72.09                       | 0.2360                       | 2.1189                        |

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TABLE 2. THERMODYNAMIC PROPERTIES OF MOIST AIR\* (STANDARD ATMOSPHERIC PRESSURE, 29.921 IN. Hg) (Continued)

| FAHR.<br>TEMP.<br>(°F) | HUMIDITY<br>RATIO<br>$W \times 10$ | VOLUME<br>CU FT/LB DRY AIR |          |        | ENTHALPY<br>BTU/LB DRY AIR |          |        | ENTROPY<br>BTU PER (°F) (LB DRY AIR) |          |        | CONDENSED WATER             |                              |                               |
|------------------------|------------------------------------|----------------------------|----------|--------|----------------------------|----------|--------|--------------------------------------|----------|--------|-----------------------------|------------------------------|-------------------------------|
|                        |                                    | CU FT/LB DRY AIR           |          |        | BTU/LB DRY AIR             |          |        | BTU PER (°F) (LB DRY AIR)            |          |        | CONDENSED WATER             |                              |                               |
|                        |                                    | $v_a$                      | $v_{as}$ | $v_s$  | $h_a$                      | $h_{as}$ | $h_s$  | $s_a$                                | $s_{as}$ | $s_s$  | Enthalpy<br>Btu/LB<br>$h_w$ | Entropy<br>Btu/(°F)<br>$s_w$ | Vap. Press<br>In. Hg<br>$p_s$ |
| 105                    | 0.5070                             | 14.232                     | 1.155    | 15.387 | 25.232                     | 25.611   | 81.34  | 0.04943                              | 0.1052   | 0.1546 | 73.04                       | 0.1385                       | 2.2439                        |
| 106                    | 0.5224                             | 14.258                     | 1.141    | 15.413 | 25.473                     | 25.89    | 82.42  | 0.04938                              | 0.1056   | 0.1581 | 74.04                       | 0.1403                       | 2.3109                        |
| 107                    | 0.5394                             | 14.283                     | 1.127    | 15.439 | 25.713                     | 26.16    | 83.49  | 0.04933                              | 0.1115   | 0.1621 | 75.04                       | 0.1421                       | 2.3787                        |
| 108                    | 0.5578                             | 14.308                     | 1.113    | 15.465 | 25.953                     | 26.43    | 84.56  | 0.04928                              | 0.1118   | 0.1656 | 76.04                       | 0.1439                       | 2.4462                        |
| 109                    | 0.5768                             | 14.333                     | 1.101    | 15.491 | 26.194                     | 26.69    | 85.63  | 0.04923                              | 0.1180   | 0.1700 | 77.04                       | 0.1456                       | 2.5125                        |
| 110                    | 0.5964                             | 14.359                     | 1.105    | 15.517 | 26.434                     | 26.94    | 86.70  | 0.04918                              | 0.1226   | 0.1742 | 78.03                       | 0.1472                       | 2.5860                        |
| 111                    | 0.6135                             | 14.384                     | 1.112    | 15.543 | 26.675                     | 27.19    | 87.77  | 0.04913                              | 0.1264   | 0.1784 | 79.03                       | 0.1491                       | 2.6720                        |
| 112                    | 0.6333                             | 14.409                     | 1.109    | 15.569 | 26.915                     | 27.45    | 88.84  | 0.04908                              | 0.1286   | 0.1826 | 80.03                       | 0.1508                       | 2.7505                        |
| 113                    | 0.6536                             | 14.435                     | 1.106    | 15.595 | 27.156                     | 27.71    | 89.91  | 0.04903                              | 0.1334   | 0.1868 | 81.03                       | 0.1526                       | 2.8304                        |
| 114                    | 0.6746                             | 14.460                     | 1.100    | 15.621 | 27.397                     | 27.97    | 90.98  | 0.04898                              | 0.1384   | 0.1910 | 82.03                       | 0.1543                       | 2.9123                        |
| 115                    | 0.6969                             | 14.485                     | 1.101    | 15.647 | 27.637                     | 28.24    | 92.05  | 0.04893                              | 0.1426   | 0.1953 | 83.02                       | 0.1560                       | 2.9962                        |
| 116                    | 0.7186                             | 14.510                     | 1.098    | 15.673 | 27.878                     | 28.50    | 93.12  | 0.04888                              | 0.1470   | 0.2001 | 84.02                       | 0.1577                       | 3.0821                        |
| 117                    | 0.7416                             | 14.535                     | 1.095    | 15.699 | 28.119                     | 28.76    | 94.19  | 0.04883                              | 0.1515   | 0.2050 | 85.02                       | 0.1595                       | 3.1701                        |
| 118                    | 0.7653                             | 14.560                     | 1.090    | 15.725 | 28.360                     | 29.02    | 95.26  | 0.04878                              | 0.1565   | 0.2100 | 86.02                       | 0.1612                       | 3.2603                        |
| 119                    | 0.7897                             | 14.586                     | 1.084    | 15.751 | 28.600                     | 29.28    | 96.33  | 0.04873                              | 0.1610   | 0.2153 | 87.02                       | 0.1630                       | 3.3527                        |
| 120                    | 0.8149                             | 14.611                     | 1.095    | 15.777 | 28.841                     | 29.54    | 97.40  | 0.04868                              | 0.1659   | 0.2210 | 88.01                       | 0.1646                       | 3.4474                        |
| 121                    | 0.8410                             | 14.637                     | 1.095    | 15.803 | 29.082                     | 29.81    | 98.47  | 0.04863                              | 0.1710   | 0.2271 | 89.01                       | 0.1664                       | 3.5443                        |
| 122                    | 0.8686                             | 14.662                     | 1.093    | 15.829 | 29.323                     | 30.07    | 99.54  | 0.04858                              | 0.1763   | 0.2339 | 90.01                       | 0.1681                       | 3.6430                        |
| 123                    | 0.8965                             | 14.687                     | 1.090    | 15.855 | 29.563                     | 30.33    | 100.61 | 0.04853                              | 0.1817   | 0.2407 | 91.01                       | 0.1698                       | 3.7432                        |
| 124                    | 0.9242                             | 14.712                     | 1.085    | 15.881 | 29.804                     | 30.59    | 101.68 | 0.04848                              | 0.1872   | 0.2476 | 92.01                       | 0.1716                       | 3.8463                        |
| 125                    | 0.9537                             | 14.738                     | 1.087    | 15.907 | 30.044                     | 30.84    | 102.75 | 0.04843                              | 0.1930   | 0.2508 | 93.01                       | 0.1732                       | 3.9538                        |
| 126                    | 0.9841                             | 14.763                     | 1.083    | 15.933 | 30.285                     | 31.09    | 103.82 | 0.04838                              | 0.1989   | 0.2571 | 94.01                       | 0.1749                       | 4.0649                        |
| 127                    | 1.016                              | 14.788                     | 1.079    | 15.959 | 30.525                     | 31.34    | 104.89 | 0.04833                              | 0.2050   | 0.2636 | 95.00                       | 0.1766                       | 4.1795                        |
| 128                    | 1.049                              | 14.813                     | 1.074    | 15.985 | 30.765                     | 31.59    | 105.96 | 0.04828                              | 0.2113   | 0.2703 | 96.00                       | 0.1783                       | 4.2967                        |
| 129                    | 1.083                              | 14.839                     | 1.068    | 16.011 | 31.006                     | 31.84    | 107.03 | 0.04823                              | 0.2178   | 0.2772 | 97.00                       | 0.1800                       | 4.4076                        |
| 130                    | 1.116                              | 14.864                     | 1.062    | 16.037 | 31.246                     | 32.09    | 108.10 | 0.04818                              | 0.2245   | 0.2844 | 98.00                       | 0.1817                       | 4.5272                        |
| 131                    | 1.152                              | 14.889                     | 1.054    | 16.063 | 31.486                     | 32.34    | 109.17 | 0.04813                              | 0.2314   | 0.2917 | 99.00                       | 0.1834                       | 4.6465                        |
| 132                    | 1.189                              | 14.915                     | 1.046    | 16.089 | 31.726                     | 32.59    | 110.24 | 0.04808                              | 0.2386   | 0.2993 | 100.00                      | 0.1851                       | 4.7747                        |
| 133                    | 1.227                              | 14.940                     | 1.038    | 16.115 | 31.966                     | 32.84    | 111.31 | 0.04803                              | 0.2460   | 0.3070 | 101.00                      | 0.1868                       | 4.9028                        |
| 134                    | 1.267                              | 14.965                     | 1.029    | 16.141 | 32.206                     | 33.09    | 112.38 | 0.04798                              | 0.2538   | 0.3151 | 102.00                      | 0.1885                       | 5.0337                        |
| 135                    | 1.308                              | 14.990                     | 1.021    | 16.167 | 32.446                     | 33.34    | 113.45 | 0.04793                              | 0.2614   | 0.3233 | 103.00                      | 0.1902                       | 5.1678                        |
| 136                    | 1.350                              | 15.015                     | 1.013    | 16.193 | 32.686                     | 33.59    | 114.52 | 0.04788                              | 0.2693   | 0.3318 | 104.00                      | 0.1918                       | 5.3046                        |
| 137                    | 1.393                              | 15.040                     | 1.005    | 16.219 | 32.926                     | 33.84    | 115.59 | 0.04783                              | 0.2778   | 0.3405 | 105.00                      | 0.1935                       | 5.4446                        |
| 138                    | 1.438                              | 15.065                     | 0.997    | 16.245 | 33.166                     | 34.09    | 116.66 | 0.04778                              | 0.2865   | 0.3496 | 106.00                      | 0.1952                       | 5.5878                        |
| 139                    | 1.485                              | 15.091                     | 0.989    | 16.271 | 33.406                     | 34.34    | 117.73 | 0.04773                              | 0.2954   | 0.3592 | 107.00                      | 0.1969                       | 5.7342                        |



TABLE 2. THERMODYNAMIC PROPERTIES OF MOIST AIR\* (STANDARD ATMOSPHERIC PRESSURE, 29.921 IN. Hg) (Continued)

| FAHR.<br>TEMP.<br>(°F) | HUMIDITY<br>RATIO<br>W <sub>2</sub> /W <sub>1</sub> | VOLUME           |           |        | ENTHALPY<br>BTU/LB DRY AIR |           |       | ENTROPY<br>BTU PER (°F) (LB DRY AIR) |           |        | CONDENSED WATER             |                              |                               |
|------------------------|-----------------------------------------------------|------------------|-----------|--------|----------------------------|-----------|-------|--------------------------------------|-----------|--------|-----------------------------|------------------------------|-------------------------------|
|                        |                                                     | CU FT/LB DRY AIR |           |        | BTU/LB DRY AIR             |           |       | BTU PER (°F) (LB DRY AIR)            |           |        | BTU/LB                      |                              |                               |
|                        |                                                     | $v_a$            | $v_{a,s}$ | $v_s$  | $h_a$                      | $h_{a,s}$ | $h_s$ | $s_a$                                | $s_{a,s}$ | $s_s$  | Enthalpy<br>Btu/Lb<br>$h_w$ | Entropy<br>Btu/(°F)<br>$s_w$ | Vap. Press<br>In. Hg<br>$p_s$ |
| 140                    | 0.1524                                              | 15.117           | 8.703     | 18.919 | 33.955                     | 172.0     | 205.7 | 0.05300                              | 0.3047    | 0.3888 | 107.99                      | 0.1063                       | 5.9338                        |
| 141                    | 0.1534                                              | 15.142           | 8.829     | 19.071 | 33.896                     | 177.7     | 211.6 | 0.05430                              | 0.3142    | 0.3785 | 108.99                      | 0.2002                       | 6.0367                        |
| 142                    | 0.1544                                              | 15.167           | 8.951     | 19.228 | 33.836                     | 183.5     | 217.7 | 0.05560                              | 0.3241    | 0.3688 | 109.99                      | 0.2018                       | 6.1390                        |
| 143                    | 0.1554                                              | 15.192           | 9.068     | 19.390 | 33.777                     | 189.7     | 224.1 | 0.05690                              | 0.3343    | 0.3594 | 110.99                      | 0.2033                       | 6.2407                        |
| 144                    | 0.1564                                              | 15.217           | 9.189     | 19.557 | 33.718                     | 196.0     | 230.6 | 0.05820                              | 0.3449    | 0.3504 | 111.99                      | 0.2051                       | 6.3416                        |
| 145                    | 0.1574                                              | 15.243           | 9.314     | 19.729 | 33.659                     | 202.5     | 237.4 | 0.05950                              | 0.3559    | 0.3418 | 112.99                      | 0.2068                       | 6.4423                        |
| 146                    | 0.1584                                              | 15.268           | 9.440     | 19.907 | 33.600                     | 209.3     | 244.4 | 0.06080                              | 0.3672    | 0.3335 | 113.99                      | 0.2084                       | 6.5428                        |
| 147                    | 0.1594                                              | 15.293           | 9.566     | 20.091 | 33.540                     | 216.4     | 251.7 | 0.06210                              | 0.3790    | 0.3257 | 114.99                      | 0.2101                       | 6.6432                        |
| 148                    | 0.1604                                              | 15.318           | 9.692     | 20.281 | 33.481                     | 223.7     | 259.3 | 0.06340                              | 0.3912    | 0.3183 | 115.99                      | 0.2117                       | 6.7437                        |
| 149                    | 0.1614                                              | 15.344           | 9.819     | 20.477 | 33.422                     | 231.3     | 267.1 | 0.06470                              | 0.4038    | 0.3113 | 116.99                      | 0.2134                       | 6.8441                        |
| 150                    | 0.1624                                              | 15.369           | 9.946     | 20.670 | 33.363                     | 239.3     | 275.3 | 0.06600                              | 0.4169    | 0.3048 | 117.99                      | 0.2150                       | 6.9445                        |
| 151                    | 0.1634                                              | 15.394           | 10.073    | 20.866 | 33.304                     | 247.3     | 283.6 | 0.06730                              | 0.4304    | 0.2987 | 118.99                      | 0.2167                       | 7.0449                        |
| 152                    | 0.1644                                              | 15.420           | 10.200    | 21.067 | 33.245                     | 255.9     | 292.4 | 0.06860                              | 0.4444    | 0.2932 | 119.99                      | 0.2183                       | 7.1453                        |
| 153                    | 0.1654                                              | 15.445           | 10.327    | 21.273 | 33.186                     | 264.7     | 301.5 | 0.06990                              | 0.4591    | 0.2882 | 120.99                      | 0.2200                       | 7.2457                        |
| 154                    | 0.1664                                              | 15.470           | 10.454    | 21.484 | 33.127                     | 273.9     | 310.9 | 0.07120                              | 0.4743    | 0.2838 | 121.99                      | 0.2216                       | 7.3461                        |
| 155                    | 0.1674                                              | 15.495           | 10.581    | 21.699 | 33.068                     | 283.5     | 320.8 | 0.07250                              | 0.4901    | 0.2799 | 122.99                      | 0.2232                       | 7.4465                        |
| 156                    | 0.1684                                              | 15.521           | 10.708    | 21.919 | 33.009                     | 293.5     | 331.0 | 0.07380                              | 0.5064    | 0.2765 | 123.99                      | 0.2248                       | 7.5469                        |
| 157                    | 0.1694                                              | 15.546           | 10.835    | 22.144 | 32.950                     | 303.9     | 341.7 | 0.07510                              | 0.5232    | 0.2737 | 124.99                      | 0.2265                       | 7.6473                        |
| 158                    | 0.1704                                              | 15.571           | 10.962    | 22.374 | 32.891                     | 314.7     | 352.7 | 0.07640                              | 0.5405    | 0.2713 | 125.99                      | 0.2281                       | 7.7477                        |
| 159                    | 0.1714                                              | 15.596           | 11.089    | 22.609 | 32.832                     | 326.0     | 364.2 | 0.07770                              | 0.5583    | 0.2693 | 126.99                      | 0.2297                       | 7.8481                        |
| 160                    | 0.1724                                              | 15.621           | 11.216    | 22.849 | 32.773                     | 337.8     | 376.3 | 0.07900                              | 0.5767    | 0.2679 | 127.99                      | 0.2313                       | 7.9485                        |
| 161                    | 0.1734                                              | 15.646           | 11.343    | 23.094 | 32.714                     | 350.1     | 388.8 | 0.08030                              | 0.5956    | 0.2671 | 128.99                      | 0.2330                       | 8.0489                        |
| 162                    | 0.1744                                              | 15.671           | 11.470    | 23.344 | 32.655                     | 363.0     | 402.0 | 0.08160                              | 0.6150    | 0.2667 | 129.99                      | 0.2346                       | 8.1493                        |
| 163                    | 0.1754                                              | 15.696           | 11.597    | 23.599 | 32.596                     | 376.5     | 415.7 | 0.08290                              | 0.6349    | 0.2667 | 130.99                      | 0.2361                       | 8.2497                        |
| 164                    | 0.1764                                              | 15.721           | 11.724    | 23.859 | 32.537                     | 390.5     | 429.9 | 0.08420                              | 0.6553    | 0.2673 | 131.99                      | 0.2377                       | 8.3501                        |
| 165                    | 0.1774                                              | 15.746           | 11.851    | 24.119 | 32.478                     | 405.3     | 445.0 | 0.08550                              | 0.6762    | 0.2689 | 133.00                      | 0.2393                       | 8.4505                        |
| 166                    | 0.1784                                              | 15.771           | 11.978    | 24.384 | 32.419                     | 420.8     | 460.7 | 0.08680                              | 0.6976    | 0.2703 | 134.00                      | 0.2409                       | 8.5509                        |
| 167                    | 0.1794                                              | 15.796           | 12.105    | 24.654 | 32.360                     | 437.0     | 477.2 | 0.08810                              | 0.7195    | 0.2721 | 135.01                      | 0.2426                       | 8.6513                        |
| 168                    | 0.1804                                              | 15.821           | 12.232    | 24.929 | 32.301                     | 454.0     | 494.4 | 0.08940                              | 0.7419    | 0.2743 | 136.01                      | 0.2442                       | 8.7517                        |
| 169                    | 0.1814                                              | 15.846           | 12.359    | 25.209 | 32.242                     | 471.3     | 512.4 | 0.09070                              | 0.7648    | 0.2769 | 137.01                      | 0.2457                       | 8.8521                        |
| 170                    | 0.1824                                              | 15.871           | 12.486    | 25.494 | 32.183                     | 490.6     | 531.5 | 0.09200                              | 0.7882    | 0.2800 | 138.01                      | 0.2473                       | 8.9525                        |
| 171                    | 0.1834                                              | 15.896           | 12.613    | 25.784 | 32.124                     | 510.4     | 551.5 | 0.09330                              | 0.8121    | 0.2835 | 139.01                      | 0.2489                       | 9.0529                        |
| 172                    | 0.1844                                              | 15.921           | 12.740    | 26.079 | 32.065                     | 531.3     | 572.7 | 0.09460                              | 0.8365    | 0.2875 | 140.01                      | 0.2505                       | 9.1533                        |
| 173                    | 0.1854                                              | 15.946           | 12.867    | 26.379 | 32.006                     | 553.3     | 594.9 | 0.09590                              | 0.8614    | 0.2920 | 141.01                      | 0.2521                       | 9.2537                        |
| 174                    | 0.1864                                              | 15.971           | 12.994    | 26.684 | 31.947                     | 576.5     | 618.5 | 0.09720                              | 0.8868    | 0.2969 | 142.02                      | 0.2537                       | 9.3541                        |

\* Compiled by John A. Goff and S. Gratch.

TABLE 2. THERMODYNAMIC PROPERTIES OF MOIST AIR\* (STANDARD ATMOSPHERIC PRESSURE, 29.921 IN. Hg) (Continued)

| FAHR.<br>TEMP.<br>(°F) | HUMIDITY<br>RATIO<br>W <sub>2</sub> /W <sub>1</sub> | VOLUME           |           |        | ENTHALPY<br>BTU/LB DRY AIR |           |       | ENTROPY<br>BTU PER (°F) (LB DRY AIR) |           |       | CONDENSED WATER             |                              |                               |
|------------------------|-----------------------------------------------------|------------------|-----------|--------|----------------------------|-----------|-------|--------------------------------------|-----------|-------|-----------------------------|------------------------------|-------------------------------|
|                        |                                                     | CU FT/LB DRY AIR |           |        | BTU/LB DRY AIR             |           |       | BTU PER (°F) (LB DRY AIR)            |           |       | BTU/LB                      |                              |                               |
|                        |                                                     | $v_a$            | $v_{a,s}$ | $v_s$  | $h_a$                      | $h_{a,s}$ | $h_s$ | $s_a$                                | $s_{a,s}$ | $s_s$ | Enthalpy<br>Btu/Lb<br>$h_w$ | Entropy<br>Btu/(°F)<br>$s_w$ | Vap. Press<br>In. Hg<br>$p_s$ |
| 175                    | 0.5292                                              | 16.091           | 13.475    | 29.476 | 42.087                     | 601.1     | 643.2 | 0.07150                              | 1.005     | 1.083 | 143.02                      | 0.2533                       | 13.678                        |
| 176                    | 0.5519                                              | 16.026           | 13.074    | 30.100 | 42.328                     | 627.1     | 690.4 | 0.07784                              | 1.047     | 1.124 | 145.02                      | 0.2584                       | 14.304                        |
| 177                    | 0.5760                                              | 16.031           | 14.710    | 30.781 | 42.569                     | 654.1     | 697.5 | 0.07832                              | 1.091     | 1.169 | 146.02                      | 0.2634                       | 14.930                        |
| 178                    | 0.6016                                              | 16.076           | 16.386    | 31.463 | 42.810                     | 684.1     | 725.9 | 0.07870                              | 1.137     | 1.216 | 147.03                      | 0.2680                       | 15.558                        |
| 179                    | 0.6288                                              | 16.102           | 16.104    | 32.206 | 43.051                     | 715.2     | 758.3 | 0.07908                              | 1.187     | 1.268 | 148.03                      | 0.2726                       | 16.186                        |
| 180                    | 0.6578                                              | 16.127           | 16.870    | 32.997 | 43.292                     | 748.5     | 791.8 | 0.07946                              | 1.240     | 1.319 | 149.03                      | 0.2771                       | 16.814                        |
| 181                    | 0.6887                                              | 16.152           | 17.689    | 33.841 | 43.534                     | 783.9     | 827.4 | 0.07984                              | 1.296     | 1.376 | 150.03                      | 0.2817                       | 17.442                        |
| 182                    | 0.7218                                              | 16.177           | 18.565    | 34.742 | 43.775                     | 821.9     | 865.7 | 0.08021                              | 1.357     | 1.437 | 151.04                      | 0.2862                       | 18.070                        |
| 183                    | 0.7572                                              | 16.203           | 19.504    | 35.707 | 44.016                     | 862.5     | 906.5 | 0.08059                              | 1.421     | 1.502 | 152.04                      | 0.2907                       | 18.700                        |
| 184                    | 0.7953                                              | 16.228           | 20.513    | 36.741 | 44.257                     | 906.2     | 950.5 | 0.08096                              | 1.490     | 1.571 | 153.04                      | 0.2953                       | 19.330                        |
| 185                    | 0.8363                                              | 16.253           | 21.601    | 37.854 | 44.498                     | 953.2     | 997.7 | 0.08134                              | 1.565     | 1.646 | 154.05                      | 0.2999                       | 19.960                        |
| 186                    | 0.8805                                              | 16.278           | 22.775    | 39.053 | 44.740                     | 1004      | 1049  | 0.08171                              | 1.645     | 1.727 | 155.05                      | 0.3045                       | 20.590                        |
| 187                    | 0.9283                                              | 16.304           | 24.047    | 40.351 | 44.981                     | 1059      | 1104  | 0.08208                              | 1.731     | 1.813 | 156.05                      | 0.3091                       | 21.220                        |
| 188                    | 0.9797                                              | 16.329           | 25.427    | 41.766 | 45.222                     | 1119      | 1164  | 0.08245                              | 1.825     | 1.907 | 157.06                      | 0.3137                       | 21.850                        |
| 189                    | 1.0357                                              | 16.354           | 26.934    | 43.288 | 45.463                     | 1184      | 1229  | 0.08283                              | 1.923     | 2.011 | 158.07                      | 0.3183                       | 22.480                        |
| 190                    | 1.0969                                              | 16.379           | 28.580    | 44.935 | 45.704                     | 1255      | 1301  | 0.08320                              | 2.029     | 2.122 | 159.07                      | 0.3229                       | 23.110                        |
| 191                    | 1.1656                                              | 16.405           | 30.385    | 46.790 | 45.946                     | 1332      | 1378  | 0.08357                              | 2.161     | 2.245 | 160.07                      | 0.3275                       | 23.740                        |
| 192                    | 1.2421                                              | 16.430           | 32.376    | 48.806 | 46.187                     | 1413      | 1464  | 0.08394                              | 2.296     | 2.380 | 161.07                      | 0.3321                       | 24.370                        |
| 193                    | 1.3284                                              | 16.455           | 34.581    | 51.058 | 46.428                     | 1501      | 1559  | 0.08431                              | 2.444     | 2.528 | 162.08                      | 0.3367                       | 25.000                        |
| 194                    | 1.4244                                              | 16.480           | 37.056    | 53.516 | 46.670                     | 1619      | 1666  | 0.08468                              | 2.606     | 2.684 | 163.09                      | 0.3413                       | 25.630                        |
| 195                    | 1.5319                                              | 16.506           | 39.785    | 56.291 | 46.911                     | 1757      | 1784  | 0.08505                              | 2.784     | 2.879 | 164.09                      | 0.3459                       | 26.260                        |
| 196                    | 1.6531                                              | 16.531           | 42.885    | 59.416 | 47.153                     | 1871      | 1918  | 0.08542                              | 3.002     | 3.087 | 165.09                      | 0.3505                       | 26.890                        |
| 197                    | 1.7897                                              | 16.556           | 46.402    | 62.958 | 47.394                     | 2022      | 2099  | 0.08579                              | 3.238     | 3.324 | 166.10                      | 0.3551                       | 27.520                        |
| 198                    | 1.9426                                              | 16.581           | 50.476    | 67.007 | 47.635                     | 2195      | 2243  | 0.08616                              | 3.507     | 3.593 | 167.11                      | 0.3597                       | 28.150                        |
| 199                    | 2.1137                                              | 16.606           | 55.071    | 71.671 | 47.876                     | 2391      | 2417  | 0.08653                              | 3.817     | 3.903 | 168.12                      | 0.3643                       | 28.780                        |
| 200                    | 2.305                                               | 16.631           | 60.510    | 77.142 | 48.117                     | 2629      | 2677  | 0.08690                              | 4.179     | 4.266 | 169.13                      | 0.3689                       | 29.410                        |

\* Compiled by John A. Goff and S. Gratch.

TABLE 3. THERMODYNAMIC PROPERTIES OF WATER AT SATURATION\*

| FAHR.<br>TEMP.<br>(°F) | ABSOLUTE PRESSURE<br>PS X 10 <sup>3</sup> |         | SPECIFIC VOLUME, CU FT PER LB |                                             |                                                 |                              |                          | ENTHALPY, BTU PER LB         |                              |                          |                              |                              | ENTROPY, BTU PER (LB) (°F) |                              |                              |                          |                              | FAHR.<br>TEMP.<br>(°F) |
|------------------------|-------------------------------------------|---------|-------------------------------|---------------------------------------------|-------------------------------------------------|------------------------------|--------------------------|------------------------------|------------------------------|--------------------------|------------------------------|------------------------------|----------------------------|------------------------------|------------------------------|--------------------------|------------------------------|------------------------|
|                        | Lb/Sq In.                                 | In. Hg  | Sat. Solid<br>v <sub>1</sub>  | Evap.<br>v <sub>1g</sub> X 10 <sup>-3</sup> | Sat. Vapor<br>v <sub>g</sub> X 10 <sup>-3</sup> | Sat. Solid<br>h <sub>1</sub> | Evap.<br>h <sub>1g</sub> | Sat. Vapor<br>h <sub>g</sub> | Sat. Solid<br>s <sub>1</sub> | Evap.<br>s <sub>1g</sub> | Sat. Vapor<br>s <sub>g</sub> | Sat. Solid<br>h <sub>1</sub> | Evap.<br>h <sub>1g</sub>   | Sat. Vapor<br>h <sub>g</sub> | Sat. Solid<br>s <sub>1</sub> | Evap.<br>s <sub>1g</sub> | Sat. Vapor<br>s <sub>g</sub> |                        |
| -160                   | 0.000449                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -160                       | 3.5849                       | -160                         | 3.5849                   | -160                         | 3.5849                 |
| -155                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -155                       | 3.5849                       | -155                         | 3.5849                   | -155                         | 3.5849                 |
| -150                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -150                       | 3.5849                       | -150                         | 3.5849                   | -150                         | 3.5849                 |
| -145                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -145                       | 3.5849                       | -145                         | 3.5849                   | -145                         | 3.5849                 |
| -140                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -140                       | 3.5849                       | -140                         | 3.5849                   | -140                         | 3.5849                 |
| -135                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -135                       | 3.5849                       | -135                         | 3.5849                   | -135                         | 3.5849                 |
| -130                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -130                       | 3.5849                       | -130                         | 3.5849                   | -130                         | 3.5849                 |
| -125                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -125                       | 3.5849                       | -125                         | 3.5849                   | -125                         | 3.5849                 |
| -120                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -120                       | 3.5849                       | -120                         | 3.5849                   | -120                         | 3.5849                 |
| -115                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -115                       | 3.5849                       | -115                         | 3.5849                   | -115                         | 3.5849                 |
| -110                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -110                       | 3.5849                       | -110                         | 3.5849                   | -110                         | 3.5849                 |
| -105                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -105                       | 3.5849                       | -105                         | 3.5849                   | -105                         | 3.5849                 |
| -100                   | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -100                       | 3.5849                       | -100                         | 3.5849                   | -100                         | 3.5849                 |
| -95                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -95                        | 3.5849                       | -95                          | 3.5849                   | -95                          | 3.5849                 |
| -90                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -90                        | 3.5849                       | -90                          | 3.5849                   | -90                          | 3.5849                 |
| -85                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -85                        | 3.5849                       | -85                          | 3.5849                   | -85                          | 3.5849                 |
| -80                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -80                        | 3.5849                       | -80                          | 3.5849                   | -80                          | 3.5849                 |
| -75                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -75                        | 3.5849                       | -75                          | 3.5849                   | -75                          | 3.5849                 |
| -70                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -70                        | 3.5849                       | -70                          | 3.5849                   | -70                          | 3.5849                 |
| -65                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -65                        | 3.5849                       | -65                          | 3.5849                   | -65                          | 3.5849                 |
| -60                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -60                        | 3.5849                       | -60                          | 3.5849                   | -60                          | 3.5849                 |
| -55                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -55                        | 3.5849                       | -55                          | 3.5849                   | -55                          | 3.5849                 |
| -50                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -50                        | 3.5849                       | -50                          | 3.5849                   | -50                          | 3.5849                 |
| -45                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -45                        | 3.5849                       | -45                          | 3.5849                   | -45                          | 3.5849                 |
| -40                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -40                        | 3.5849                       | -40                          | 3.5849                   | -40                          | 3.5849                 |
| -35                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -35                        | 3.5849                       | -35                          | 3.5849                   | -35                          | 3.5849                 |
| -30                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -30                        | 3.5849                       | -30                          | 3.5849                   | -30                          | 3.5849                 |
| -25                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -25                        | 3.5849                       | -25                          | 3.5849                   | -25                          | 3.5849                 |
| -20                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -20                        | 3.5849                       | -20                          | 3.5849                   | -20                          | 3.5849                 |
| -15                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -15                        | 3.5849                       | -15                          | 3.5849                   | -15                          | 3.5849                 |
| -10                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -10                        | 3.5849                       | -10                          | 3.5849                   | -10                          | 3.5849                 |
| -5                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | -5                         | 3.5849                       | -5                           | 3.5849                   | -5                           | 3.5849                 |
| 0                      | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 0                          | 3.5849                       | 0                            | 3.5849                   | 0                            | 3.5849                 |
| 5                      | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 5                          | 3.5849                       | 5                            | 3.5849                   | 5                            | 3.5849                 |
| 10                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 10                         | 3.5849                       | 10                           | 3.5849                   | 10                           | 3.5849                 |
| 15                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 15                         | 3.5849                       | 15                           | 3.5849                   | 15                           | 3.5849                 |
| 20                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 20                         | 3.5849                       | 20                           | 3.5849                   | 20                           | 3.5849                 |
| 25                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 25                         | 3.5849                       | 25                           | 3.5849                   | 25                           | 3.5849                 |
| 30                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 30                         | 3.5849                       | 30                           | 3.5849                   | 30                           | 3.5849                 |
| 35                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 35                         | 3.5849                       | 35                           | 3.5849                   | 35                           | 3.5849                 |
| 40                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 40                         | 3.5849                       | 40                           | 3.5849                   | 40                           | 3.5849                 |
| 45                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 45                         | 3.5849                       | 45                           | 3.5849                   | 45                           | 3.5849                 |
| 50                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 50                         | 3.5849                       | 50                           | 3.5849                   | 50                           | 3.5849                 |
| 55                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 55                         | 3.5849                       | 55                           | 3.5849                   | 55                           | 3.5849                 |
| 60                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 60                         | 3.5849                       | 60                           | 3.5849                   | 60                           | 3.5849                 |
| 65                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 65                         | 3.5849                       | 65                           | 3.5849                   | 65                           | 3.5849                 |
| 70                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 70                         | 3.5849                       | 70                           | 3.5849                   | 70                           | 3.5849                 |
| 75                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 75                         | 3.5849                       | 75                           | 3.5849                   | 75                           | 3.5849                 |
| 80                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 80                         | 3.5849                       | 80                           | 3.5849                   | 80                           | 3.5849                 |
| 85                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 85                         | 3.5849                       | 85                           | 3.5849                   | 85                           | 3.5849                 |
| 90                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 90                         | 3.5849                       | 90                           | 3.5849                   | 90                           | 3.5849                 |
| 95                     | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 95                         | 3.5849                       | 95                           | 3.5849                   | 95                           | 3.5849                 |
| 100                    | 0.000440                                  | 0.01008 | 0.01723                       | 38070                                       | 38070                                           | 1212.43                      | -223.05                  | 1212.43                      | 990.38                       | -0.4607                  | 4.0456                       | 3.5849                       | 100                        | 3.5849                       | 100                          | 3.5849                   | 100                          | 3.5849                 |

\* Compiled by John A. Goff and B. Gratch.

TABLE 3. THERMODYNAMIC PROPERTIES OF WATER AT SATURATION\* (Continued)

| FAHR.<br>TEMP.<br>(°F) | ABSOLUTE PRESSURE<br>PS X 10 <sup>3</sup> |        | SPECIFIC VOLUME, CU FT PER LB |                                             |                                                 |                              |                          | ENTHALPY, BTU PER LB         |                              |                          |                              |     | ENTROPY, BTU PER (LB) (°F) |     |  |  |  | FAHR.<br>TEMP.<br>(°F) |
|------------------------|-------------------------------------------|--------|-------------------------------|---------------------------------------------|-------------------------------------------------|------------------------------|--------------------------|------------------------------|------------------------------|--------------------------|------------------------------|-----|----------------------------|-----|--|--|--|------------------------|
|                        | Lb/Sq In.                                 | In. Hg | Sat. Solid<br>v <sub>1</sub>  | Evap.<br>v <sub>1g</sub> X 10 <sup>-3</sup> | Sat. Vapor<br>v <sub>g</sub> X 10 <sup>-3</sup> | Sat. Solid<br>h <sub>1</sub> | Evap.<br>h <sub>1g</sub> | Sat. Vapor<br>h <sub>g</sub> | Sat. Solid<br>s <sub>1</sub> | Evap.<br>s <sub>1g</sub> | Sat. Vapor<br>s <sub>g</sub> |     |                            |     |  |  |  |                        |
| -80                    | 0.3440                                    | 0.7003 | 0.01728                       | 7.441                                       | 7.441                                           | -172.68                      | 1220.52                  | 1047.84                      | -0.3552                      | 2.8408                   | 2.4853                       | -80 | 2.4853                     | -80 |  |  |  |                        |
| -75                    | 0.3275                                    | 0.6823 | 0.01728                       | 7.441                                       | 7.441                                           | -172.68                      | 1220.52                  | 1047.84                      | -0.3552                      | 2.8408                   | 2.4853                       | -75 | 2.4853                     | -75 |  |  |  |                        |
| -70                    | 0.3110                                    | 0.6643 | 0.01728                       | 7.441                                       | 7.441                                           | -170.91                      | 1220.51                  | 1046.40                      | -0.3511                      | 2.8413                   | 2.4847                       | -70 | 2.4847                     | -70 |  |  |  |                        |
| -65                    | 0.2945                                    | 0.6463 | 0.01728                       | 7.441                                       | 7.441                                           | -170.91                      | 1220.51                  | 1046.40                      | -0.3460                      | 2.8413                   | 2.4838                       | -65 | 2.4838                     | -65 |  |  |  |                        |
| -60                    | 0.2780                                    | 0.6283 | 0.01728                       | 7.441                                       | 7.441                                           | -169.12                      | 1220.49                  | 1045.37                      | -0.3419                      | 2.8418                   | 2.4831                       | -60 | 2.4831                     | -60 |  |  |  |                        |
| -55                    | 0.2615                                    | 0.6103 | 0.01728                       | 7.441                                       | 7.441                                           | -169.12                      | 1220.47                  | 1045.37                      | -0.3378                      | 2.8423                   | 2.4824                       | -55 | 2.4824                     | -55 |  |  |  |                        |
| -50                    | 0.2450                                    | 0.5923 | 0.01728                       | 7.441                                       | 7.441                                           | -167.31                      | 1220.45                  | 1045.14                      | -0.3329                      | 2.8428                   | 2.4817                       | -50 | 2.4817                     | -50 |  |  |  |                        |
| -45                    | 0.2285                                    | 0.5743 | 0.01728                       | 7.441                                       | 7.441                                           | -165.58                      | 1220.43                  | 1044.92                      | -0.3280                      | 2.8433                   | 2.4810                       | -45 | 2.4810                     | -45 |  |  |  |                        |
| -40                    | 0.2120                                    | 0.5563 | 0.01728                       | 7.441                                       | 7.441                                           | -165.58                      | 1220.43                  | 1044.92                      | -0.3239                      | 2.8438                   | 2.4803                       | -40 | 2.4803                     | -40 |  |  |  |                        |
| -35                    | 0.1955                                    | 0.5383 | 0.01728                       | 7.441                                       | 7.441                                           | -163.84                      | 1220.39                  | 1044.71                      | -0.3188                      | 2.8443                   | 2.4796                       | -35 | 2.4796                     | -35 |  |  |  |                        |
| -30                    | 0.1790                                    | 0.5203 | 0.01728                       | 7.441                                       | 7.441                                           | -163.84                      | 1220.39                  | 1044.71                      | -0.3147                      | 2.8448                   | 2.4789                       | -30 | 2.4789                     | -30 |  |  |  |                        |
| -25                    | 0.1625                                    | 0.5023 | 0.01728                       | 7.441                                       | 7.441                                           | -162.07                      | 1220.36                  | 1044.50                      | -0.3097                      | 2.8453                   | 2.4782                       | -25 | 2.4782                     | -25 |  |  |  |                        |
| -20                    | 0.1460                                    | 0.4843 | 0.01728                       | 7.441                                       | 7.441                                           | -162.07                      | 1220.36                  | 1044.50                      | -0.3056                      | 2.8458                   | 2.4775                       | -20 | 2.4775                     | -20 |  |  |  |                        |
| -15                    | 0.1295                                    | 0.4663 | 0.01728                       | 7.441                                       | 7.441                                           | -160.26                      | 1220.32                  | 1044.29                      | -0.3005                      | 2.8463                   | 2.4768                       | -15 | 2.4768                     | -15 |  |  |  |                        |
| -10                    | 0.1130                                    | 0.4483 | 0.01728                       | 7.441                                       | 7.441                                           | -160.26                      | 1220.32                  | 1044.29                      | -0.2964                      | 2.8468                   | 2.4761                       | -10 | 2.4761                     | -10 |  |  |  |                        |
| -5                     | 0.0965                                    | 0.4303 | 0.01728                       | 7.441                                       | 7.441                                           | -158.45                      | 1220.28                  | 1044.08                      | -0.2913                      | 2.8473                   | 2.4754                       | -5  | 2.4754                     | -5  |  |  |  |                        |
| 0                      | 0.0800                                    | 0.4123 | 0.01728                       | 7.441                                       | 7.441                                           | -158.45                      | 1220.28                  | 1044.08                      | -0.2872                      | 2.8478                   | 2.4747                       | 0   | 2.4747                     | 0   |  |  |  |                        |
| 5                      | 0.0635                                    | 0.3943 | 0.01728                       | 7.441                                       | 7.441                                           | -156.64                      | 1220.23                  | 1043.87                      | -0.2821                      | 2.8483                   | 2.4740                       | 5   | 2.4740                     | 5   |  |  |  |                        |
| 10                     | 0.0470                                    | 0.3763 | 0.01728                       | 7.441                                       | 7.441                                           | -156.64                      | 1220.23                  | 1043.87                      | -0.2780                      | 2.8488                   | 2.4733                       | 10  | 2.4733                     | 10  |  |  |  |                        |
| 15                     | 0.0305                                    | 0.3583 | 0.01728                       | 7.441                                       | 7.441                                           | -154.83                      | 1220.18                  | 1043.66                      | -0.2729                      | 2.8493                   | 2.4726                       | 15  | 2.4726                     | 15  |  |  |  |                        |
| 20                     | 0.0140                                    | 0.3403 | 0.01728                       | 7.441                                       | 7.441                                           | -154.83                      | 1220.18                  | 1043.66                      | -0.2688                      | 2.8498                   | 2.4719                       | 20  | 2.4719                     | 20  |  |  |  |                        |
| 25                     | 0.0075                                    | 0.3223 | 0.01728                       | 7.441                                       | 7.441                                           | -153.02                      | 1220.13                  | 1043.45                      | -0.2637                      | 2.8503                   | 2.4712                       | 25  | 2.4712                     | 25  |  |  |  |                        |
| 30                     | 0.0010                                    | 0.3043 | 0.01728                       | 7.441                                       | 7.441                                           | -153.02                      | 1220.13                  | 1043.45                      | -0.2596                      | 2.8508                   | 2.4705                       | 30  | 2.4705                     | 30  |  |  |  |                        |
| 35                     | 0.0005                                    | 0.2863 | 0.01728                       | 7.441                                       | 7.441                                           | -151.21                      | 1220.08                  | 1043.24                      | -0.2545                      | 2.8513                   | 2.4698                       | 35  | 2.4698                     | 35  |  |  |  |                        |
| 40                     | 0.0000                                    | 0.2683 | 0.01728                       | 7.441                                       | 7.441                                           | -151.21                      | 1220.08                  | 1043.24                      | -0.2504                      | 2.8518                   | 2.4691                       | 40  | 2.4691                     | 40  |  |  |  |                        |
| 45                     | 0.0000                                    | 0.2503 | 0.01728                       | 7.441                                       | 7.441                                           | -149.40                      | 1220.03                  | 1043.03                      | -0.2453                      | 2.8523                   | 2.4684                       | 45  | 2.4684                     | 45  |  |  |  |                        |
| 50                     | 0.0000                                    | 0.2323 | 0.01728                       | 7.441                                       | 7.441                                           | -149.40                      | 1220.03                  | 1043.03                      | -0.2412                      | 2.8528                   | 2.4677                       | 50  | 2.4677                     | 50  |  |  |  |                        |
| 55                     | 0.0000                                    | 0.2143 | 0.01728                       | 7.441                                       | 7.441                                           | -147.59                      | 1220.00                  | 1042.82                      | -0.2361                      | 2.8533                   | 2.4670                       | 55  | 2.4670                     | 55  |  |  |  |                        |
| 60                     | 0.0000                                    | 0.1963 | 0.01728                       | 7.441                                       | 7.441                                           | -147.59                      | 1220.00                  | 1042.82                      | -0.2320                      | 2.8538                   | 2.4663                       | 60  | 2.4663                     | 60  |  |  |  |                        |
| 65                     | 0.0000                                    | 0.1783 | 0.01728                       | 7.441                                       | 7.441                                           | -145.78                      | 1220.00                  | 1042.61                      | -0.2269                      | 2.8543                   | 2.4656                       | 65  | 2.4656                     | 65  |  |  |  |                        |
| 70                     | 0.0000                                    | 0.1603 | 0.01728                       | 7.441                                       | 7.441                                           | -145.78                      | 1220.00                  | 1042.61                      | -0.2228                      | 2.8548                   | 2.4649                       | 70  | 2.4649                     | 70  |  |  |  |                        |
| 75                     | 0.0000                                    | 0.1423 | 0.01728                       | 7.441                                       | 7.441                                           | -143.97                      | 1220.00                  | 1042.40                      | -0.2177                      | 2.8553                   | 2.4642                       | 75  | 2.4642                     | 75  |  |  |  |                        |
| 80                     | 0.0000                                    | 0.1243 | 0.01728                       | 7.441                                       | 7.441                                           | -143.97                      | 1220.00                  | 1042.40                      | -0.2136                      | 2.8558                   | 2.4635                       | 80  | 2.4635                     | 80  |  |  |  |                        |
| 85                     | 0.0000                                    | 0.1063 | 0.01728                       | 7.441                                       | 7.441                                           | -142.16                      | 1220.00                  | 1042.19                      | -0.2085                      | 2.8563                   | 2.4628                       | 85  | 2.4628                     | 85  |  |  |  |                        |
| 90                     | 0.0000                                    | 0.0883 | 0.01728                       | 7.441                                       | 7.441                                           | -142.16                      | 1220.00                  | 1042.19                      | -0.2044                      | 2.8568                   | 2.4621                       | 90  | 2.4621                     | 90  |  |  |  |                        |
| 95                     | 0.0000                                    | 0.0703 | 0.01728                       | 7.441                                       | 7.441                                           | -140.35                      | 1220.00                  | 1041.98                      | -0.1993                      | 2.8573                   | 2.4614                       | 95  | 2.4614                     | 95  |  |  |  |                        |
| 100                    | 0.0000                                    | 0.0523 | 0.01728                       | 7.441                                       | 7.441                                           | -140.35                      | 1220.00                  | 1041.98                      | -0.1952                      | 2.8578                   | 2.4607                       | 100 | 2.4607                     | 100 |  |  |  |                        |
| 105                    | 0.0000                                    | 0.0343 | 0.01728                       | 7.441                                       | 7.441                                           | -138.54                      | 1220.00                  | 1041.77                      | -0.1901                      | 2.8583                   | 2.4600                       | 105 | 2.4600                     | 105 |  |  |  |                        |
| 110                    | 0.0000                                    | 0.0163 | 0.01728                       | 7.441                                       | 7.441                                           | -138.54                      | 1220.00                  | 1041.77                      | -0.1860                      | 2.8588                   | 2.4593                       | 110 | 2.4593                     | 110 |  |  |  |                        |
| 115                    | 0.0000                                    | 0.0083 | 0.01728                       | 7.441                                       | 7.441                                           | -136.73                      | 1220.00                  | 1041.56                      | -0.1809                      | 2.8593                   | 2.4586                       | 115 | 2.4586                     | 115 |  |  |  |                        |
| 120                    | 0.0000                                    | 0.0003 | 0.01728                       | 7.441                                       | 7.441                                           | -136.73                      | 1220.00                  | 1041.56                      | -0.1768                      | 2.8598                   | 2.4579                       | 120 | 2.4579                     | 120 |  |  |  |                        |
| 125                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -134.92                      | 1220.00                  | 1041.35                      | -0.1717                      | 2.8603                   | 2.4572                       | 125 | 2.4572                     | 125 |  |  |  |                        |
| 130                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -134.92                      | 1220.00                  | 1041.35                      | -0.1676                      | 2.8608                   | 2.4565                       | 130 | 2.4565                     | 130 |  |  |  |                        |
| 135                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -133.11                      | 1220.00                  | 1041.14                      | -0.1625                      | 2.8613                   | 2.4558                       | 135 | 2.4558                     | 135 |  |  |  |                        |
| 140                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -133.11                      | 1220.00                  | 1041.14                      | -0.1584                      | 2.8618                   | 2.4551                       | 140 | 2.4551                     | 140 |  |  |  |                        |
| 145                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -131.30                      | 1220.00                  | 1040.93                      | -0.1533                      | 2.8623                   | 2.4544                       | 145 | 2.4544                     | 145 |  |  |  |                        |
| 150                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -131.30                      | 1220.00                  | 1040.93                      | -0.1492                      | 2.8628                   | 2.4537                       | 150 | 2.4537                     | 150 |  |  |  |                        |
| 155                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -129.49                      | 1220.00                  | 1040.72                      | -0.1441                      | 2.8633                   | 2.4530                       | 155 | 2.4530                     | 155 |  |  |  |                        |
| 160                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -129.49                      | 1220.00                  | 1040.72                      | -0.1400                      | 2.8638                   | 2.4523                       | 160 | 2.4523                     | 160 |  |  |  |                        |
| 165                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -127.68                      | 1220.00                  | 1040.51                      | -0.1349                      | 2.8643                   | 2.4516                       | 165 | 2.4516                     | 165 |  |  |  |                        |
| 170                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -127.68                      | 1220.00                  | 1040.51                      | -0.1308                      | 2.8648                   | 2.4509                       | 170 | 2.4509                     | 170 |  |  |  |                        |
| 175                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -125.87                      | 1220.00                  | 1040.30                      | -0.1257                      | 2.8653                   | 2.4502                       | 175 | 2.4502                     | 175 |  |  |  |                        |
| 180                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -125.87                      | 1220.00                  | 1040.30                      | -0.1216                      | 2.8658                   | 2.4495                       | 180 | 2.4495                     | 180 |  |  |  |                        |
| 185                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -124.06                      | 1220.00                  | 1040.09                      | -0.1165                      | 2.8663                   | 2.4488                       | 185 | 2.4488                     | 185 |  |  |  |                        |
| 190                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -124.06                      | 1220.00                  | 1040.09                      | -0.1124                      | 2.8668                   | 2.4481                       | 190 | 2.4481                     | 190 |  |  |  |                        |
| 195                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -122.25                      | 1220.00                  | 1039.88                      | -0.1073                      | 2.8673                   | 2.4474                       | 195 | 2.4474                     | 195 |  |  |  |                        |
| 200                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -122.25                      | 1220.00                  | 1039.88                      | -0.1032                      | 2.8678                   | 2.4467                       | 200 | 2.4467                     | 200 |  |  |  |                        |
| 205                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -120.44                      | 1220.00                  | 1039.67                      | -0.0981                      | 2.8683                   | 2.4460                       | 205 | 2.4460                     | 205 |  |  |  |                        |
| 210                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -120.44                      | 1220.00                  | 1039.67                      | -0.0940                      | 2.8688                   | 2.4453                       | 210 | 2.4453                     | 210 |  |  |  |                        |
| 215                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -118.63                      | 1220.00                  | 1039.46                      | -0.0889                      | 2.8693                   | 2.4446                       | 215 | 2.4446                     | 215 |  |  |  |                        |
| 220                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -118.63                      | 1220.00                  | 1039.46                      | -0.0848                      | 2.8698                   | 2.4439                       | 220 | 2.4439                     | 220 |  |  |  |                        |
| 225                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -116.82                      | 1220.00                  | 1039.25                      | -0.0797                      | 2.8703                   | 2.4432                       | 225 | 2.4432                     | 225 |  |  |  |                        |
| 230                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -116.82                      | 1220.00                  | 1039.25                      | -0.0756                      | 2.8708                   | 2.4425                       | 230 | 2.4425                     | 230 |  |  |  |                        |
| 235                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -115.01                      | 1220.00                  | 1039.04                      | -0.0705                      | 2.8713                   | 2.4418                       | 235 | 2.4418                     | 235 |  |  |  |                        |
| 240                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -115.01                      | 1220.00                  | 1039.04                      | -0.0664                      | 2.8718                   | 2.4411                       | 240 | 2.4411                     | 240 |  |  |  |                        |
| 245                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -113.20                      | 1220.00                  | 1038.83                      | -0.0613                      | 2.8723                   | 2.4404                       | 245 | 2.4404                     | 245 |  |  |  |                        |
| 250                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -113.20                      | 1220.00                  | 1038.83                      | -0.0572                      | 2.8728                   | 2.4397                       | 250 | 2.4397                     | 250 |  |  |  |                        |
| 255                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -111.39                      | 1220.00                  | 1038.62                      | -0.0521                      | 2.8733                   | 2.4390                       | 255 | 2.4390                     | 255 |  |  |  |                        |
| 260                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -111.39                      | 1220.00                  | 1038.62                      | -0.0480                      | 2.8738                   | 2.4383                       | 260 | 2.4383                     | 260 |  |  |  |                        |
| 265                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -109.58                      | 1220.00                  | 1038.41                      | -0.0429                      | 2.8743                   | 2.4376                       | 265 | 2.4376                     | 265 |  |  |  |                        |
| 270                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -109.58                      | 1220.00                  | 1038.41                      | -0.0388                      | 2.8748                   | 2.4369                       | 270 | 2.4369                     | 270 |  |  |  |                        |
| 275                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -107.77                      | 1220.00                  | 1038.20                      | -0.0337                      | 2.8753                   | 2.4362                       | 275 | 2.4362                     | 275 |  |  |  |                        |
| 280                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -107.77                      | 1220.00                  | 1038.20                      | -0.0296                      | 2.8758                   | 2.4355                       | 280 | 2.4355                     | 280 |  |  |  |                        |
| 285                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -105.96                      | 1220.00                  | 1037.99                      | -0.0245                      | 2.8763                   | 2.4348                       | 285 | 2.4348                     | 285 |  |  |  |                        |
| 290                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -105.96                      | 1220.00                  | 1037.99                      | -0.0204                      | 2.8768                   | 2.4341                       | 290 | 2.4341                     | 290 |  |  |  |                        |
| 295                    | 0.0000                                    | 0.0000 | 0.01728                       | 7.441                                       | 7.441                                           | -104.15                      | 1220.00                  | 1037.78                      | -0                           |                          |                              |     |                            |     |  |  |  |                        |

TABLE 3. THERMODYNAMIC PROPERTIES OF WATER AT SATURATION\* (Continued)

| FAHR.<br>TEMP.<br>t (°F) | ABSOLUTE PRESSURE<br>p <sub>a</sub> |         | SPECIFIC VOLUME, CU FT PER LB |                          |                              | ENTHALPY, BTU PER LB          |                          |                              | ENTROPY, BTU PER (LB) (°F)    |                          |                              | FAHR.<br>TEMP.<br>t (°F) |
|--------------------------|-------------------------------------|---------|-------------------------------|--------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|--------------------------|
|                          | Lb/Sq In.                           | In. Hg  | Sat. Liquid<br>v <sub>l</sub> | Evap.<br>v <sub>fg</sub> | Sat. Vapor<br>v <sub>g</sub> | Sat. Liquid<br>h <sub>l</sub> | Evap.<br>h <sub>fg</sub> | Sat. Vapor<br>h <sub>g</sub> | Sat. Liquid<br>s <sub>l</sub> | Evap.<br>s <sub>fg</sub> | Sat. Vapor<br>s <sub>g</sub> |                          |
| 7                        | 0.03553                             | 0.05403 | 0.01743                       | 10480                    | 10480                        | -155.66                       | 1218.84                  | 1064.18                      | -0.3172                       | 2.6138                   | 2.2868                       | 7                        |
| 8                        | 0.03781                             | 0.05683 | 0.01743                       | 9979                     | 9979                         | -155.18                       | 1219.80                  | 1064.62                      | -0.3162                       | 2.6081                   | 2.2819                       | 8                        |
| 9                        | 0.03939                             | 0.05977 | 0.01744                       | 9607                     | 9607                         | -154.70                       | 1219.85                  | 1065.06                      | -0.3152                       | 2.6025                   | 2.2773                       | 9                        |
| 10                       | 0.04087                             | 0.06286 | 0.01744                       | 9300                     | 9300                         | -154.22                       | 1219.72                  | 1065.50                      | -0.3142                       | 2.5969                   | 2.2727                       | 10                       |
| 11                       | 0.04246                             | 0.06608 | 0.01744                       | 9046                     | 9046                         | -153.74                       | 1219.68                  | 1065.94                      | -0.3131                       | 2.5912                   | 2.2781                       | 11                       |
| 12                       | 0.04412                             | 0.06946 | 0.01744                       | 8824                     | 8824                         | -153.26                       | 1219.64                  | 1066.38                      | -0.3121                       | 2.5857                   | 2.2735                       | 12                       |
| 13                       | 0.04585                             | 0.07300 | 0.01744                       | 8621                     | 8621                         | -152.77                       | 1219.59                  | 1066.82                      | -0.3111                       | 2.5801                   | 2.2689                       | 13                       |
| 14                       | 0.04767                             | 0.07669 | 0.01744                       | 8436                     | 8436                         | -152.29                       | 1219.55                  | 1067.26                      | -0.3101                       | 2.5746                   | 2.2643                       | 14                       |
| 15                       | 0.04957                             | 0.08056 | 0.01744                       | 8264                     | 8264                         | -151.80                       | 1219.50                  | 1067.70                      | -0.3090                       | 2.5690                   | 2.2600                       | 15                       |
| 16                       | 0.05156                             | 0.08461 | 0.01745                       | 8104                     | 8104                         | -151.32                       | 1219.45                  | 1068.14                      | -0.3080                       | 2.5635                   | 2.2555                       | 16                       |
| 17                       | 0.05363                             | 0.08884 | 0.01745                       | 7956                     | 7956                         | -150.83                       | 1219.41                  | 1068.58                      | -0.3070                       | 2.5581                   | 2.2511                       | 17                       |
| 18                       | 0.05581                             | 0.09328 | 0.01745                       | 7819                     | 7819                         | -150.34                       | 1219.36                  | 1069.02                      | -0.3060                       | 2.5526                   | 2.2466                       | 18                       |
| 19                       | 0.05809                             | 0.09789 | 0.01745                       | 7692                     | 7692                         | -149.85                       | 1219.31                  | 1069.46                      | -0.3049                       | 2.5471                   | 2.2422                       | 19                       |
| 20                       | 0.06046                             | 0.10267 | 0.01745                       | 7574                     | 7574                         | -149.36                       | 1219.26                  | 1069.90                      | -0.3039                       | 2.5417                   | 2.2378                       | 20                       |
| 21                       | 0.06293                             | 0.1076  | 0.01745                       | 7465                     | 7465                         | -148.87                       | 1219.21                  | 1070.34                      | -0.3029                       | 2.5364                   | 2.2335                       | 21                       |
| 22                       | 0.06553                             | 0.11280 | 0.01746                       | 7364                     | 7364                         | -148.38                       | 1219.16                  | 1070.78                      | -0.3019                       | 2.5310                   | 2.2291                       | 22                       |
| 23                       | 0.06823                             | 0.1182  | 0.01746                       | 7271                     | 7271                         | -147.89                       | 1219.10                  | 1071.22                      | -0.3008                       | 2.5256                   | 2.2248                       | 23                       |
| 24                       | 0.07105                             | 0.1239  | 0.01746                       | 7185                     | 7185                         | -147.39                       | 1219.05                  | 1071.66                      | -0.2998                       | 2.5203                   | 2.2205                       | 24                       |
| 25                       | 0.07400                             | 0.1303  | 0.01746                       | 7105                     | 7105                         | -146.89                       | 1218.98                  | 1072.09                      | -0.2988                       | 2.5150                   | 2.2162                       | 25                       |
| 26                       | 0.07708                             | 0.1366  | 0.01746                       | 7031                     | 7031                         | -146.40                       | 1218.93                  | 1072.53                      | -0.2978                       | 2.5097                   | 2.2119                       | 26                       |
| 27                       | 0.08030                             | 0.1431  | 0.01746                       | 6962                     | 6962                         | -145.90                       | 1218.87                  | 1072.97                      | -0.2968                       | 2.5045                   | 2.2074                       | 27                       |
| 28                       | 0.08364                             | 0.1500  | 0.01747                       | 6898                     | 6898                         | -145.40                       | 1218.81                  | 1073.41                      | -0.2957                       | 2.4991                   | 2.2034                       | 28                       |
| 29                       | 0.08715                             | 0.1571  | 0.01747                       | 6839                     | 6839                         | -144.90                       | 1218.75                  | 1073.85                      | -0.2947                       | 2.4939                   | 2.1992                       | 29                       |
| 30                       | 0.09080                             | 0.1646  | 0.01747                       | 6784                     | 6784                         | -144.40                       | 1218.69                  | 1074.29                      | -0.2937                       | 2.4887                   | 2.1950                       | 30                       |
| 31                       | 0.09461                             | 0.1723  | 0.01747                       | 6733                     | 6733                         | -143.90                       | 1218.63                  | 1074.73                      | -0.2927                       | 2.4835                   | 2.1908                       | 31                       |
| 32                       | 0.09858                             | 0.1803  | 0.01747                       | 6685                     | 6685                         | -143.40                       | 1218.56                  | 1075.16                      | -0.2916                       | 2.4783                   | 2.1867                       | 32                       |
| *32                      | 0.098586                            | 0.18036 | 0.01602                       | 3304.6                   | 3304.6                       | 0.00                          | 1075.16                  | 1075.16                      | 0.00000                       | 2.1867                   | 2.1867                       | *32                      |

\* Compiled by John A. Goff and S. Gratch.

\* Extrapolated to represent metastable equilibrium with undercooled liquid.

TABLE 3. THERMODYNAMIC PROPERTIES OF WATER AT SATURATION\* (Continued)

| FAHR.<br>TEMP.<br>t (°F) | ABSOLUTE PRESSURE<br>p <sub>a</sub> |         | SPECIFIC VOLUME, CU FT PER LB |                          |                              | ENTHALPY, BTU PER LB          |                          |                              | ENTROPY, BTU PER (LB) (°F)    |                          |                              | FAHR.<br>TEMP.<br>t (°F) |
|--------------------------|-------------------------------------|---------|-------------------------------|--------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|--------------------------|
|                          | Lb/Sq In.                           | In. Hg  | Sat. Liquid<br>v <sub>l</sub> | Evap.<br>v <sub>fg</sub> | Sat. Vapor<br>v <sub>g</sub> | Sat. Liquid<br>h <sub>l</sub> | Evap.<br>h <sub>fg</sub> | Sat. Vapor<br>h <sub>g</sub> | Sat. Liquid<br>s <sub>l</sub> | Evap.<br>s <sub>fg</sub> | Sat. Vapor<br>s <sub>g</sub> |                          |
| *33                      | 0.098586                            | 0.18036 | 0.01602                       | 3304.6                   | 3304.6                       | 0.00                          | 1075.16                  | 1075.16                      | 0.00000                       | 2.1867                   | 2.1867                       | *33                      |
| 33                       | 0.099227                            | 0.18778 | 0.01602                       | 3180.5                   | 3180.5                       | 1.01                          | 1074.93                  | 1075.94                      | 0.00235                       | 2.1811                   | 2.1831                       | 33                       |
| 34                       | 0.099999                            | 0.19546 | 0.01602                       | 3061.7                   | 3061.7                       | 2.01                          | 1074.68                  | 1076.69                      | 0.00458                       | 2.1756                   | 2.1776                       | 34                       |
| 35                       | 0.100808                            | 0.20342 | 0.01602                       | 2947.8                   | 2947.8                       | 3.02                          | 1074.43                  | 1076.44                      | 0.00681                       | 2.1700                   | 2.1720                       | 35                       |
| 36                       | 0.101656                            | 0.21166 | 0.01602                       | 2838.7                   | 2838.7                       | 4.03                          | 1074.18                  | 1076.19                      | 0.00904                       | 2.1644                   | 2.1664                       | 36                       |
| 37                       | 0.102545                            | 0.22020 | 0.01602                       | 2734.1                   | 2734.1                       | 5.03                          | 1073.93                  | 1075.94                      | 0.01127                       | 2.1588                   | 2.1608                       | 37                       |
| 38                       | 0.103476                            | 0.22904 | 0.01602                       | 2633.8                   | 2633.8                       | 6.03                          | 1073.68                  | 1075.69                      | 0.01350                       | 2.1532                   | 2.1552                       | 38                       |
| 39                       | 0.104449                            | 0.23819 | 0.01602                       | 2537.6                   | 2537.6                       | 7.04                          | 1073.43                  | 1075.44                      | 0.01573                       | 2.1476                   | 2.1496                       | 39                       |
| 40                       | 0.105464                            | 0.24767 | 0.01602                       | 2445.4                   | 2445.4                       | 8.04                          | 1073.18                  | 1075.19                      | 0.01796                       | 2.1420                   | 2.1440                       | 40                       |
| 41                       | 0.106519                            | 0.25748 | 0.01602                       | 2356.9                   | 2356.9                       | 9.05                          | 1072.93                  | 1074.94                      | 0.02019                       | 2.1364                   | 2.1384                       | 41                       |
| 42                       | 0.107614                            | 0.26763 | 0.01602                       | 2272.0                   | 2272.0                       | 10.05                         | 1072.68                  | 1074.69                      | 0.02242                       | 2.1308                   | 2.1328                       | 42                       |
| 43                       | 0.108750                            | 0.27813 | 0.01602                       | 2190.5                   | 2190.5                       | 11.05                         | 1072.43                  | 1074.44                      | 0.02465                       | 2.1252                   | 2.1272                       | 43                       |
| 44                       | 0.109926                            | 0.28899 | 0.01602                       | 2112.3                   | 2112.3                       | 12.06                         | 1072.18                  | 1074.19                      | 0.02688                       | 2.1196                   | 2.1216                       | 44                       |
| 45                       | 0.111142                            | 0.30023 | 0.01602                       | 2037.3                   | 2037.3                       | 13.06                         | 1071.93                  | 1073.94                      | 0.02911                       | 2.1140                   | 2.1160                       | 45                       |
| 46                       | 0.112407                            | 0.31185 | 0.01602                       | 1965.2                   | 1965.2                       | 14.06                         | 1071.68                  | 1073.69                      | 0.03134                       | 2.1084                   | 2.1104                       | 46                       |
| 47                       | 0.113719                            | 0.32387 | 0.01602                       | 1896.0                   | 1896.0                       | 15.06                         | 1071.43                  | 1073.44                      | 0.03357                       | 2.1028                   | 2.1048                       | 47                       |
| 48                       | 0.115078                            | 0.33629 | 0.01602                       | 1829.5                   | 1829.5                       | 16.07                         | 1071.18                  | 1073.19                      | 0.03580                       | 2.0972                   | 2.0992                       | 48                       |
| 49                       | 0.116474                            | 0.34913 | 0.01602                       | 1765.7                   | 1765.7                       | 17.07                         | 1070.93                  | 1072.94                      | 0.03803                       | 2.0916                   | 2.0936                       | 49                       |
| 50                       | 0.117907                            | 0.36240 | 0.01602                       | 1704.3                   | 1704.3                       | 18.07                         | 1070.68                  | 1072.69                      | 0.04026                       | 2.0860                   | 2.0880                       | 50                       |
| 51                       | 0.119378                            | 0.37611 | 0.01602                       | 1645.4                   | 1645.4                       | 19.07                         | 1070.43                  | 1072.44                      | 0.04249                       | 2.0804                   | 2.0824                       | 51                       |
| 52                       | 0.120894                            | 0.39028 | 0.01602                       | 1588.7                   | 1588.7                       | 20.07                         | 1070.18                  | 1072.19                      | 0.04472                       | 2.0748                   | 2.0768                       | 52                       |
| 53                       | 0.122454                            | 0.40492 | 0.01603                       | 1534.3                   | 1534.3                       | 21.07                         | 1069.93                  | 1071.94                      | 0.04695                       | 2.0692                   | 2.0712                       | 53                       |
| 54                       | 0.124058                            | 0.42003 | 0.01603                       | 1481.9                   | 1481.9                       | 22.08                         | 1069.68                  | 1071.69                      | 0.04918                       | 2.0636                   | 2.0656                       | 54                       |
| 55                       | 0.125707                            | 0.43564 | 0.01603                       | 1431.5                   | 1431.5                       | 23.08                         | 1069.43                  | 1071.44                      | 0.05141                       | 2.0580                   | 2.0600                       | 55                       |
| 56                       | 0.127401                            | 0.45176 | 0.01603                       | 1383.1                   | 1383.1                       | 24.08                         | 1069.18                  | 1071.19                      | 0.05364                       | 2.0524                   | 2.0544                       | 56                       |
| 57                       | 0.129140                            | 0.46840 | 0.01603                       | 1336.5                   | 1336.5                       | 25.08                         | 1068.93                  | 1070.94                      | 0.05587                       | 2.0468                   | 2.0488                       | 57                       |
| 58                       | 0.130924                            | 0.48558 | 0.01603                       | 1291.7                   | 1291.7                       | 26.08                         | 1068.68                  | 1070.69                      | 0.05810                       | 2.0412                   | 2.0432                       | 58                       |
| 59                       | 0.132754                            | 0.50330 | 0.01603                       | 1248.6                   | 1248.6                       | 27.08                         | 1068.43                  | 1070.44                      | 0.06033                       | 2.0356                   | 2.0376                       | 59                       |
| 60                       | 0.134630                            | 0.52160 | 0.01603                       | 1207.1                   | 1207.1                       | 28.08                         | 1068.18                  | 1070.19                      | 0.06256                       | 2.0300                   | 2.0320                       | 60                       |
| 61                       | 0.136554                            | 0.54047 | 0.01604                       | 1167.2                   | 1167.2                       | 29.08                         | 1067.93                  | 1069.94                      | 0.06479                       | 2.0244                   | 2.0264                       | 61                       |

\* Compiled by John A. Goff and S. Gratch.

\* Extrapolated to represent metastable equilibrium with undercooled liquid.

TABLE 3. THERMODYNAMIC PROPERTIES OF WATER AT SATURATION\* (Continued)

| FAHR.<br>TEMP.<br>t (F) | ABSOLUTE PRESSURE<br>P <sub>a</sub> |        | SPECIFIC VOLUME, CU FT PER LB |                          |                              |                               | ENTHALPY, BTU PER LB     |                              |                               |                          | ENTROPY, BTU PER (LB) (°F)   |    |  |  | FAHR.<br>TEMP.<br>t (F) |
|-------------------------|-------------------------------------|--------|-------------------------------|--------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|----|--|--|-------------------------|
|                         | Lb/Sq In.                           | In. Hg | Sat. Liquid<br>v <sub>l</sub> | Evap.<br>v <sub>lg</sub> | Sat. Vapor<br>v <sub>g</sub> | Sat. Liquid<br>h <sub>l</sub> | Evap.<br>h <sub>lg</sub> | Sat. Vapor<br>h <sub>g</sub> | Sat. Liquid<br>s <sub>l</sub> | Evap.<br>s <sub>lg</sub> | Sat. Vapor<br>s <sub>g</sub> |    |  |  |                         |
| 82                      | 0.2702                              | 0.4894 | 0.01604                       | 1128.7                   | 1128.7                       | 80.08                         | 1058.22                  | 1058.22                      | 0.05637                       | 2.0284                   | 2.0876                       | 62 |  |  |                         |
| 83                      | 0.2848                              | 0.5004 | 0.01604                       | 1091.7                   | 1091.7                       | 81.08                         | 1057.65                  | 1058.73                      | 0.06129                       | 2.0235                   | 2.0846                       | 63 |  |  |                         |
| 84                      | 0.2986                              | 0.5097 | 0.01604                       | 1056.1                   | 1056.1                       | 82.08                         | 1057.09                  | 1059.17                      | 0.06320                       | 2.0186                   | 2.0816                       | 64 |  |  |                         |
| 85                      | 0.3064                              | 0.5170 | 0.01604                       | 1021.7                   | 1021.7                       | 83.08                         | 1056.52                  | 1060.80                      | 0.06510                       | 2.0136                   | 2.0787                       | 65 |  |  |                         |
| 86                      | 0.3153                              | 0.5241 | 0.01604                       | 988.53                   | 988.53                       | 84.07                         | 1055.97                  | 1065.04                      | 0.06700                       | 2.0087                   | 2.0757                       | 66 |  |  |                         |
| 87                      | 0.3270                              | 0.5305 | 0.01605                       | 955.35                   | 955.35                       | 85.07                         | 1055.40                  | 1069.47                      | 0.06890                       | 2.0039                   | 2.0728                       | 67 |  |  |                         |
| 88                      | 0.3390                              | 0.5369 | 0.01605                       | 922.08                   | 922.08                       | 86.07                         | 1054.84                  | 1073.91                      | 0.07080                       | 1.9990                   | 2.0698                       | 68 |  |  |                         |
| 89                      | 0.3504                              | 0.5429 | 0.01605                       | 889.49                   | 889.49                       | 87.07                         | 1054.27                  | 1078.34                      | 0.07269                       | 1.9941                   | 2.0668                       | 69 |  |  |                         |
| 90                      | 0.3614                              | 0.5486 | 0.01605                       | 856.73                   | 856.73                       | 88.07                         | 1053.71                  | 1082.76                      | 0.07459                       | 1.9892                   | 2.0638                       | 70 |  |  |                         |
| 91                      | 0.3751                              | 0.5547 | 0.01605                       | 824.47                   | 824.47                       | 89.07                         | 1053.14                  | 1087.19                      | 0.07646                       | 1.9845                   | 2.0610                       | 71 |  |  |                         |
| 92                      | 0.3856                              | 0.5611 | 0.01606                       | 793.95                   | 793.95                       | 90.07                         | 1052.58                  | 1091.65                      | 0.07834                       | 1.9797                   | 2.0582                       | 72 |  |  |                         |
| 93                      | 0.4190                              | 0.5829 | 0.01606                       | 768.40                   | 768.40                       | 91.07                         | 1052.01                  | 1096.08                      | 0.08022                       | 1.9749                   | 2.0551                       | 73 |  |  |                         |
| 94                      | 0.4374                              | 0.5934 | 0.01606                       | 738.97                   | 738.97                       | 92.07                         | 1051.44                  | 1099.53                      | 0.08210                       | 1.9701                   | 2.0522                       | 74 |  |  |                         |
| 95                      | 0.4570                              | 0.6047 | 0.01607                       | 717.01                   | 717.01                       | 93.07                         | 1050.89                  | 1103.95                      | 0.08398                       | 1.9654                   | 2.0493                       | 75 |  |  |                         |
| 96                      | 0.4443                              | 0.6047 | 0.01606                       | 717.01                   | 717.01                       | 94.06                         | 1050.32                  | 1094.38                      | 0.08582                       | 1.9607                   | 2.0465                       | 76 |  |  |                         |
| 97                      | 0.4535                              | 0.6324 | 0.01607                       | 694.68                   | 694.68                       | 95.09                         | 1049.76                  | 1094.82                      | 0.08769                       | 1.9560                   | 2.0437                       | 77 |  |  |                         |
| 98                      | 0.4778                              | 0.6722 | 0.01607                       | 672.52                   | 672.52                       | 96.08                         | 1049.19                  | 1095.25                      | 0.08954                       | 1.9513                   | 2.0408                       | 78 |  |  |                         |
| 99                      | 0.4970                              | 0.7120 | 0.01608                       | 650.36                   | 650.36                       | 97.07                         | 1048.62                  | 1095.68                      | 0.09139                       | 1.9466                   | 2.0379                       | 79 |  |  |                         |
| 80                      | 0.5070                              | 0.7337 | 0.01607                       | 633.01                   | 633.01                       | 98.05                         | 1048.07                  | 1096.13                      | 0.09323                       | 1.9419                   | 2.0350                       | 80 |  |  |                         |
| 81                      | 0.5232                              | 0.7613 | 0.01608                       | 613.80                   | 613.82                       | 99.05                         | 1047.50                  | 1096.55                      | 0.09508                       | 1.9373                   | 2.0324                       | 81 |  |  |                         |
| 82                      | 0.5411                              | 1.1017 | 0.01608                       | 595.26                   | 595.27                       | 90.05                         | 1046.93                  | 1096.98                      | 0.09694                       | 1.9328                   | 2.0297                       | 82 |  |  |                         |
| 83                      | 0.5675                              | 1.1762 | 0.01608                       | 570.04                   | 570.05                       | 91.05                         | 1046.36                  | 1097.38                      | 0.09879                       | 1.9281                   | 2.0270                       | 83 |  |  |                         |
| 84                      | 0.5772                              | 1.2136 | 0.01608                       | 550.04                   | 550.05                       | 92.05                         | 1045.80                  | 1097.83                      | 0.10062                       | 1.9233                   | 2.0242                       | 84 |  |  |                         |
| 85                      | 0.6004                              | 1.2586 | 0.01609                       | 534.25                   | 534.25                       | 93.05                         | 1045.23                  | 1098.28                      | 0.10246                       | 1.9189                   | 2.0214                       | 85 |  |  |                         |
| 86                      | 0.6160                              | 1.2530 | 0.01609                       | 527.19                   | 527.21                       | 94.04                         | 1044.67                  | 1098.71                      | 0.10429                       | 1.9144                   | 2.0187                       | 86 |  |  |                         |
| 87                      | 0.6350                              | 1.2935 | 0.01609                       | 511.40                   | 511.62                       | 95.04                         | 1044.10                  | 1099.14                      | 0.10611                       | 1.9099                   | 2.0160                       | 87 |  |  |                         |
| 88                      | 0.6575                              | 1.3331 | 0.01610                       | 496.25                   | 496.54                       | 96.04                         | 1043.54                  | 1099.58                      | 0.10794                       | 1.9054                   | 2.0133                       | 88 |  |  |                         |
| 89                      | 0.6767                              | 1.3779 | 0.01610                       | 481.95                   | 481.98                       | 97.04                         | 1042.97                  | 1100.01                      | 0.10976                       | 1.9008                   | 2.0105                       | 89 |  |  |                         |
| 90                      | 0.6935                              | 1.4219 | 0.01610                       | 467.88                   | 467.90                       | 98.04                         | 1042.40                  | 1100.44                      | 0.11159                       | 1.8963                   | 2.0077                       | 90 |  |  |                         |
| 91                      | 0.72059                             | 1.4671 | 0.01610                       | 454.26                   | 454.28                       | 99.03                         | 1041.84                  | 1100.87                      | 0.11359                       | 1.8917                   | 2.0053                       | 91 |  |  |                         |

TABLE 3. THERMODYNAMIC PROPERTIES OF WATER AT SATURATION\* (Continued)

| FAHR.<br>TEMP.<br>t (°F) | ABSOLUTE PRESSURE<br>p <sub>a</sub> |        | SPECIFIC VOLUME, CU FT PER LB |                          |                              |                              | ENTHALPY, BTU PER LB          |                          |                              |                               | ENTROPY, BTU PER (LB) (°F) |                              |                          |  |
|--------------------------|-------------------------------------|--------|-------------------------------|--------------------------|------------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|-------------------------------|----------------------------|------------------------------|--------------------------|--|
|                          | Lb/Sq. In.                          | In. Hg | Sat. Liquid<br>v <sub>f</sub> | Evap.<br>v <sub>fg</sub> | Sat. Vapor<br>v <sub>g</sub> | Sat. Vapor<br>v <sub>g</sub> | Sat. Liquid<br>h <sub>f</sub> | Evap.<br>h <sub>fg</sub> | Sat. Vapor<br>h <sub>g</sub> | Sat. Liquid<br>s <sub>f</sub> | Evap.<br>s <sub>fg</sub>   | Sat. Vapor<br>s <sub>g</sub> | FAHR.<br>TEMP.<br>t (°F) |  |
| 122                      | 1.7997                              | 3.6439 | 0.01931                       | 192.85                   | 192.87                       | 99.98                        | 1024.12                       | 1024.12                  | 1114.10                      | 0.16803                       | 1.7606                     | 1.9286                       | 122                      |  |
| 123                      | 1.8396                              | 3.7466 | 0.01932                       | 187.93                   | 187.95                       | 99.98                        | 1023.54                       | 1023.54                  | 1114.52                      | 0.16807                       | 1.7556                     | 1.9284                       | 123                      |  |
| 124                      | 1.8807                              | 3.8496 | 0.01933                       | 183.15                   | 183.17                       | 99.98                        | 1022.96                       | 1022.96                  | 1114.94                      | 0.16811                       | 1.7506                     | 1.9281                       | 124                      |  |
| 125                      | 1.9330                              | 3.9531 | 0.01934                       | 178.51                   | 178.53                       | 99.98                        | 1022.39                       | 1022.39                  | 1115.37                      | 0.16815                       | 1.7456                     | 1.9278                       | 125                      |  |
| 126                      | 1.9966                              | 4.0581 | 0.01935                       | 174.00                   | 174.02                       | 99.98                        | 1021.81                       | 1021.81                  | 1115.79                      | 0.16819                       | 1.7406                     | 1.9275                       | 126                      |  |
| 127                      | 2.0514                              | 4.1768 | 0.01936                       | 169.63                   | 169.65                       | 99.97                        | 1021.24                       | 1021.24                  | 1116.21                      | 0.16823                       | 1.7357                     | 1.9272                       | 127                      |  |
| 128                      | 2.1075                              | 4.2910 | 0.01937                       | 165.38                   | 165.40                       | 99.97                        | 1020.66                       | 1020.66                  | 1116.63                      | 0.16827                       | 1.7307                     | 1.9269                       | 128                      |  |
| 129                      | 2.1649                              | 4.4078 | 0.01938                       | 161.25                   | 161.28                       | 99.97                        | 1020.08                       | 1020.08                  | 1117.05                      | 0.16831                       | 1.7257                     | 1.9266                       | 129                      |  |
| 130                      | 2.2237                              | 4.5274 | 0.01939                       | 157.25                   | 157.27                       | 99.97                        | 1019.50                       | 1019.50                  | 1117.47                      | 0.16835                       | 1.7207                     | 1.9263                       | 130                      |  |
| 131                      | 2.2838                              | 4.6498 | 0.01940                       | 153.36                   | 153.38                       | 99.97                        | 1018.92                       | 1018.92                  | 1117.89                      | 0.16839                       | 1.7157                     | 1.9260                       | 131                      |  |
| 132                      | 2.3452                              | 4.7750 | 0.01941                       | 149.58                   | 149.60                       | 99.97                        | 1018.34                       | 1018.34                  | 1118.31                      | 0.16843                       | 1.7107                     | 1.9257                       | 132                      |  |
| 133                      | 2.4081                              | 4.9030 | 0.01942                       | 145.91                   | 145.93                       | 100.97                       | 1017.76                       | 1017.76                  | 1118.73                      | 0.16847                       | 1.7057                     | 1.9254                       | 133                      |  |
| 134                      | 2.4725                              | 5.0340 | 0.01943                       | 142.34                   | 142.36                       | 100.97                       | 1017.18                       | 1017.18                  | 1119.15                      | 0.16851                       | 1.7007                     | 1.9251                       | 134                      |  |
| 135                      | 2.5382                              | 5.1679 | 0.01944                       | 138.87                   | 138.89                       | 100.97                       | 1016.60                       | 1016.60                  | 1119.58                      | 0.16855                       | 1.6957                     | 1.9248                       | 135                      |  |
| 136                      | 2.6055                              | 5.3046 | 0.01945                       | 135.50                   | 135.52                       | 100.97                       | 1016.01                       | 1016.01                  | 1119.99                      | 0.16859                       | 1.6907                     | 1.9245                       | 136                      |  |
| 137                      | 2.6745                              | 5.4450 | 0.01946                       | 132.22                   | 132.24                       | 100.97                       | 1015.43                       | 1015.43                  | 1120.40                      | 0.16863                       | 1.6857                     | 1.9242                       | 137                      |  |
| 138                      | 2.7446                              | 5.5891 | 0.01947                       | 129.04                   | 129.06                       | 100.97                       | 1014.85                       | 1014.85                  | 1120.82                      | 0.16867                       | 1.6807                     | 1.9239                       | 138                      |  |
| 139                      | 2.8166                              | 5.7365 | 0.01948                       | 125.94                   | 125.96                       | 100.97                       | 1014.26                       | 1014.26                  | 1121.24                      | 0.16871                       | 1.6757                     | 1.9236                       | 139                      |  |
| 140                      | 2.8900                              | 5.8872 | 0.01949                       | 122.94                   | 122.96                       | 100.97                       | 1013.68                       | 1013.68                  | 1121.65                      | 0.16875                       | 1.6707                     | 1.9233                       | 140                      |  |
| 141                      | 2.9651                              | 6.0411 | 0.01950                       | 120.01                   | 120.03                       | 100.96                       | 1013.10                       | 1013.10                  | 1122.07                      | 0.16879                       | 1.6657                     | 1.9230                       | 141                      |  |
| 142                      | 3.0419                              | 6.1984 | 0.01951                       | 117.16                   | 117.18                       | 100.96                       | 1012.52                       | 1012.52                  | 1122.48                      | 0.16883                       | 1.6607                     | 1.9227                       | 142                      |  |
| 143                      | 3.1204                              | 6.3592 | 0.01952                       | 114.40                   | 114.42                       | 100.96                       | 1011.94                       | 1011.94                  | 1122.89                      | 0.16887                       | 1.6557                     | 1.9224                       | 143                      |  |
| 144                      | 3.2006                              | 6.5234 | 0.01953                       | 111.70                   | 111.72                       | 100.96                       | 1011.36                       | 1011.36                  | 1123.31                      | 0.16891                       | 1.6507                     | 1.9221                       | 144                      |  |
| 145                      | 3.2825                              | 6.6912 | 0.01954                       | 109.09                   | 109.11                       | 100.96                       | 1010.78                       | 1010.77                  | 1123.73                      | 0.16895                       | 1.6457                     | 1.9218                       | 145                      |  |
| 146                      | 3.3662                              | 6.8626 | 0.01955                       | 106.54                   | 106.56                       | 100.96                       | 1010.20                       | 1010.19                  | 1124.14                      | 0.16899                       | 1.6407                     | 1.9215                       | 146                      |  |
| 147                      | 3.4517                              | 7.0377 | 0.01956                       | 104.06                   | 104.08                       | 100.96                       | 1009.62                       | 1009.60                  | 1124.55                      | 0.16903                       | 1.6357                     | 1.9212                       | 147                      |  |
| 148                      | 3.5390                              | 7.2166 | 0.01957                       | 101.65                   | 101.67                       | 100.96                       | 1009.04                       | 1009.02                  | 1124.97                      | 0.16907                       | 1.6307                     | 1.9209                       | 148                      |  |
| 149                      | 3.6282                              | 7.3992 | 0.01958                       | 99.309                   | 99.322                       | 100.96                       | 1008.46                       | 1008.44                  | 1125.38                      | 0.16911                       | 1.6257                     | 1.9206                       | 149                      |  |
| 150                      | 3.7194                              | 7.5857 | 0.01959                       | 97.022                   | 97.035                       | 100.96                       | 1007.88                       | 1007.83                  | 1125.79                      | 0.16915                       | 1.6207                     | 1.9203                       | 150                      |  |
| 151                      | 3.8124                              | 7.7762 | 0.01960                       | 94.799                   | 94.813                       | 100.96                       | 1007.30                       | 1007.24                  | 1126.20                      | 0.16919                       | 1.6157                     | 1.9200                       | 151                      |  |

\* Compiled by John A. Goff and S. Gratch.

TABLE 3. THERMODYNAMIC PROPERTIES OF WATER AT SATURATION\* (Continued)

| FAHR.<br>TEMP.<br>(°F) | ABSOLUTE PRESSURE<br>P <sub>a</sub> |        | SPECIFIC VOLUME CU FT PER LB. |                          |                              |                              | ENTHALPY, BTU PER LB          |                          |                              |                               | ENTROPY, BTU PER (LB) (°F) |                              |  |  | FAHR.<br>TEMP.<br>(°F) |
|------------------------|-------------------------------------|--------|-------------------------------|--------------------------|------------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|-------------------------------|----------------------------|------------------------------|--|--|------------------------|
|                        | Lb/Sq In.                           | In. Hg | Sat. Liquid<br>v <sub>f</sub> | Evap.<br>v <sub>fg</sub> | Sat. Vapor<br>v <sub>g</sub> | Sat. Vapor<br>v <sub>g</sub> | Sat. Liquid<br>h <sub>f</sub> | Evap.<br>h <sub>fg</sub> | Sat. Vapor<br>h <sub>g</sub> | Sat. Liquid<br>s <sub>f</sub> | Evap.<br>s <sub>fg</sub>   | Sat. Vapor<br>s <sub>g</sub> |  |  |                        |
| 152                    | 3.9074                              | 7.9556 | 0.01635                       | 92.635                   | 92.651                       | 119.96                       | 1006.66                       | 1126.62                  | 0.21830                      | 1.6457                        | 1.9200                     | 152                          |  |  |                        |
| 153                    | 4.0044                              | 8.1532 | 0.01636                       | 90.528                   | 90.544                       | 120.97                       | 1006.06                       | 1127.03                  | 0.21834                      | 1.6407                        | 1.9197                     | 153                          |  |  |                        |
| 154                    | 4.1035                              | 8.3549 | 0.01636                       | 88.477                   | 88.493                       | 121.97                       | 1005.47                       | 1127.44                  | 0.21838                      | 1.6357                        | 1.9194                     | 154                          |  |  |                        |
| 155                    | 4.2046                              | 8.5596 | 0.01637                       | 86.480                   | 86.496                       | 122.97                       | 1004.88                       | 1127.85                  | 0.21842                      | 1.6307                        | 1.9191                     | 155                          |  |  |                        |
| 156                    | 4.3078                              | 8.7668 | 0.01637                       | 84.536                   | 84.552                       | 123.97                       | 1004.29                       | 1128.26                  | 0.21846                      | 1.6257                        | 1.9188                     | 156                          |  |  |                        |
| 157                    | 4.4132                              | 8.9853 | 0.01638                       | 82.642                   | 82.658                       | 124.97                       | 1003.70                       | 1128.67                  | 0.21850                      | 1.6207                        | 1.9185                     | 157                          |  |  |                        |
| 158                    | 4.5207                              | 9.2052 | 0.01638                       | 80.798                   | 80.814                       | 125.97                       | 1003.11                       | 1129.08                  | 0.21854                      | 1.6157                        | 1.9182                     | 158                          |  |  |                        |
| 159                    | 4.6304                              | 9.4274 | 0.01639                       | 79.001                   | 79.017                       | 126.97                       | 1002.51                       | 1129.49                  | 0.21858                      | 1.6107                        | 1.9179                     | 159                          |  |  |                        |
| 160                    | 4.7424                              | 9.6520 | 0.01640                       | 77.250                   | 77.266                       | 127.97                       | 1001.92                       | 1129.90                  | 0.21862                      | 1.6057                        | 1.9176                     | 160                          |  |  |                        |
| 161                    | 4.8566                              | 9.8892 | 0.01640                       | 75.546                   | 75.562                       | 128.97                       | 1001.33                       | 1130.31                  | 0.21866                      | 1.6007                        | 1.9173                     | 161                          |  |  |                        |
| 162                    | 4.9732                              | 10.129 | 0.01640                       | 73.885                   | 73.901                       | 129.97                       | 1000.74                       | 1130.71                  | 0.21870                      | 1.5957                        | 1.9170                     | 162                          |  |  |                        |
| 163                    | 5.0921                              | 10.368 | 0.01641                       | 72.267                   | 72.283                       | 130.98                       | 1000.15                       | 1131.11                  | 0.21874                      | 1.5907                        | 1.9167                     | 163                          |  |  |                        |
| 164                    | 5.2144                              | 10.610 | 0.01641                       | 70.690                   | 70.706                       | 131.98                       | 999.56                        | 1131.52                  | 0.21878                      | 1.5857                        | 1.9164                     | 164                          |  |  |                        |
| 165                    | 5.3372                              | 10.857 | 0.01642                       | 69.153                   | 69.169                       | 132.98                       | 998.97                        | 1131.93                  | 0.21882                      | 1.5807                        | 1.9161                     | 165                          |  |  |                        |
| 166                    | 5.4634                              | 11.124 | 0.01643                       | 67.654                   | 67.670                       | 133.98                       | 998.38                        | 1132.33                  | 0.21886                      | 1.5757                        | 1.9158                     | 166                          |  |  |                        |
| 167                    | 5.5921                              | 11.398 | 0.01643                       | 66.194                   | 66.210                       | 134.98                       | 997.79                        | 1132.73                  | 0.21890                      | 1.5707                        | 1.9155                     | 167                          |  |  |                        |
| 168                    | 5.7233                              | 11.683 | 0.01644                       | 64.763                   | 64.779                       | 135.98                       | 997.20                        | 1133.14                  | 0.21894                      | 1.5657                        | 1.9152                     | 168                          |  |  |                        |
| 169                    | 5.8566                              | 11.972 | 0.01644                       | 63.360                   | 63.376                       | 136.98                       | 996.61                        | 1133.54                  | 0.21898                      | 1.5607                        | 1.9149                     | 169                          |  |  |                        |
| 170                    | 5.9936                              | 12.265 | 0.01645                       | 62.029                   | 62.045                       | 137.98                       | 996.02                        | 1133.95                  | 0.21902                      | 1.5557                        | 1.9146                     | 170                          |  |  |                        |
| 171                    | 6.1358                              | 12.562 | 0.01645                       | 60.770                   | 60.786                       | 138.98                       | 995.43                        | 1134.35                  | 0.21906                      | 1.5507                        | 1.9143                     | 171                          |  |  |                        |
| 172                    | 6.2746                              | 12.775 | 0.01646                       | 59.582                   | 59.598                       | 139.99                       | 994.84                        | 1134.76                  | 0.21910                      | 1.5457                        | 1.9140                     | 172                          |  |  |                        |
| 173                    | 6.4182                              | 13.000 | 0.01646                       | 58.423                   | 58.439                       | 141.00                       | 994.25                        | 1135.16                  | 0.21914                      | 1.5407                        | 1.9137                     | 173                          |  |  |                        |
| 174                    | 6.5668                              | 13.228 | 0.01647                       | 57.290                   | 57.306                       | 142.00                       | 993.66                        | 1135.57                  | 0.21918                      | 1.5357                        | 1.9134                     | 174                          |  |  |                        |
| 175                    | 6.7198                              | 13.470 | 0.01647                       | 56.184                   | 56.199                       | 143.00                       | 993.07                        | 1135.97                  | 0.21922                      | 1.5307                        | 1.9131                     | 175                          |  |  |                        |
| 176                    | 6.8699                              | 13.676 | 0.01648                       | 55.104                   | 55.119                       | 144.00                       | 992.48                        | 1136.38                  | 0.21926                      | 1.5257                        | 1.9128                     | 176                          |  |  |                        |
| 177                    | 7.0259                              | 14.305 | 0.01648                       | 54.046                   | 54.062                       | 145.00                       | 991.89                        | 1136.78                  | 0.21930                      | 1.5207                        | 1.9125                     | 177                          |  |  |                        |
| 178                    | 7.1879                              | 14.959 | 0.01649                       | 53.009                   | 53.025                       | 146.01                       | 991.30                        | 1137.19                  | 0.21934                      | 1.5157                        | 1.9122                     | 178                          |  |  |                        |
| 179                    | 7.3559                              | 15.630 | 0.01650                       | 52.000                   | 52.016                       | 147.01                       | 990.71                        | 1137.59                  | 0.21938                      | 1.5107                        | 1.9119                     | 179                          |  |  |                        |
| 180                    | 7.5199                              | 15.995 | 0.01651                       | 51.016                   | 51.032                       | 148.01                       | 990.12                        | 1138.00                  | 0.21942                      | 1.5057                        | 1.9116                     | 180                          |  |  |                        |
| 181                    | 7.6801                              | 15.637 | 0.01651                       | 50.053                   | 50.069                       | 149.02                       | 989.53                        | 1138.40                  | 0.21946                      | 1.5007                        | 1.9113                     | 181                          |  |  |                        |

\* Compiled by John A. Goff and S. Gratch.

TABLE 3. THERMODYNAMIC PROPERTIES OF WATER AT SATURATION\* (Continued)

| Fah.<br>Temp.<br>(°F) | Abs.<br>Press.<br>psia | Specific Volume, cu ft per lb |                   |                     | Enthalpy, Btu per lb |                   |                     | Entropy, Btu per (lb) (°F) |                   |                     | Fah.<br>Temp.<br>(°F) |
|-----------------------|------------------------|-------------------------------|-------------------|---------------------|----------------------|-------------------|---------------------|----------------------------|-------------------|---------------------|-----------------------|
|                       |                        | Sat. Liquid<br>$v_f$          | Evap.<br>$v_{fg}$ | Sat. Vapor<br>$v_g$ | Sat. Liquid<br>$h_f$ | Evap.<br>$h_{fg}$ | Sat. Vapor<br>$h_g$ | Sat. Liquid<br>$s_f$       | Evap.<br>$s_{fg}$ | Sat. Vapor<br>$s_g$ |                       |
| 122                   | 1.7897                 | 0.01621                       | 192.85            | 89.98               | 192.87               | 1034.12           | 1114.10             | 0.16035                    | 1.7695            | 1.9293              | 122                   |
| 123                   | 1.8306                 | 0.01622                       | 187.15            | 90.18               | 197.17               | 1034.12           | 1114.32             | 0.16037                    | 1.7695            | 1.9294              | 123                   |
| 124                   | 1.8715                 | 0.01623                       | 181.45            | 90.38               | 201.47               | 1034.12           | 1114.54             | 0.16039                    | 1.7695            | 1.9295              | 124                   |
| 125                   | 1.9124                 | 0.01624                       | 175.75            | 90.58               | 205.77               | 1034.12           | 1114.76             | 0.16041                    | 1.7695            | 1.9296              | 125                   |
| 126                   | 1.9533                 | 0.01625                       | 170.05            | 90.78               | 210.07               | 1034.12           | 1114.98             | 0.16043                    | 1.7695            | 1.9297              | 126                   |
| 127                   | 2.0014                 | 0.01626                       | 164.35            | 90.98               | 214.37               | 1034.12           | 1115.20             | 0.16045                    | 1.7695            | 1.9298              | 127                   |
| 128                   | 2.0495                 | 0.01627                       | 158.65            | 91.18               | 218.67               | 1034.12           | 1115.42             | 0.16047                    | 1.7695            | 1.9299              | 128                   |
| 129                   | 2.0976                 | 0.01628                       | 152.95            | 91.38               | 222.97               | 1034.12           | 1115.64             | 0.16049                    | 1.7695            | 1.9300              | 129                   |
| 130                   | 2.1457                 | 0.01629                       | 147.25            | 91.58               | 227.27               | 1034.12           | 1115.86             | 0.16051                    | 1.7695            | 1.9301              | 130                   |
| 131                   | 2.1938                 | 0.01630                       | 141.55            | 91.78               | 231.57               | 1034.12           | 1116.08             | 0.16053                    | 1.7695            | 1.9302              | 131                   |
| 132                   | 2.2419                 | 0.01631                       | 135.85            | 91.98               | 235.87               | 1034.12           | 1116.30             | 0.16055                    | 1.7695            | 1.9303              | 132                   |
| 133                   | 2.2899                 | 0.01632                       | 130.15            | 92.18               | 240.17               | 1034.12           | 1116.52             | 0.16057                    | 1.7695            | 1.9304              | 133                   |
| 134                   | 2.3380                 | 0.01633                       | 124.45            | 92.38               | 244.47               | 1034.12           | 1116.74             | 0.16059                    | 1.7695            | 1.9305              | 134                   |
| 135                   | 2.3861                 | 0.01634                       | 118.75            | 92.58               | 248.77               | 1034.12           | 1116.96             | 0.16061                    | 1.7695            | 1.9306              | 135                   |
| 136                   | 2.4342                 | 0.01635                       | 113.05            | 92.78               | 253.07               | 1034.12           | 1117.18             | 0.16063                    | 1.7695            | 1.9307              | 136                   |
| 137                   | 2.4823                 | 0.01636                       | 107.35            | 92.98               | 257.37               | 1034.12           | 1117.40             | 0.16065                    | 1.7695            | 1.9308              | 137                   |
| 138                   | 2.5304                 | 0.01637                       | 101.65            | 93.18               | 261.67               | 1034.12           | 1117.62             | 0.16067                    | 1.7695            | 1.9309              | 138                   |
| 139                   | 2.5785                 | 0.01638                       | 95.95             | 93.38               | 265.97               | 1034.12           | 1117.84             | 0.16069                    | 1.7695            | 1.9310              | 139                   |
| 140                   | 2.6266                 | 0.01639                       | 90.25             | 93.58               | 270.27               | 1034.12           | 1118.06             | 0.16071                    | 1.7695            | 1.9311              | 140                   |
| 141                   | 2.6747                 | 0.01640                       | 84.55             | 93.78               | 274.57               | 1034.12           | 1118.28             | 0.16073                    | 1.7695            | 1.9312              | 141                   |
| 142                   | 2.7228                 | 0.01641                       | 78.85             | 93.98               | 278.87               | 1034.12           | 1118.50             | 0.16075                    | 1.7695            | 1.9313              | 142                   |
| 143                   | 2.7709                 | 0.01642                       | 73.15             | 94.18               | 283.17               | 1034.12           | 1118.72             | 0.16077                    | 1.7695            | 1.9314              | 143                   |
| 144                   | 2.8190                 | 0.01643                       | 67.45             | 94.38               | 287.47               | 1034.12           | 1118.94             | 0.16079                    | 1.7695            | 1.9315              | 144                   |
| 145                   | 2.8671                 | 0.01644                       | 61.75             | 94.58               | 291.77               | 1034.12           | 1119.16             | 0.16081                    | 1.7695            | 1.9316              | 145                   |
| 146                   | 2.9152                 | 0.01645                       | 56.05             | 94.78               | 296.07               | 1034.12           | 1119.38             | 0.16083                    | 1.7695            | 1.9317              | 146                   |
| 147                   | 2.9633                 | 0.01646                       | 50.35             | 94.98               | 300.37               | 1034.12           | 1119.60             | 0.16085                    | 1.7695            | 1.9318              | 147                   |
| 148                   | 3.0114                 | 0.01647                       | 44.65             | 95.18               | 304.67               | 1034.12           | 1119.82             | 0.16087                    | 1.7695            | 1.9319              | 148                   |
| 149                   | 3.0595                 | 0.01648                       | 38.95             | 95.38               | 308.97               | 1034.12           | 1120.04             | 0.16089                    | 1.7695            | 1.9320              | 149                   |
| 150                   | 3.1076                 | 0.01649                       | 33.25             | 95.58               | 313.27               | 1034.12           | 1120.26             | 0.16091                    | 1.7695            | 1.9321              | 150                   |
| 151                   | 3.1557                 | 0.01650                       | 27.55             | 95.78               | 317.57               | 1034.12           | 1120.48             | 0.16093                    | 1.7695            | 1.9322              | 151                   |

\* Compiled by John A. Goff and S. Gratch.

TABLE 4. PROPERTIES OF SATURATED STEAM: PRESSURE TABLE\*

| Abs.<br>Press.<br>In. Hg<br>p | Temp.<br>t<br>°F | Specific Volume               |                              | Enthalpy                      |                          |                              | Entropy                       |                          |                              | Abs.<br>Press.<br>In. Hg<br>p |
|-------------------------------|------------------|-------------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|-------------------------------|--------------------------|------------------------------|-------------------------------|
|                               |                  | Sat. Liquid<br>v <sub>f</sub> | Sat. Vapor<br>v <sub>g</sub> | Sat. Liquid<br>h <sub>f</sub> | Evap.<br>h <sub>fg</sub> | Sat. Vapor<br>h <sub>g</sub> | Sat. Liquid<br>s <sub>f</sub> | Evap.<br>s <sub>fg</sub> | Sat. Vapor<br>s <sub>g</sub> |                               |
| 0.25                          | 40.23            | 0.01602                       | 2423.7                       | 8.28                          | 1071.1                   | 1079.4                       | 0.0166                        | 2.1423                   | 2.1589                       | 0.25                          |
| 0.50                          | 58.80            | 0.01604                       | 1258.4                       | 26.88                         | 1060.6                   | 1087.5                       | 0.0532                        | 2.0453                   | 2.0985                       | 0.50                          |
| 0.75                          | 70.43            | 0.01606                       | 856.1                        | 38.47                         | 1054.0                   | 1092.5                       | 0.0764                        | 1.981                    | 2.0325                       | 0.75                          |
| 1.00                          | 79.93            | 0.01608                       | 632.3                        | 47.05                         | 1049.3                   | 1096.3                       | 0.0914                        | 1.9473                   | 2.0387                       | 1.00                          |
| 1.5                           | 91.72            | 0.01611                       | 444.9                        | 59.71                         | 1042.0                   | 1101.7                       | 0.1147                        | 1.8894                   | 2.0041                       | 1.5                           |
| 2                             | 101.14           | 0.01614                       | 339.2                        | 69.10                         | 1036.6                   | 1105.7                       | 0.1316                        | 1.8481                   | 1.9797                       | 2                             |
| 4                             | 125.43           | 0.01622                       | 176.7                        | 93.34                         | 1022.7                   | 1116.0                       | 0.1738                        | 1.7476                   | 1.9214                       | 4                             |
| 6                             | 140.78           | 0.01630                       | 120.72                       | 108.67                        | 1013.6                   | 1122.3                       | 0.1998                        | 1.6581                   | 1.8877                       | 6                             |
| 8                             | 152.24           | 0.01635                       | 92.16                        | 120.13                        | 1006.9                   | 1127.0                       | 0.2188                        | 1.5854                   | 1.8480                       | 8                             |
| 10                            | 161.49           | 0.01640                       | 74.76                        | 129.38                        | 1001.4                   | 1130.8                       | 0.2335                        | 1.5121                   | 1.8458                       | 10                            |
| 12                            | 169.28           | 0.01644                       | 63.03                        | 137.18                        | 996.7                    | 1133.9                       | 0.2460                        | 1.4587                   | 1.8307                       | 12                            |
| 14                            | 176.05           | 0.01648                       | 54.55                        | 143.96                        | 992.6                    | 1136.6                       | 0.2568                        | 1.4113                   | 1.8181                       | 14                            |
| 16                            | 182.05           | 0.01652                       | 48.14                        | 149.98                        | 988.9                    | 1138.9                       | 0.2662                        | 1.3690                   | 1.8072                       | 16                            |
| 18                            | 187.45           | 0.01655                       | 43.11                        | 155.39                        | 985.7                    | 1141.1                       | 0.2746                        | 1.3231                   | 1.7977                       | 18                            |
| 20                            | 192.37           | 0.01658                       | 39.07                        | 160.33                        | 982.7                    | 1143.0                       | 0.2822                        | 1.2809                   | 1.7891                       | 20                            |
| 22                            | 196.90           | 0.01661                       | 35.72                        | 164.87                        | 982.8                    | 1144.7                       | 0.2891                        | 1.2404                   | 1.7814                       | 22                            |
| 24                            | 201.09           | 0.01664                       | 32.94                        | 169.09                        | 982.7                    | 1146.3                       | 0.2955                        | 1.1978                   | 1.7744                       | 24                            |
| 26                            | 205.00           | 0.01667                       | 30.56                        | 173.02                        | 974.8                    | 1147.8                       | 0.3014                        | 1.1655                   | 1.7679                       | 26                            |
| 28                            | 208.67           | 0.01669                       | 28.52                        | 176.72                        | 972.7                    | 1149.2                       | 0.3069                        | 1.1350                   | 1.7619                       | 28                            |
| 30                            | 212.13           | 0.01672                       | 26.74                        | 180.19                        | 970.3                    | 1150.5                       | 0.3122                        | 1.1042                   | 1.7564                       | 30                            |
| Lb/Sq In.<br>14.696           | 212.00           | 0.01672                       | 26.80                        | 180.07                        | 970.3                    | 1150.4                       | 0.3120                        | 1.4446                   | 1.7566                       | Lb/Sq In.<br>14.696           |
| 16                            | 216.32           | 0.01674                       | 24.75                        | 184.42                        | 967.6                    | 1152.0                       | 0.3184                        | 1.4313                   | 1.7497                       | 16                            |
| 18                            | 222.41           | 0.01679                       | 22.17                        | 190.56                        | 963.6                    | 1154.2                       | 0.3275                        | 1.4128                   | 1.7403                       | 18                            |
| 20                            | 227.97           | 0.01683                       | 20.08                        | 196.16                        | 960.1                    | 1156.3                       | 0.3356                        | 1.3962                   | 1.7319                       | 20                            |
| 22                            | 233.07           | 0.01687                       | 18.15                        | 201.33                        | 956.8                    | 1157.9                       | 0.3427                        | 1.3804                   | 1.7242                       | 22                            |
| 24                            | 237.82           | 0.01691                       | 16.38                        | 206.14                        | 953.7                    | 1159.8                       | 0.3500                        | 1.3672                   | 1.7172                       | 24                            |
| 26                            | 242.25           | 0.01694                       | 15.71                        | 210.62                        | 950.7                    | 1161.3                       | 0.3564                        | 1.3544                   | 1.7106                       | 26                            |
| 28                            | 246.41           | 0.01698                       | 14.663                       | 214.83                        | 947.9                    | 1162.7                       | 0.3623                        | 1.3425                   | 1.7048                       | 28                            |
| 30                            | 250.33           | 0.01701                       | 13.746                       | 218.82                        | 945.3                    | 1164.1                       | 0.3680                        | 1.3313                   | 1.6993                       | 30                            |
| 32                            | 254.05           | 0.01704                       | 12.949                       | 222.56                        | 942.8                    | 1165.3                       | 0.3733                        | 1.3209                   | 1.6941                       | 32                            |
| 34                            | 257.58           | 0.01707                       | 12.226                       | 226.18                        | 940.3                    | 1166.5                       | 0.3783                        | 1.3110                   | 1.6893                       | 34                            |
| 36                            | 260.95           | 0.01709                       | 11.588                       | 229.60                        | 938.0                    | 1167.6                       | 0.3831                        | 1.3017                   | 1.6848                       | 36                            |
| 38                            | 264.16           | 0.01712                       | 11.015                       | 232.89                        | 935.8                    | 1168.7                       | 0.3876                        | 1.2929                   | 1.6805                       | 38                            |
| 40                            | 267.25           | 0.01715                       | 10.498                       | 236.03                        | 933.7                    | 1169.7                       | 0.3919                        | 1.2844                   | 1.6763                       | 40                            |
| 42                            | 270.21           | 0.01717                       | 10.029                       | 239.04                        | 931.6                    | 1170.7                       | 0.3960                        | 1.2761                   | 1.6722                       | 42                            |
| 44                            | 273.05           | 0.01720                       | 9.601                        | 241.95                        | 929.6                    | 1171.6                       | 0.4000                        | 1.2687                   | 1.6687                       | 44                            |
| 46                            | 275.80           | 0.01722                       | 9.209                        | 244.77                        | 927.7                    | 1172.4                       | 0.4038                        | 1.2613                   | 1.6652                       | 46                            |
| 48                            | 278.45           | 0.01725                       | 8.848                        | 247.47                        | 925.8                    | 1173.3                       | 0.4075                        | 1.2542                   | 1.6617                       | 48                            |
| 50                            | 281.01           | 0.01727                       | 8.515                        | 250.09                        | 924.0                    | 1174.1                       | 0.4110                        | 1.2474                   | 1.6585                       | 50                            |
| 52                            | 283.49           | 0.01729                       | 8.208                        | 252.63                        | 922.2                    | 1174.8                       | 0.4144                        | 1.2409                   | 1.6553                       | 52                            |
| 54                            | 285.90           | 0.01731                       | 7.922                        | 255.06                        | 920.5                    | 1175.6                       | 0.4177                        | 1.2346                   | 1.6523                       | 54                            |
| 56                            | 288.23           | 0.01733                       | 7.656                        | 257.40                        | 918.8                    | 1176.3                       | 0.4209                        | 1.2285                   | 1.6494                       | 56                            |
| 58                            | 290.50           | 0.01735                       | 7.407                        | 259.62                        | 917.1                    | 1176.9                       | 0.4240                        | 1.2226                   | 1.6466                       | 58                            |
| 60                            | 292.71           | 0.01738                       | 7.176                        | 262.09                        | 915.5                    | 1177.6                       | 0.4270                        | 1.2168                   | 1.6438                       | 60                            |
| 62                            | 294.85           | 0.01740                       | 6.957                        | 264.30                        | 913.9                    | 1178.2                       | 0.4300                        | 1.2113                   | 1.6409                       | 62                            |
| 64                            | 296.94           | 0.01742                       | 6.752                        | 266.45                        | 912.4                    | 1178.8                       | 0.4329                        | 1.2059                   | 1.6387                       | 64                            |
| 66                            | 298.99           | 0.01744                       | 6.560                        | 268.55                        | 910.8                    | 1179.4                       | 0.4358                        | 1.2006                   | 1.6362                       | 66                            |
| 68                            | 300.98           | 0.01746                       | 6.378                        | 270.60                        | 909.4                    | 1180.0                       | 0.4383                        | 1.1955                   | 1.6338                       | 68                            |
| 70                            | 302.92           | 0.01748                       | 6.206                        | 272.61                        | 907.9                    | 1180.6                       | 0.4409                        | 1.1906                   | 1.6315                       | 70                            |
| 72                            | 304.83           | 0.01750                       | 6.044                        | 274.58                        | 906.5                    | 1181.1                       | 0.4434                        | 1.1857                   | 1.6292                       | 72                            |
| 74                            | 306.68           | 0.01752                       | 5.890                        | 276.49                        | 905.1                    | 1181.6                       | 0.4460                        | 1.1810                   | 1.6270                       | 74                            |
| 76                            | 308.50           | 0.01754                       | 5.743                        | 278.37                        | 903.7                    | 1182.1                       | 0.4484                        | 1.1764                   | 1.6248                       | 76                            |
| 78                            | 310.29           | 0.01755                       | 5.604                        | 280.21                        | 902.4                    | 1182.6                       | 0.4508                        | 1.1720                   | 1.6228                       | 78                            |
| 80                            | 312.03           | 0.01757                       | 5.472                        | 282.02                        | 901.1                    | 1183.1                       | 0.4531                        | 1.1676                   | 1.6207                       | 80                            |
| 82                            | 313.74           | 0.01759                       | 5.346                        | 283.79                        | 899.7                    | 1183.5                       | 0.4554                        | 1.1633                   | 1.6187                       | 82                            |
| 84                            | 315.42           | 0.01761                       | 5.225                        | 285.53                        | 898.3                    | 1183.9                       | 0.4576                        | 1.1592                   | 1.6168                       | 84                            |
| 86                            | 317.07           | 0.01762                       | 5.111                        | 287.24                        | 897.2                    | 1184.4                       | 0.4598                        | 1.1551                   | 1.6149                       | 86                            |
| 88                            | 318.68           | 0.01764                       | 5.001                        | 288.91                        | 895.9                    | 1184.8                       | 0.4620                        | 1.1510                   | 1.6130                       | 88                            |
| 90                            | 320.27           | 0.01766                       | 4.896                        | 290.56                        | 894.7                    | 1185.3                       | 0.4641                        | 1.1471                   | 1.6112                       | 90                            |
| 92                            | 321.83           | 0.01768                       | 4.795                        | 292.18                        | 893.5                    | 1185.7                       | 0.4661                        | 1.1433                   | 1.6094                       | 92                            |
| 94                            | 323.36           | 0.01769                       | 4.699                        | 293.78                        | 892.3                    | 1186.1                       | 0.4682                        | 1.1394                   | 1.6076                       | 94                            |
| 96                            | 324.87           | 0.01771                       | 4.606                        | 295.34                        | 891.1                    | 1186.4                       | 0.4702                        | 1.1358                   | 1.6060                       | 96                            |
| 98                            | 326.35           | 0.01772                       | 4.517                        | 296.89                        | 889.9                    | 1186.8                       | 0.4721                        | 1.1322                   | 1.6043                       | 98                            |
| 100                           | 327.81           | 0.01774                       | 4.432                        | 298.40                        | 888.8                    | 1187.2                       | 0.4740                        | 1.1286                   | 1.6026                       | 100                           |
| 200                           | 359.42           | 0.01809                       | 3.015                        | 330.51                        | 863.6                    | 1194.1                       | 0.5138                        | 1.0556                   | 1.5694                       | 200                           |
| 300                           | 385.79           | 0.01835                       | 2.043                        | 355.30                        | 840.6                    | 1200.1                       | 0.5415                        | 1.0015                   | 1.5387                       | 300                           |
| 400                           | 417.73           | 0.01880                       | 1.5433                       | 383.84                        | 800.0                    | 1202.8                       | 0.5879                        | 0.9225                   | 1.5104                       | 400                           |
| 400                           | 444.59           | 0.0193                        | 1.1613                       | 424.0                         | 780.5                    | 1204.5                       | 0.6214                        | 0.8830                   | 1.4844                       | 400                           |
| 500                           | 457.01           | 0.0197                        | 0.9278                       | 429.4                         | 755.0                    | 1204.4                       | 0.6487                        | 0.8147                   | 1.4634                       | 500                           |

veniently used to interpolate values for the enthalpy, specific volume, and entropy of moist air from the data of Table 2. Within the estimated precision of the data of Table 2, at temperatures below 150 F, the volume  $v$ , enthalpy  $h$ , and entropy  $s$ , of moist air *per pound of dry air* at any degree of saturation  $\mu$  may be computed from the simple relations:

$$v = v_a + \mu v_{sa} \quad (27)$$

$$h = h_a + \mu h_{sa} \quad (28)$$

$$s = s_a + \mu s_{sa} \quad (29)$$

Thus, the degree of saturation is used in conjunction with Table 2 in the same manner as the quality is used with tables of the thermodynamic properties of steam.

#### Correction of Table 2 for Temperatures Above 150 F

The simple relations expressed in Equations 27, 28, and 29 give the properties of unsaturated air with satisfactory precision for most engineering-design problems. Above 150 F, when greater precision than obtained by Table 2 is required, these simple relations can be adjusted by the addition of supplementary terms.

To correct the volume, it is necessary to add a correction term  $\bar{v}$  which is defined as

$$\bar{v} = \frac{\mu(1-\mu)A}{1 + aW_{sa}} \quad (30)$$

where  $a$  denotes the ratio of the apparent molecular weight of dry air (28.966) to the molecular weight of water (18.016) and is equal to 1.6078. Table 5 gives the values of the coefficient  $A$  for several higher temperatures, the value of  $\mu$  at which the correction term  $\bar{v}$  attains its maximum value, and the maximum value of  $\bar{v}$  term there attained.

The correction term for the enthalpy is

$$\bar{h} = \frac{\mu(1-\mu)B}{1 + aW_{sa}} \quad (31)$$

TABLE 5. COEFFICIENTS A, B, C APPEARING IN EQUATIONS 30, 31, 32, MAXIMUM VALUES OF CORRECTIONS DEFINED BY EQUATIONS 30, 31, 32. DEGREE OF SATURATION AT WHICH THESE MAXIMA OCCUR,  $\bar{\mu}_m$ . MAXIMUM VALUE OF CORRECTION DEFINED BY EQUATION 33. DEGREE OF SATURATION AT WHICH THIS MAXIMUM OCCURS,  $\bar{\mu}_m$ . (Standard Atmospheric Pressure)

| t<br>(F) | A<br>(ft <sup>3</sup> /lb <sub>a</sub> ) | B<br>(Btu/lb <sub>a</sub> ) | C<br>(Btu/F/lb <sub>a</sub> ) | $\bar{v}_{max}$<br>(ft <sup>3</sup> /lb <sub>a</sub> ) | $\bar{h}_{max}$<br>(Btu/lb <sub>a</sub> ) | $\bar{s}_{max}$<br>(Btu/F/lb <sub>a</sub> ) | $\bar{\mu}_m$ | $\bar{s}_{max}$<br>(Btu/F/lb <sub>a</sub> ) | $\bar{\mu}_m$ |
|----------|------------------------------------------|-----------------------------|-------------------------------|--------------------------------------------------------|-------------------------------------------|---------------------------------------------|---------------|---------------------------------------------|---------------|
| 96       | 0.0018                                   | 0.0268                      | 0.00004                       | 0.0004                                                 | 0.0069                                    | 0.00001                                     | 0.4925        | 0.0015                                      | 0.3650        |
| 112      | 0.0042                                   | 0.0650                      | 0.00009                       | 0.0010                                                 | 0.0155                                    | 0.00002                                     | 0.4878        | 0.0025                                      | 0.3632        |
| 128      | 0.0096                                   | 0.1439                      | 0.00020                       | 0.0022                                                 | 0.0332                                    | 0.00005                                     | 0.4805        | 0.0040                                      | 0.3602        |
| 144      | 0.0215                                   | 0.3149                      | 0.00042                       | 0.0047                                                 | 0.0693                                    | 0.00009                                     | 0.4691        | 0.0065                                      | 0.3557        |
| 160      | 0.0487                                   | 0.6969                      | 0.00091                       | 0.0099                                                 | 0.1418                                    | 0.00019                                     | 0.4511        | 0.0106                                      | 0.3485        |
| 176      | 0.1169                                   | 1.636                       | 0.00207                       | 0.0207                                                 | 0.2903                                    | 0.00037                                     | 0.4213        | 0.0179                                      | 0.3363        |
| 192      | 0.3363                                   | 4.608                       | 0.00567                       | 0.0451                                                 | 0.6180                                    | 0.00076                                     | 0.3662        | 0.0333                                      | 0.3129        |

Table 5 gives the values of the coefficient B and maximum values of  $\bar{h}$ , the maximum values occurring at the same degree of saturation as  $\bar{v}$ .

Corrections for the entropy consist of two terms:  $\bar{s}$  which is defined as

$$\bar{s} = \frac{\mu(1-\mu)C}{1 + aW_{sa}} \quad (32)$$

and  $\bar{s}$ , the so-called *mixing entropy*, which contributes the larger part of the error. The *mixing entropy* is defined as

$$\bar{s} = 0.1579 [(1 + \mu a W_{sa}) \log_{10}(1 + \mu a W_{sa}) - \mu a W_{sa} \log_{10}(\mu) - \mu(1 + a W_{sa}) \log_{10}(1 + a W_{sa})] \quad (33)$$

Table 5 lists the values of the coefficient C, the maximum values of  $\bar{s}$  and  $\bar{s}$  and the values of  $\mu$  at which they occur. The maximum  $\bar{s}$  occurs at the same degree of saturation as the maximum values of  $\bar{v}$  and  $\bar{h}$ .

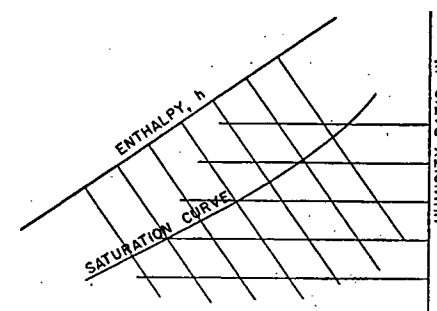


FIG. 3. BASIC COORDINATES OF A.S.H.A.E. PSYCHROMETRIC CHART

#### THE ASHAE PSYCHROMETRIC CHART

A psychrometric chart is a graphical representation of the thermodynamic properties of moist air. To be of real value in the solution of engineering problems, it must have distinctive features which aid in problem analysis.

An examination of psychrometric mass and energy balances shows that no properties other than *enthalpy* and *humidity ratio* are required for the solution of problems. It is logical, then, to use these properties as the coordinates of a psychrometric chart. This was initially done by Mollier in 1923,<sup>7, 8</sup> and is the arrangement followed in the chart included with THE GUIDE. The A.S.H.A.E. Psychrometric Chart is based on the best thermodynamic data available today, namely, those of Goff and Gratch, as given in Table 2. The chart is plotted on oblique coordinates of enthalpy and humidity ratio; the enthalpy axis making an angle of approximately 40 deg with the humidity ratio axis. This is shown in Fig. 3.

For practical use, the inclusion of dry-bulb and wet-bulb temperatures, volumes, and indices of the condition of the air in relation to saturation, is necessary for locating and describing states on the chart. The arrange-

ment of the families of curves of constant dry-bulb temperature, wet-bulb temperature, volume, relative humidity and degree of saturation, are shown in Fig. 4.

Mass and energy balances deal only with net changes between definite states; the detailed history of a change is not involved. A chart used to facilitate such calculations must primarily aid in clearly establishing states. Lines drawn on the chart to connect different states need have

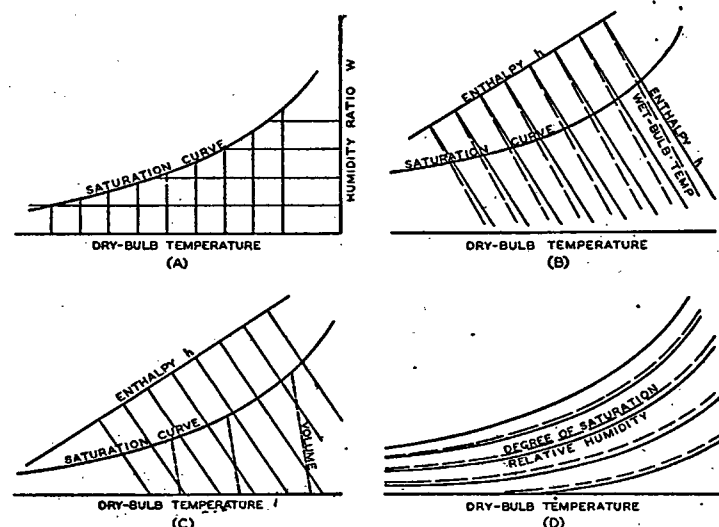


FIG. 4. ARRANGEMENT OF FAMILIES OF CURVES ON A.S.H.A.E. PSYCHROMETRIC CHART

no other significance than being loci lines; that is, lines which contain the two terminal points of a change according to the particular overall conditions imposed. Loci lines are commonly called *condition lines* for the processes concerned. On the A.S.H.A.E. chart a condition line is characterized by the ratio  $(h_2 - h_1)/(W_2 - W_1)$ .

An abridgment of the A.S.H.A.E. Psychrometric Chart appears in Fig. 5. A large size (24 x 32) chart will be found on the inside of the back cover.

The chart is drawn for standard atmospheric pressure. Steady flow changes commonly involve pressure drops with the flow, but so long as these pressure drops remain a small fraction of the barometric pressure, no appreciable errors need arise from using a constant pressure chart. For many design problems, the use of the standard pressure chart will not incur any undue error up to about 2000 ft above sea level.

The region above the saturation curve is a two-phase region giving equilibrium states for water in both the liquid and vapor phases. The ordinate of a point in this region is the weight of water in both phases per pound of dry air in the vapor phase, neglecting any dissolved air

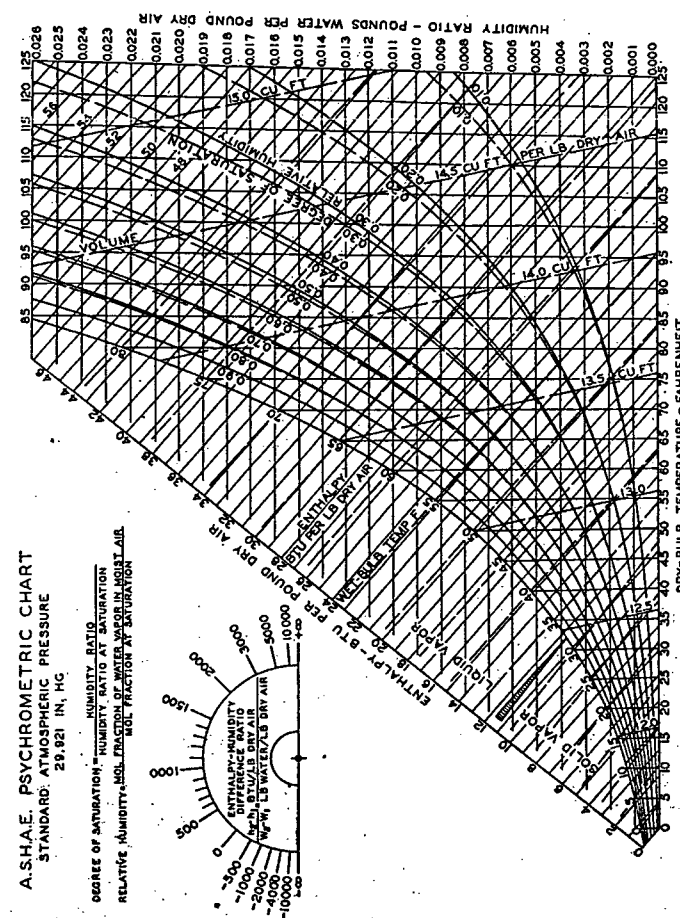


FIG. 5. ABRIDGMENT OF A.S.H.A.E. PSYCHROMETRIC CHART

in the condensed phase. The ordinate at the saturation curve, or the point at which the break in the isotherm through the point in question occurs, is the weight of water per pound of dry air in the vapor phase. Consequently, the difference between the two ordinates is the weight of condensed moisture per pound of dry air in the vapor phase.

The shaded solid-liquid-vapor region at 32 F is an isothermal three-phase zone, and separates the liquid-vapor zone from the solid-vapor zone. The temperature is 32 F throughout the shaded area.



It is possible to obtain two values for the wet-bulb temperature when this temperature is below 32 F. If the bulb of a thermometer is dipped into water at a temperature slightly above 32 F and held in a stream of air whose wet-bulb temperature is below 32 F, the temperature indicated by the thermometer will drop rapidly until a minimum is reached below 32 F. This will be accomplished without the formation of ice on the bulb of the thermometer. After reaching this minimum temperature, the reading will jump back to 32 F and remain there until the water on the bulb is frozen, after which it will slowly drop again until equilibrium is reached. The final temperature may be higher or lower than the first minimum reading, or it may be the same depending on the amount of moisture present in the mixture. In the absence of reliable data on the wet-bulb temperature over sub-cooled water, the chart, below 32 F, has been drawn for the equilibrium condition, that is, the values plotted on the A.S.H.A.E. chart are for the condition where the minimum temperature is reached with ice on the bulb of the thermometer.

#### USE OF TABLE 2 AND THE A.S.H.A.E. PSYCHROMETRIC CHART

The use of Table 2 and the A.S.H.A.E. Psychrometric Chart in analyzing typical air conditioning problems, is best explained by means of illustrative examples. In each of the following it is to be understood that the processes in question take place at a constant pressure of 29.921 in. Hg, *i.e.*, standard atmospheric pressure.

**Example 1:** Determine the enthalpy of moist air at 80 F dry-bulb temperature and 0.40 degree of saturation.

**Solution a:** From the data of Table 2, at 80 F,  $h_a = 19.221$  Btu per lb of dry air and  $h_{sa} = 24.47$  Btu per lb of dry air. Then  $h$  at the specified conditions is  $19.221 + 0.40(24.47) = 29.01$  Btu per lb of dry air.

**Solution b:** From the A.S.H.A.E. Chart. Follow the 80 F dry-bulb line vertically until it intersects the 0.40 degree of saturation line. From this intersection, follow the line of constant enthalpy to the enthalpy scale and read 29.00 Btu per lb of dry air.

**Example 2:** Determine the thermodynamic wet-bulb temperature of moist air at the conditions of Example 1.

**Solution a:** From the data of Table 2. Applying Equation 8,  $h_1 = 29.01$  Btu per lb of dry air (Example 1). As a first approximation this is  $h^*$ , the enthalpy at saturation at the thermodynamic wet-bulb temperature which is, therefore, approximately 63.5 F.  $W^*$  at 63.5 F is  $12.57 \times 10^{-3}$  lb of water vapor per lb of dry air, and  $W_1$  is  $0.02233 \times 0.40 = 0.00893$  lb of water vapor per lb of dry air. The specific enthalpy of liquid water at 63.5 F is 31.58 Btu per lb of water. As a second approximation,  $h^* = 29.01 + (0.01257 - 0.00893)(31.58) = 29.12$  Btu per lb of dry air. Interpolation in Table 2 gives as the final answer  $t^* = 63.64$  F.

**Solution b:** From the A.S.H.A.E. Chart. At the intersection of the 80 F dry-bulb temperature line and the 0.40 degree of saturation line, read the thermodynamic wet-bulb temperature.

#### Heating of Moist Air at Constant Pressure Without Addition of Moisture

**Example 3:** Air initially at 20 F, 0.80 degree of saturation, is heated to 120 F. Find the quantity of heat required to process 20,000 cfm of heated air.

The process is diagrammatically illustrated in Fig. 6. The energy equation for the process is

$$Gh_1 + \dot{q}_2 = Gh_2$$

$$\dot{q}_2 = G(h_2 - h_1)$$

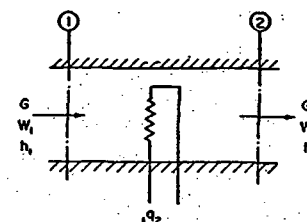


FIG. 6. ILLUSTRATION OF PROCESS OF EXAMPLE 3

**Solution a:** From the data of Table 2. The initial humidity ratio, which is the same as the final humidity ratio, is  $0.80(0.002152) = 0.001722$  lb of water vapor per lb of dry air; the initial enthalpy is  $4.804 + 0.80(2.302) = 6.646$  Btu per lb of dry air; the final degree of saturation is  $0.001722/0.03149 = 0.02113$ ; the final enthalpy is  $28.841 + 0.02113(90.70) = 30.757$  Btu per lb of dry air; the final volume is  $14.611 + 0.02113(1.905) = 14.651$  cu ft per lb of dry air. Since 20,000 cfm of heated air are to be processed, the total quantity of heat required is

$$\dot{q}_2 = (20,000/14.651) \times 24.111 = 32,914 \text{ Btu per min.}$$

**Solution b:** From the A.S.H.A.E. Chart. The process is represented by the horizontal line 1-2, Fig. 7. The initial enthalpy, at 20 F dry-bulb temperature and 0.80 degree of saturation, is 6.65 Btu per lb of dry air. Since the final humidity ratio is the same as the initial humidity ratio, the ratio  $(h_2 - h_1)/(W_2 - W_1) = \infty$ . The horizontal line 1-2, Fig. 7, then represents the condition line for the process, and the final state of the moist air must lie on this line. The final state is located at the point at which the 120 F dry-bulb temperature line crosses the condition line, and is labeled point 2 on the figure. At this condition the final enthalpy is 30.8 Btu per lb of dry air and the final specific volume is 14.65 cu ft per lb of dry air. Substituting these values in the energy equation,

$$\dot{q}_2 = (20,000/14.65) \times (30.8 - 6.65) = 32,950 \text{ Btu per min.}$$

#### Cooling of Moist Air at Constant Pressure with Condensation of Water

Referring to Fig. 8, moist air cooled from state 1 passes through successive states along the line  $W = W_1 = \text{constant}$  until the saturation line is intersected. The

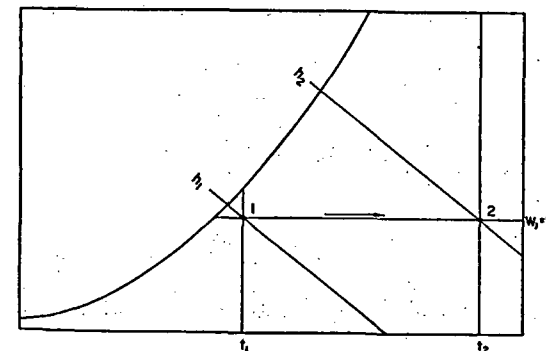


FIG. 7. SOLUTION OF EXAMPLE 3 ON A.S.H.V.E. PSYCHROMETRIC CHART



$$\frac{20.270 - h_2}{h_2 - 0.668} = \frac{0.003164 - W_2}{W_2 - 0.000630} = \frac{1}{4}$$

from which  $h_2 = 16.350$  and  $W_2 = 0.002657$ . The enthalpy of the final mixture may also be expressed by Equation 28:

$$h_2 = h_a + \mu h_{w2}$$

Since  $\mu$  by definition is  $W_2/W_a$ , Equation 28 may be rewritten as

$$16.350 = h_a + (0.002657/W_a) \times h_{w2}$$

At 56 F the right side of the equation is 16.332, and at 57 F it is 16.582. Interpolation gives as the final dry-bulb temperature of the mixture 56.07 F. At this temperature the humidity ratio at saturation is 0.00960 lb of water vapor per lb of dry air. Therefore, the final degree of saturation is

$$\mu = 0.002657/0.00960 = 0.277$$

**Solution b.** From the A.S.H.A.E. Chart, Equation 34 indicates that the state point of the resulting mixture lies on a straight line connecting the state points of

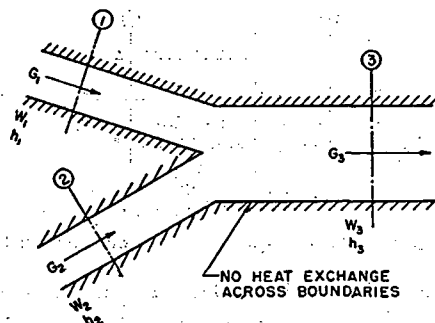


FIG. 10. ILLUSTRATION OF MIXING OF TWO STEADY FLOW STREAMS AT CONSTANT PRESSURE

the two streams being mixed, and divides this line into two segments whose respective lengths are inversely proportional to the rates of dry air flow in the corresponding streams. This is illustrated in Fig. 11. Points 1 and 2 are located and connected by a straight line. The state of the final mixture is set so that

$$\frac{G_1}{G_2} = \frac{D_{2-1}}{D_{1-1}} = \frac{1}{4}$$

Scaling the distances on the chart, the required solution to Example 5 is 56 F dry-bulb temperature and 0.28 degree of saturation.

#### Addition of Moisture to an Adiabatic Stream

Consider a stream of moist air flowing adiabatically between two sections, 1 and 2, as in Fig. 12, with moisture addition at the rate  $G_1(W_2 - W_1)$  and the moisture having the enthalpy  $h_w$  Btu per pound of moisture.

An energy balance yields

$$G_1 h_1 + G_1(W_2 - W_1)h_w = G_2 h_2 \quad (35)$$

**Example 6:** Liquid water chilled to 40 F is injected into an air stream initially at

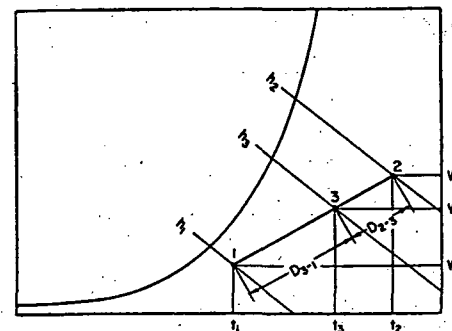


FIG. 11. SOLUTION OF EXAMPLE 5 ON A.S.H.V.E. PSYCHROMETRIC CHART

95 F dry-bulb temperature and 80 F thermodynamic wet-bulb temperature. At what temperature will saturation be reached? How much water must be evaporated to reach saturation?

**Solution a:** From the data of Table 2. The solution of Equation 35 for  $h_2$  yields

$$h_2 = h_1 + (W_2 - W_1)h_w$$

The initial enthalpy of the moist air  $h_1$  must be found from Equation 8,

$$h_1 = h^* - (W^* - W_1)h_w^*$$

from which  $\mu = 0.511$ .

$$\begin{aligned} \text{Hence, } h_1 &= 22.827 + 0.511(40.49) \\ &= 43.52 \text{ Btu per lb of dry air} \\ \text{and } W_1 &= 0.03673(0.511) \\ &= 0.01877 \text{ lb per lb of dry air.} \end{aligned}$$

The solution of Equation 35 is

$$h_2 = 43.52 + (W_2 - 0.01877)(8.09)$$

By trial and error, this equation will be satisfied at the temperature 79.87 F. At this temperature the humidity ratio  $W_2$  is 0.02223. The weight of water evaporated is therefore  $0.02223 - 0.01877 = 0.00346$  lb per lb of dry air.

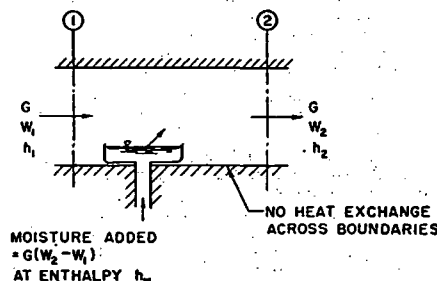


FIG. 12. ILLUSTRATION OF ADDITION OF MOISTURE TO AN ADIABATIC STREAM

**Solution b:** From the A.S.H.A.E. Chart. Solution of Equation 35 for the ratio  $(h_2 - h_1)/(W_2 - W_1)$  yields

$$\frac{h_2 - h_1}{W_2 - W_1} = h_w \quad (36)$$

The slope of the condition line is therefore determined by the enthalpy of the water which is supplied. This slope is established on the chart by connecting the center of the protractor on the psychrometric chart with the value of  $h_w$  on the protractor. Draw a line parallel to this reference line through the initial point 1 (Fig. 13). The second line is the condition line for the process. Since the conditions of the problem require the final point to lie on the saturation line, the intersection of the condition line with the saturation line gives the desired solution.

### Adiabatic Saturation

Adiabatic saturation is the designation given any process in which the state of moist air is changed from some initial unsaturated condition to a saturated one with-

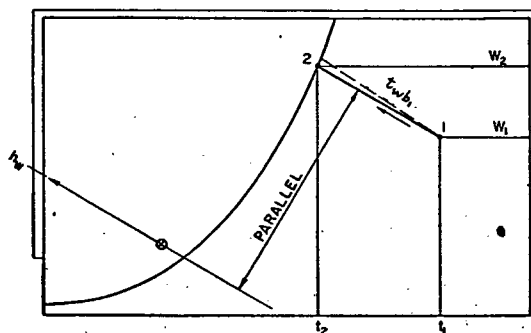


FIG. 13. SOLUTION OF EXAMPLE 6 ON A.S.H.A.E. PSYCHROMETRIC CHART

out the addition or removal of heat. According to this definition, the addition of moisture to an adiabatic stream may become an adiabatic saturation process. *Example 6* is an illustration.

A type of adiabatic saturation of further practical interest is the use of continually recirculated spray water in a saturating air washer. Here the spray water will ultimately come to the same temperature as the saturated leaving air; this temperature is, by definition, the thermodynamic wet-bulb temperature. Hence, adiabatic saturation in this manner will have the final state point on the saturation curve, with the same thermodynamic wet-bulb temperature as the original state point.

In a process such as this, the moist air enthalpy changes very slightly. The moisture added and temperature change may be obtained from the psychrometric chart as sketched in Fig. 14.

**Example 7:** Moist air at 75 F dry-bulb temperature and 0.60 degree of saturation, is saturated adiabatically with recirculating spray water. Find the amount of water added and the change in enthalpy.

**Solution a:** From the data of Table 2. As previously stated, the final temperature of the mixture will be the thermodynamic wet-bulb temperature at the initial state. This must first be determined by the method of *Example 2*, and is 65.51 F. At this temperature the humidity ratio at saturation and enthalpy at saturation are 0.01350 and 30.45, respectively. The humidity ratio at the initial state is 0.60 (0.01882) = 0.01129; the initial enthalpy is  $0.60(20.59) + 18.018 = 30.372$ . The weight of water

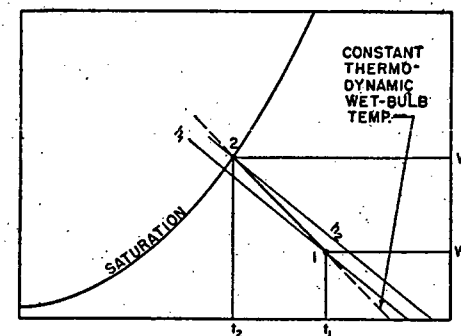


FIG. 14. MOISTURE ADDED AND TEMPERATURE CHANGE

added is therefore  $0.01350 - 0.01129 = 0.00221$  lb per lb of dry air; the enthalpy change is  $30.45 - 30.372 = 0.078$  Btu per lb of dry air.

**Solution b:** From the A.S.H.A.E. Chart. Since the initial and final states have the same thermodynamic wet-bulb temperature, the results may be read directly from the chart.

### Addition of Heat and Water Vapor to an Air Stream in Steady Flow

Fig. 15 is a schematic representation of a system operating at constant pressure, where

$G_1$  is the rate of flow of dry air, pounds per minute.

$G_w$  is the rate of evaporation of the water, pounds per minute.

$h_w$  is the enthalpy of the liquid water entering, Btu per pound.

$Q$  is the rate of heat addition, Btu per minute.

An energy balance for the system gives

$$G_1 h_1 + Q + G_w h_w = G_2 h_2 \quad (37)$$

A mass balance gives

$$G_1 + G_1 W_1 + G_w = G_2 + G_2 W_2$$

or

$$G_1 W_1 + G_w = G_2 W_2 \quad (38)$$

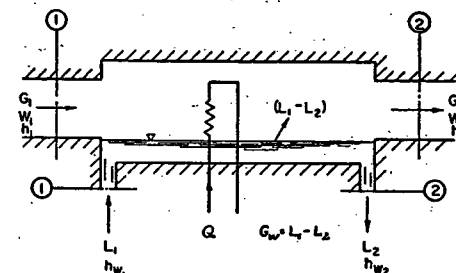


FIG. 15. ILLUSTRATION OF ADDITION OF HEAT AND WATER VAPOR TO AN AIR STREAM IN STEADY FLOW

Combining equations 37 and 38 and solving for the ratio  $(h_2 - h_1)/(W_2 - W_1)$ ,

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{Q}{G_w} + h_w \quad (39)$$

**Example 8:** Moist air at 20 F dry-bulb temperature and 0.80 degree of saturation is heated and humidified until it is at 120 F dry-bulb temperature and 71.5 F thermodynamic wet-bulb temperature. Water at 55 F is supplied. If the air flow rate is 20,000 cfm at the initial conditions, how much heat is required?

**Solution a:** From the data of Table 2. The initial humidity ratio is 0.80(0.002152) = 0.00172; the initial enthalpy is 4.804 + 0.80(2.302) = 6.6456; the initial specific volume is 12.084 + 0.80(0.042) = 12.118. The degree of saturation at the final state may be determined from Equation 8 which may be rewritten as

$$h_{a2} + \mu h_{a2} + h_w^*(W^* - \mu W_{a2}) = h^*$$

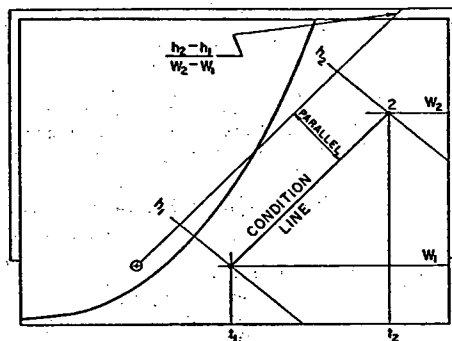


FIG. 16. SOLUTION OF EXAMPLE 8 ON A.S.H.A.E. PSYCHROMETRIC CHART

The values of these properties are:  $h^* = 35.39$ ;  $W^* = 0.01668$ ;  $h_w^* = 39.61$ ;  $h_{a2} = 90.70$ ;  $W_{a2} = 0.08149$ ;  $h_{a1} = 28.84$ .

Making the proper substitutions and solving for degree of saturation,

$$\mu = 0.0681.$$

The final humidity ratio is therefore 0.0681(0.08149) = 0.005549; the final enthalpy is 28.84 + 0.0681(90.70) = 35.02 Btu per lb dry air.

The rate of water addition is obtained from Equation 38.

$$G_w = \frac{20,000}{12.12} (0.005549 - 0.00172) \\ = 6.32 \text{ lb per min.}$$

The heat supplied is obtained from Equation 37.

$$Q = G_1(h_2 - h_1) - G_w h_w \\ = \frac{20,000}{12.12} (35.02 - 6.65) - 6.32(28.08) \\ = 46,667 \text{ Btu per min.}$$

**Solution b:** From the A.S.H.A.E. Chart. Locate the initial and final states on the chart and connect them with a straight line. Through the reference point on the chart, draw a line parallel to the line connecting the initial and final state points, the condition line, and read the value of the ratio  $(h_2 - h_1)/(W_2 - W_1)$  as 7500 from

the protractor on the chart (Fig. 16). From Equation 39

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{Q}{G_w} + h_w = 7500$$

The rate of water supply was determined in *Solution a*, but will be found from the chart. It is

$$G_w = \frac{20,000}{12.1} (0.0055 - 0.0017) \\ = 6.28 \text{ lb per min} \\ Q = G_w(7500 - h_w) \\ = 6.28(7500 - 23) \\ = 46,900 \text{ Btu per min.}$$

TABLE 6. PRESSURE AND TEMPERATURE FOR ALTITUDES IN U. S. STANDARD ATMOSPHERE

| ALTITUDE FEET<br>Z | PRESSURE IN. OF HG<br>P | TEMP F<br>t |
|--------------------|-------------------------|-------------|
| - 1,000            | 31.02                   | +62.6       |
| - 500              | 30.47                   | +60.8       |
| 0                  | 29.921                  | +59.0       |
| + 500              | 29.38                   | +57.2       |
| + 1,000            | 28.86                   | +55.4       |
| + 5,000            | 24.89                   | +41.2       |
| 10,000             | 20.58                   | +23.4       |
| 15,000             | 16.88                   | + 5.5       |
| 20,000             | 13.75                   | -12.3       |
| 25,000             | 11.10                   | -30.1       |
| 30,000             | 8.88                    | -47.9       |
| 35,000             | 7.04                    | -65.8       |
| 40,000             | 5.54                    | -67.0       |
| 45,000             | 4.36                    | -67.0       |
| 50,000             | 3.436                   | -67.0       |

### U. S. STANDARD ATMOSPHERE

The definition of the U. S. Standard Atmosphere is important to the air conditioning engineer as an essential standard of reference. The basic assumptions in defining the Standard Atmosphere are:

1. There is a linear decrease in temperature  $T$  with altitude up to the limit of the isothermal atmosphere at 35,332 ft. Thus,

$$T = T_0 - 0.003566 Z \quad (40)$$

2. The air is dry.

3. Air is a perfect gas obeying the laws of Charles and Boyle:

$$PV = RT$$

4. Gravity is constant at all altitudes with the standard value.

5. The temperature of the isothermal atmosphere is -66 F.

Standard values at sea level, which are part of the definition of the Standard Atmosphere, are:

|             |               |
|-------------|---------------|
| Pressure    | 29.921 in. Hg |
| Temperature | 59 F          |

|                      |                             |
|----------------------|-----------------------------|
| Absolute Temperature | 518.67 F Abs                |
| Gravity              | 32.1740 ft per (sec) (sec). |
| Density              | 0.076505 lb per cu ft       |

Values of pressure and temperature are listed in Table 6 for altitudes in the standard atmosphere from -1000 to 50,000 ft above sea level. For further explanation, References 9 and 10 should be consulted.

### LETTER SYMBOLS USED IN CHAPTER 3

- $\mu$  = degree of saturation (decimal).
- $\rho$  = density of fluid, pounds per cubic foot.
- $\phi$  = relative humidity (decimal).
- $\alpha$  = ratio of apparent molecular weight of dry air (28.966) to the molecular weight of water (18.016) = 1.6078.
- $A$  = coefficient from Table 5 for use in Equation 30 (obtained from Table 5).
- $B$  = coefficient to be used in Equation 31 (obtained from Table 5).
- $C$  = coefficient for use in Equation 32 (obtained from Table 5).
- $f_s$  = factor accounting for effect of mixing air and water, dimensionless.
- $G$  = flow rate of dry air, pounds per hour.
- $G_1$  = flow rate of dry air, pounds per minute.
- $G_w$  = rate of evaporation of water, pounds per minute.
- $H$  = enthalpy of the system.
- $H$  = enthalpy of the flowing medium, Btu per pound of dry air.
- $h$  = enthalpy of moist air, Btu per pound of dry air.
- $\bar{h}$  = enthalpy correction term to be added above 150 F, to enthalpy.
- $h_a$  = specific enthalpy of dry air, Btu per pound.
- $h_a = h_s - h_{sa}$  = the difference between the enthalpy of moist air at saturation per pound of dry air, and the specific enthalpy of the dry air itself, Btu per pound of dry air.
- $h_s$  = enthalpy of saturated water vapor, Btu per pound.
- $h_{sa}$  = enthalpy of moist air at saturation per pound of dry air, Btu per pound of dry air.
- $h_{sa}^*$  = enthalpy of moist air at saturation at thermodynamic wet-bulb temperature,  $t^*$ , Btu per pound of dry air.
- $h_w$  = specific enthalpy of condensed water (liquid or solid) at standard pressure, Btu per pound water.
- $h_w^*$  = specific enthalpy of water as added at the thermodynamic wet-bulb temperature  $t^*$ , Btu per pound of dry air.
- $h_{w1}$  = enthalpy of liquid water, Btu per pound.
- $h_{w2}$  = enthalpy of solid water, Btu per pound.
- $KE$  = average kinetic energy, Btu per pound.
- $\overline{KE}$  = average kinetic energy, Btu per pound.
- $L$  = flow rate of liquid water, pounds per hour.
- $m$  = weight of dry air crossing any duct section, pounds per minute.
- $n_a$  = mols dry air.
- $n_s$  = mols of water vapor at saturation.
- $n_w$  = mols of water vapor.
- $P$  = absolute pressure.
- $P_a$  = atmospheric pressure, inches Hg.

### LETTER SYMBOLS (Continued)

- $P_a$  = standard atmospheric pressure by definition 29.921 in. Hg.
- $P_s$  = saturation pressure of pure water at prevailing temperature.
- $p$  = total pressure of a mixture of air and water vapor, pounds per square inch or inches Hg.
- $p_a$  = partial pressure of dry air, pounds per square inch or inches Hg.
- $p_s$  = saturation pressure of pure water vapor, pounds per square inch or inches Hg.
- $p_w$  = partial pressure of water vapor in mixture of air and water vapor, pounds per square inch or inches Hg.
- $PE$  = potential energy, Btu per pound dry air.
- $\overline{PE}$  = average potential energy, Btu per pound dry air.
- $Q$  = total heat added or subtracted, between sections, Btu per minute.
- $q$  = ratio of energy added (or removed) to water added (or removed), Btu per pound. Also called specific enthalpy of water added.
- $q_1$  = energy added between points 1 and 2.
- $q_2$  = heat added between sections 1 and 2, Btu per pound dry air.
- $R$  = universal gas constant, 1545 foot-pounds per (Fahrenheit degree) (mol).
- $R_a$  = gas constant for dry air.
- $R_w$  = gas constant for water vapor.
- $S$  = flow rate of solid water, pounds per hour.
- $s$  = entropy of moist air per pound of dry air, Btu per (pound) (Fahrenheit degree).
- $\bar{s}$  = correction to be added to entropy of moist air obtained from Table 2.
- $\bar{s}$  = additional correction to be added to entropy because of "mixing entropy" (obtained from Table 5). Correction to be added to value of  $s$  obtained from Table 2.
- $s_a$  = specific entropy of dry air, Btu per (pound) (Fahrenheit degree, absolute).
- $s_{sa}$  = the difference between the entropy of moist air at saturation per pound of dry air, and the specific entropy of the dry air itself, Btu per (pound of dry air) (Fahrenheit degree, absolute).
- $s_s$  = entropy of moist air at saturation per pound of dry air, Btu per (pound of dry air) (Fahrenheit degree, absolute).
- $s_w$  = specific entropy of condensed water (liquid or solid) at standard atmospheric pressure, Btu per (pound of water) (Fahrenheit degree, absolute).
- $T$  = absolute temperature, Fahrenheit degrees.
- $T_a$  = standard atmospheric temperature, by definition 518.4 F absolute.
- $t$  = temperature, Fahrenheit degrees.
- $t^*$  = thermodynamic wet-bulb temperature, Fahrenheit degrees.
- $U$  = internal energy of system.
- $U$  = internal energy.
- $V$  = volume.
- $\bar{V}$  = average velocity, feet per minute.
- $v$  = volume of moist air per pound of dry air, cubic feet per pound.
- $v$  = correction to be added to volume of moist air per pound of dry air, above 150 F.
- $v_a$  = specific volume of dry air, cubic feet per pound.

## LETTER SYMBOLS (Concluded)

- $v_{a,s} = v_s - v_a$ , the difference between volume of moist air at saturation, per pound of dry air, and the volume of the dry air itself, cubic feet per pound of dry air.
- $v_s$  = volume of moist air at saturation per pound of dry air, cubic feet per pound of dry air.
- $v_T$  = total volume, cubic feet.
- $W$  = humidity ratio, of moist air, pounds of water per pound of dry air.
- $W_s$  = humidity ratio, at saturation, weight of water vapor per pound of dry air, pound per pound.
- $W_s^*$  = humidity ratio corresponding to thermodynamic wet-bulb temperature  $t^*$ , pounds of water per pound of dry air.
- $w$  = work done by system.
- $w$  = shaft work withdrawn between sections 1 and 2, Btu per pound of air.
- $Z$  = elevation above any datum, feet.
- $\bar{Z}$  = average elevation, feet.

Subscripts with symbols have following meanings: 1, 2, 3 indicate section of flow; a = air, w = water, wl = liquid water, ws = solid water, s = saturation, m = mixture; \* indicates that the value is at thermodynamic wet-bulb temperature.

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- <sup>8</sup> Das i-x Diagramm für Dampfluftgemische, by R. Mollier (ZVDI, Vol. 73, July 20, 1929, pp. 1009-1013).
- <sup>9</sup> National Advisory Committee for Aeronautics, Technical Report No. 218, 1925.
- <sup>10</sup> National Advisory Committee for Aeronautics, Technical Report No. 538, 1935.

## CHAPTER 4

## FLUID FLOW

Theory of Fluid Flow, Pressure Loss in Circular Pipes, Pressure Loss in Non-Circular Pipes; Flow of Compressible Fluids, Ideal Flow Through Nozzle or Orifice; Flow Measurement, Head Meters, Location of Head Meters and Pressure Taps Pitot Tube, Variable Area Flow Meters

THE flow of fluids is part of the branch of engineering science known as fluid mechanics, which will be discussed here insofar as it applies to the work of engineers in the fields of heating, ventilating, and air conditioning. Probably air is the most frequently handled fluid, but other gases and liquids are often involved. Compressible fluids (gases) and incompressible fluids (liquids) vary somewhat in behavior, though in cases where pressure and density changes are small, the gases may be treated as incompressible fluids.

## THEORY OF FLUID FLOW

The following energy equation for one dimensional steady flow processes will serve as a basis for the theory of the flow of fluids. This equation is presented in several ways in various texts, but a suitable form is

$$\frac{V_1^2}{2g_c} + J u_1 + p_1 v_1 + J q + \frac{g}{g_c} z_1 = \frac{V_2^2}{2g_c} + J u_2 + p_2 v_2 + W + \frac{g}{g_c} z_2 \quad (1)$$

where

- $V$  = velocity in feet per second.
- $g$  = gravitational acceleration, in feet per (second) (second).
- $g_c$  = gravitational conversion factor = 32.174 (pounds mass per pound force)  $\times$  ft per (second) (second).
- $J$  = mechanical equivalent of heat = 778 foot pounds per Btu.
- $u$  = internal energy, in Btu per pound of fluid.
- $p$  = pressure in pounds per square foot.
- $v$  = specific volume, in cubic feet per pound.
- $W$  = mechanical work done by the fluid in foot pounds per pound of fluid.
- $q$  = heat transferred to the fluid in Btu per pound of fluid flowing.
- $z$  = elevation above some arbitrary datum, in feet.
- Subscript 1 refers to the entrance, subscript 2 to the exit.

Introducing the enthalpy  $h$ , which by definition is  $u + \frac{pv}{J}$ , expressed in Btu per pound of fluid, Equation 1 becomes

$$\frac{V_1^2}{2g_c} + J h_1 + J q + \frac{g}{g_c} z_1 = \frac{V_2^2}{2g_c} + J h_2 + W + \frac{g}{g_c} z_2 \quad (2)$$

The equivalent differential form for energy Equation 1 is

$$\frac{1}{2g_c} dV^2 + J du + d(pv) + \frac{g}{g_c} dz - J dq + dW = 0 \quad (3)$$

Replacing  $v$  by its equal  $\dot{q}/g\rho$  (where  $\rho$  is density in pounds weight per cubic foot) and rearranging, Equation 3 becomes

$$\frac{1}{2g} dV^2 + \frac{1}{\rho} dp + dz + \frac{g_c}{g} [J du + p dv - J dq + dW] = 0 \quad (4)$$

In the case of flow through a pipe, no outside work is performed so that  $dW = 0$ . Furthermore,

$$J du + p dv = JT ds = J dq + JT ds' \quad (5)$$

where

$ds$  = total change in entropy.

$ds'$  = change in entropy due to internal irreversibility from turbulence and friction.

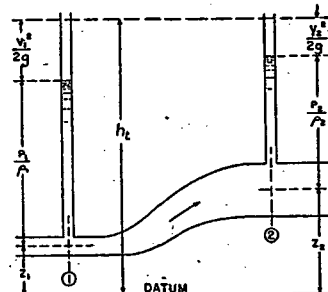


FIG. 1. RELATION OF VARIOUS FACTORS IN BERNOULLI EQUATION

Accordingly, Equation 4 may be written

$$\frac{1}{2g} dV^2 + \frac{dp}{\rho} + dz + \frac{g_c}{g} JT ds' = 0^* \quad (6)$$

In cases where there is no internal irreversibility,  $ds' = 0$ , and Equation 6 may be integrated to give

$$\frac{V_1^2}{2g} + \frac{p_1}{\rho_m} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho_m} + z_2 \quad (7)$$

where  $\rho_m$  is the proper mean density.

This is commonly called the Bernoulli equation, named after the Swiss mathematician and physician who first propounded the theory.  $\frac{V^2}{2g}$  is

known as the velocity head,  $\frac{p}{\rho}$  is the pressure head, and  $z$  is the elevation head, all in feet of the fluid; the total head,  $h_t$  is the sum of the other three heads. Fig. 1 shows diagrammatically the relation of the various factors. The pressure at point 2 is lower than at point 1 because of the elevation of point 2 over point 1, and the velocity at point 2 is lower than at point 1 because of the larger pipe diameter at point 2. If the pipe

\* In the analysis of subsequent portions of this chapter the distinction between  $g$  and  $g_c$  will be omitted. Aside from the dimensional consistency the factor,  $g/g_c$ , is not in general significant in fluid flow analysis.

diameter were the same throughout, the velocity, and consequently the velocity head, would be the same at both points, but the higher elevation at point 2 would still be responsible for a loss in pressure. The utility of the equation is evident, though it should be remembered that in it the effects of friction and turbulence are neglected, and that Fig. 1 represents ideal conditions. It should also be noted that care must be taken in determining the proper mean density. Accordingly, the Bernoulli equation is applied most conveniently to incompressible fluids for which density is constant.

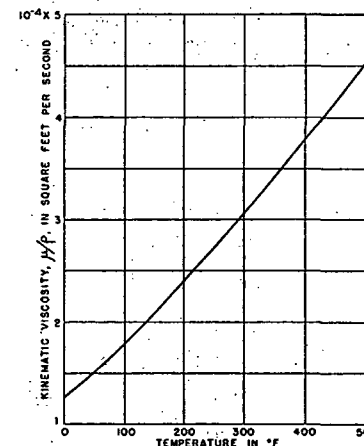


FIG. 2. RELATION OF KINEMATIC VISCOSITY TO TEMPERATURE OF AIR

### Pressure Loss in Circular Pipes

The pressure loss in circular pipes is customarily expressed by the formula:

$$h_f = \frac{f l V^2}{2g d} \quad (8)$$

where

$h_f$  = the loss in head of the fluid under conditions of flow, in feet.

$l$  = the length of the pipe, in feet.

$V$  = the velocity, in feet per second.

$g$  = the acceleration due to gravity = 32.174 ft per (second) (second).

$d$  = the internal diameter of the pipe, in feet.

$f$  = a dimensionless friction coefficient.

The formula is generally known by the name of Darcy or Fanning, though it seems to have been originated by d'Aubisson de Voisins in 1834.

The factor  $f$  is a function of the Reynolds number,

$$N_{Re} = \frac{d V \rho}{\mu} \quad (9)$$



where

$N_{Re}$  = Reynolds number.

$\rho$  = the density in pounds per cubic foot.

$\mu$  = the absolute viscosity in pounds per foot-second.

Both  $f$  and the Reynolds number are dimensionless. To aid in computing the Reynolds number, values of  $\frac{\mu}{\rho}$ , the kinematic viscosity, are shown as a function of temperature for air in Fig. 2, and for water in Fig. 3.

Fig. 4 shows the relation between  $f$  and the Reynolds number, adapted from a review by Moody.<sup>1</sup> The straight line sloping downward at the left of the chart supplies the values of  $f$  for laminar flow determined by the formula:

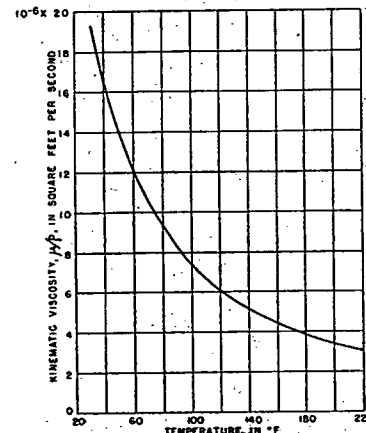


FIG. 3. RELATION OF KINEMATIC VISCOSITY TO TEMPERATURE OF WATER

$$f = \frac{64}{N_{Re}} \quad (10)$$

With laminar flow, the velocity profile is a parabola, having the formula:

$$V = \frac{\rho h_1}{4\mu L} (r^2 - L^2) \quad (11)$$

where

$r$  = the radius of the pipe in feet.

$L$  = distance perpendicularly from the axis of the pipe, in feet.

Accordingly, the maximum velocity occurs at the center of the pipe and is twice the average velocity; the average velocity is found when  $L = 0.707 r$ . It is worth noting that roughness of the pipe wall has no effect on the loss in head for laminar flow.

Between values of the Reynolds number of 2000 and 4000, there is an

<sup>1</sup> Superior numbers refer to the references at the end of chapter.

unstable region where the flow changes from laminar to turbulent, or vice versa. The actual value is impossible of prediction for any conditions of flow, though in general it may be said that the prevailing type of flow persists into the unstable region; however, once the change starts, it proceeds very rapidly.

When the flow is turbulent, the velocity profile is essentially parabolic over four-fifths of the pipe diameter, but near the pipe walls, the effect of friction becomes evident, and in the boundary layer at the pipe wall the flow is laminar. Fig. 5 compares the velocity profiles for three different Reynolds numbers, but for the same average velocity.

The lower curve in the turbulent region in Fig. 4 represents the relation of  $f$  to the Reynolds number for smooth pipe, such as drawn brass tubing

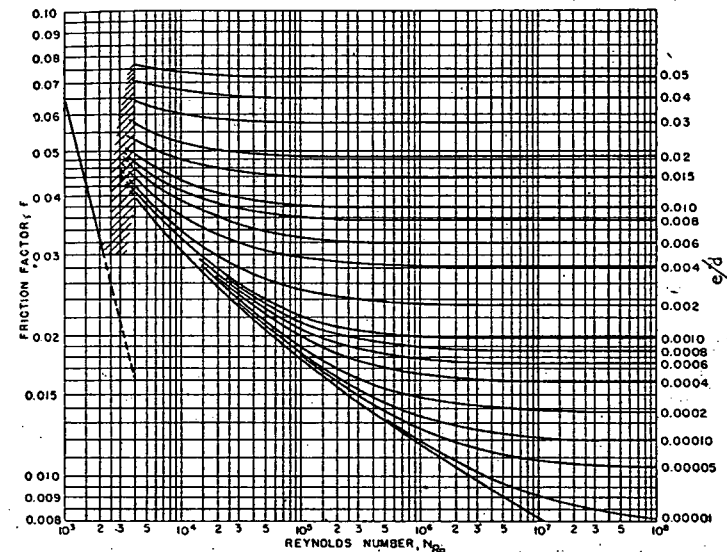


FIG. 4. RELATION BETWEEN FRICTION FACTOR AND REYNOLDS NUMBER  
NOTE: The straight line at left shows values of Friction Factor for laminar flow.  
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or glass tubing. The effect of roughness on  $f$ , an effect which is considerable in turbulent flow, is open to some conjecture; artificially roughened pipes, for instance, give results at variance with actual tests. The curves above the smooth pipe curve of Fig. 4 represent a summary of tests on rough pipe, each of them identified by a value of  $e/d$ , with  $e$  signifying the absolute roughness in feet. Values of  $e$  for different pipes are given in Table 1.

To find the friction loss for any pipe, follow the curve with the proper value of  $e/d$ , to the pertinent value of  $N_{Re}$ , and from this point proceed horizontally to left margin to find the value of  $f$  for use in Equation 8.

The curves in Fig. 4 may be approximated very closely by the empirical formula:<sup>1</sup>

$$f = 0.0055 \left[ 1 + \left( 20,000 \frac{e}{d} + \frac{10^6}{N_{Re}} \right)^{1/2} \right]$$

Equation 8 is applicable to all liquids, and to gases when the pressure loss is less than 10 percent of the initial pressure. When the loss in head is high, the formula to be used for gases is

$$\frac{p_1^2 - p_2^2}{p_1^2} = \frac{fLV_1^2}{gd p_1 v_1} \quad (13)$$

which may be arranged to give the loss in pressure,

$$p_1 - p_2 = p_1 \left[ 1 - \sqrt{1 - \frac{fLV_1^2}{gd p_1 v_1}} \right] \quad (14)$$

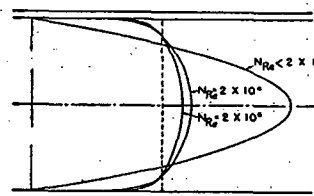


FIG. 5. COMPARISON OF VELOCITY PROFILES FOR 3 DIFFERENT REYNOLDS NUMBERS BUT FOR SAME AVERAGE VELOCITY

#### Pressure Loss in Non-Circular Pipes

The formulas for friction loss in pipes are based on the use of pipes of circular cross-section. The same formulas may be extended to non-circular sections, by suitable modification. In the basic formula, Equation 8, the internal diameter  $d$  is to be replaced by the hydraulic diameter  $d_H$  defined by the equation:

$$d_H = \frac{4 \times \text{area of cross-section}}{\text{wetted perimeter of cross-section}} \quad (15)$$

For example, in a rectangular duct, 1 ft by 2 ft, the cross-section area is 2 sq ft, and the perimeter 6 ft. Then the hydraulic diameter will be  $d_H = (4 \times 2)/6 = 1\frac{1}{3}$  ft.

In the case of a round pipe,

$$d_H = \frac{4 \times \pi d^2/4}{\pi d} = d \quad (16)$$

In computing the Reynolds number, and from that the friction factor, the hydraulic diameter is not to be used. A better approximate procedure is to replace the length in the Reynolds number by the shortest dimension plus one-fourth of the hydraulic diameter. Thus, in a duct of dimension  $a \times b$  where  $a < b$ ,  $N_{Re}$ , for the purposes of calculating friction factors, is

$$N_{Re} = (a + 0.25d_H)V\rho/\mu \quad (17)$$

TABLE 1. VALUES OF  $e$  FOR DIFFERENT KINDS OF PIPE

| TYPE OF PIPE                          | $e$             |
|---------------------------------------|-----------------|
| Smooth drawn tubing.....              | 0.00005         |
| Commercial steel or wrought iron..... | 0.00015         |
| Asphalted cast-iron.....              | 0.0004          |
| Galvanized iron.....                  | 0.0005          |
| Cast-iron.....                        | 0.00085         |
| Wood stave.....                       | 0.0008 to 0.003 |
| Concrete.....                         | 0.001 to 0.01   |
| Riveted steel.....                    | 0.003 to 0.03   |

This value of  $N_{Re}$  may be used in Equation 10 for laminar flow, and in Equation 12 or Fig. 4 for turbulent flow. The error in the approximation is somewhat greater for laminar than for turbulent flow. In the former case, the relative error may be as much as 10 percent, while in the latter it almost always is less than 3 percent.

#### FLOW OF COMPRESSIBLE FLUIDS

In the flow of compressible fluids, the large density variations make impracticable the use of the Bernoulli equation, (Equation 7). In certain special cases, however, the exact equations for compressible flow may be stated. If flow occurs with no friction or other internal irreversibility, Equation 6 becomes

$$\frac{1}{2g} dV^2 + \frac{dp}{\rho} = 0 \quad (18)$$

If, in addition, the flow is adiabatic,

$$pp^{-k} = p_1 p_1^{-k} \quad (19)$$

so that Equation 18 becomes

$$\frac{1}{2g} dV^2 + \frac{p_1^{1/k}}{\rho_1} \frac{dp}{p^{1/k}} = 0 \quad (20)$$

or by integration,

$$\frac{1}{2g} (V_2^2 - V_1^2) + \frac{k}{k-1} \frac{p_1}{\rho_1} \left[ \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right] = 0 \quad (21)$$

This extension to compressible flow of Bernoulli's equation reduces to the more familiar form if the pressure change is small.

The ratio of specific heats,  $k$ , is used extensively in fluid dynamics; values of  $k$  for various gases are given in Table 2.

TABLE 2. RATIO OF SPECIFIC HEAT AT CONSTANT PRESSURE TO SPECIFIC HEAT AT CONSTANT VOLUME FOR COMPRESSIBLE FLUIDS

| COMPRESSIBLE FLUID                                                                                        | RATIO $k = c_p/c_v$ |
|-----------------------------------------------------------------------------------------------------------|---------------------|
| Helium and other monatomic gases.....                                                                     | 1.66                |
| Air and other diatomic gases.....                                                                         | 1.40                |
| Ammonia and hydrogen sulfide.....                                                                         | 1.34                |
| Carbon dioxide, methane, natural gas, superheated steam, moist steam down to a quality of 97 percent..... | 1.28 to 1.32        |
| Sulfur dioxide, ethylene, acetylene.....                                                                  | 1.24 to 1.26        |

It is convenient in the analysis of compressible flow to introduce the velocity of propagation of pressure impulses or, more familiarly, the sonic velocity,  $a$ . For perfect gases this is given by the equation:

$$a^2 = kgp/\rho = kgRT \quad (22)$$

Accordingly, Equation 21 may be written

$$\frac{1}{2}(V_2^2 - V_1^2) + \frac{a_1^2}{k-1} \left[ \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right] = 0 \quad (23)$$

or, by rearrangement,

$$\frac{p_2}{p_1} = \left[ 1 - \frac{k-1}{a_1^2} \left( \frac{V_2^2 - V_1^2}{2} \right) \right]^{\frac{k}{k-1}} \quad (24)$$

which permits the calculation of the ratio of pressures at entrance and exit of the steady flow device—pipe, orifice, or nozzle. From Equations 19 and 22 it follows that

$$\frac{a_2^2}{a_1^2} = \frac{T_2}{T_1} = \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} \quad (25)$$

so that

$$\frac{k-1}{2} (V_2^2 - V_1^2) + a_2^2 - a_1^2 = 0 \quad (26)$$

and

$$\frac{a_2^2}{a_1^2} = \frac{1 + \frac{k-1}{2} \frac{V_1^2}{a_1^2}}{1 + \frac{k-1}{2} \frac{V_2^2}{a_2^2}} \quad (27)$$

The ratio of flow velocity to sonic velocity is known as the Mach number,

$$M = V/a$$

This parameter is particularly useful in compressible flow analysis. In general, if  $M \leq 0.1$  the flow may be considered to be incompressible. This is generally true in heating and ventilating air ducts.

In terms of the Mach number

$$\frac{a_2^2}{a_1^2} = \frac{T_2}{T_1} = \frac{1 + \frac{k-1}{2} M_1^2}{1 + \frac{k-1}{2} M_2^2} \quad (28)$$

and

$$\frac{p_2}{p_1} = \left( \frac{1 + \frac{k-1}{2} M_1^2}{1 + \frac{k-1}{2} M_2^2} \right)^{\frac{k}{k-1}} \quad (29)$$

The quantity,

$$p^0 = p \left( 1 + \frac{k-1}{2} M^2 \right)^{\frac{k}{k-1}} \quad (30)$$

is called the stagnation pressure, and gives a measure of pressure energy. For incompressible flow

$$p^0 = p + \frac{1}{2g} \rho V^2 = p + q \quad (31)$$

where

$$q = \frac{1}{2g} \rho V^2 \quad (32)$$

and is the dynamic pressure. A total head tube measures stagnation pressure directly.

From Equation 29 it follows that for frictionless, adiabatic flow

$$p^0 = p_1^0 \quad (33)$$

This represents another extension of the Bernoulli equation to compressible flow. Friction will cause a loss in pressure energy.

#### Ideal Flow through Nozzle or Orifice

The majority of low-head measuring systems depend upon a correlation between pressure drop, area, and quantity of flow. The basic formulas may be stated on the assumption that the flow is frictionless and adiabatic. Designating the main stream by station 1, and flow at some measuring restriction by station 2, the flow in pounds per second is

$$w = \rho_1 A_1 V_1 = \rho_2 A_2 V_2 \quad (34)$$

or, in terms of Mach number,

$$w = A_2 M_2 \sqrt{k g p_2 \rho_2} \quad (35)$$

According to Equation 29

$$\left( \frac{p_1}{p_2} \right)^{\frac{k-1}{k}} = \frac{1 + \frac{k-1}{2} M_1^2}{1 + \frac{k-1}{2} M_2^2} \quad (36)$$

from which

$$M_2^2 = \frac{2}{k-1} \left( \frac{1 + \frac{k-1}{2} M_1^2}{1 - M_1^2/M_2^2} \right) \left[ \left( \frac{p_1}{p_2} \right)^{\frac{k-1}{k}} - 1 \right] \quad (37)$$

so that

$$w = A_2 \sqrt{\frac{1 + \frac{k-1}{2} M_1^2}{1 - M_1^2/M_2^2}} \sqrt{\frac{2k g p_2 \rho_2}{k-1} \left[ \left( \frac{p_1}{p_2} \right)^{\frac{k-1}{k}} - 1 \right]} \quad (38)$$

If the initial velocity is sufficiently small,  $M_1^2$  will be negligible so that

$$w = A_2 \sqrt{\frac{2k g p_2 \rho_2}{k-1} \left[ \left( \frac{p_1}{p_2} \right)^{\frac{k-1}{k}} - 1 \right]} = A_2 \sqrt{\frac{2k g p_1 \rho_1}{k-1} \left( \frac{p_2}{p_1} \right)^{\frac{k+1}{k}} \left[ \left( \frac{p_1}{p_2} \right)^{\frac{k-1}{k}} - 1 \right]} \quad (39)$$

If this is computed and the figures are plotted, the curved line (partly

solid and partly broken) of Fig. 6 is found. The maximum value of  $\frac{p_2}{p_1}$  may be computed by differentiating  $w$  with respect to  $p_2$  and equating the result to zero. This operation produces the formula:

$$\frac{p_2}{p_1} = \left( \frac{2}{k+1} \right)^{\frac{k}{k-1}} \quad (40)$$

For air, with  $k = 1.40$ ,  $\frac{p_2}{p_1} = 0.53$ .

Actually, the broken part of the curve is not attained for the flow in the nozzle. If the ratio of  $p_2$  to  $p_1$  is decreased from unity, the mass rate of discharge, as well as the volume, increases from zero to a maximum, as shown by the solid section of the curve in Fig. 6; thereafter, as  $p_2/p_1$  is decreased further, the discharge is constant, as indicated by the horizontal line. The value of  $p_2$  at the maximum point is called the critical pressure, or  $p_c$ , and it is seen that  $p_c$  is approximately 53 percent of  $p_1$  when air is flowing.

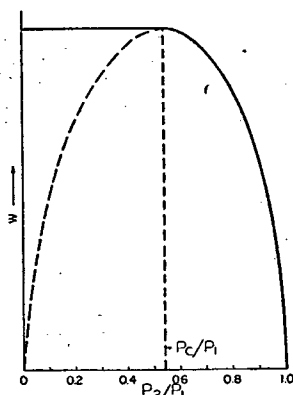


FIG. 6. RELATION OF FLOW OF GAS TO PRESSURE DROP IN A CONVERGING TUBE

To find the velocity at the critical pressure, it is assumed that the upstream velocity  $V_1$  is so small as to be negligible. Using the subscript  $c$  to indicate conditions at the critical point, from Equation 29

$$\frac{p_c}{p_1} = \frac{1}{\left( 1 + \frac{k-1}{2} M_c^2 \right)^{\frac{k}{k-1}}} \quad (41)$$

or

$$M_c = \sqrt{\frac{2}{k-1} \left[ \left( \frac{p_1}{p_c} \right)^{\frac{k-1}{k}} - 1 \right]} \quad (42)$$

Substituting the critical pressure ratio from Equation 40 it follows that

$$M_c = 1 \quad (43)$$

or that the velocity at the throat is equal to the local sonic velocity.

In developing the working equations for orifices and nozzles, it is customary to start with the incompressible form of the flow Equation 38. In this case both  $M_1$  and  $M_2$  are small quantities,  $p_1 = p_2$ , and  $(p_1 - p_2)/p_1 = \Delta p/p_1$  is small. Retaining only first order terms, it follows from Equation 35 that

$$\frac{M_1}{M_2} = \frac{A_2}{A_1} \quad (44)$$

so that

$$\sqrt{\frac{1 + \frac{k-1}{2} M_1^2}{1 - M_1^2/M_2^2}} \approx \frac{1}{\sqrt{1 - (A_2/A_1)^2}} = \frac{1}{\sqrt{1 - \beta^2}} \quad (45)$$

where  $\beta = D_2/D_1$ . The quantity  $1/\sqrt{1 - \beta^2}$  is the velocity of approach

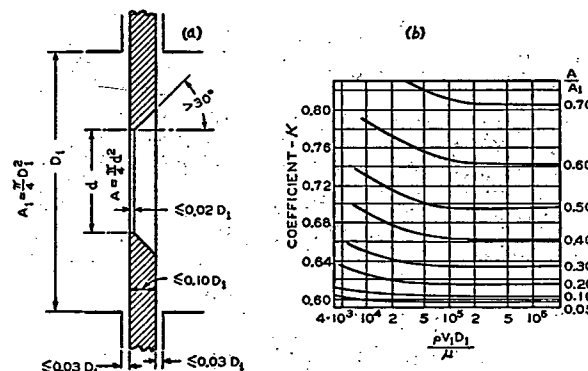


FIG. 7. DIMENSIONS AND FLOW COEFFICIENT FOR STANDARD SQUARE-EDGED ORIFICE WITH CORNER TAPS OR ANNULAR SLITS  
(Coefficient shown as a function of Reynolds Number and Ratio,  $A_1/A_2$ )

NOTE: From Reference 4. Used by permission.

factor as generally used, with  $\beta$  being the ratio of the throat or orifice diameter to the pipe diameter.

Since  $\Delta p/p_1$  is small

$$\frac{2k}{k-1} \left[ \left( \frac{p_1}{p_2} \right)^{\frac{k-1}{k}} - 1 \right] \approx \frac{2\Delta p}{p_2} \quad (46)$$

and the mass flow is

$$w = \frac{A_2}{\sqrt{1 - \beta^2}} \sqrt{2g\rho\Delta p} \quad (47)$$

The volume flow is then

$$Q = A_2 \frac{1}{\sqrt{1 - \beta^2}} \sqrt{2g\Delta p/\rho} = A_2 \frac{1}{\sqrt{1 - \beta^2}} \sqrt{2gh_1} \quad (48)$$

## FLOW MEASUREMENT

The measurement of quantity of flow of fluids is generally accomplished either by making observations on the change of state due to flow-system configuration, such as the pressure drop across a metering orifice, or by the displacement of some device, such as a rotating vane system. The selection of the metering system will be determined by the type of fluid, the precision of measurement desired, the cost of equipment and installation, the range of flow quantity, the ease of maintenance, and the method of observation and recording.

Fluid meters may be classified as follows: (1) *Head Meters* (Pressure Sensitive), which may be of *Venturi*, *flow nozzle*, *orifice plate*, or *Pilot tube* types; (2) *Area Meters*, which may be of *gate*, *tapered tube*, or *tapered plug* types; (3) *Force Meters*, which may be of *vane*, *propellor*, or *turbine* types; (4) *Quantity Meters*, which may be of *weighing tank*, *reciprocating piston*, or *geared impeller* types.

Rate meters are generally of the first three groups, although rates are

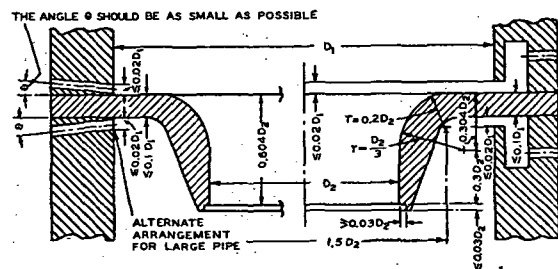


FIG. 8. DIMENSIONS FOR INTERNATIONAL STANDARDS ASSOCIATION FLOW NOZZLE

NOTE: From Reference 3. Used by permission of A.S.M.E.

obtainable from timed observations of quantity meters. Similar quantity measurements can be obtained by suitable integration of rate meter indications.

## Head Meters

The head meter is of sufficient flexibility so that almost any type of flow measuring problem can be handled. For this reason, standard and reference measurements are usually made in this way. With proper care, extreme precision can be obtained. Also, an inexpensive installation can be made to give moderate precision. In general, a head meter requires fairly competent installation and maintenance to give satisfactory service.

Among the types of head meters, the Venturi has the advantage of having a low pressure loss, but requires considerable length of space. The orifice plate reduces the required length to a minimum at the cost of considerable pressure drop. The flow nozzle represents a compromise, but must be calibrated individually, or made with extreme care from standard specifications, to obtain a good precision of measurement. Standard configurations for representative orifice plates and flow nozzles, are shown in Figs. 7 and 8, respectively. Additional specifications are given in References 2, 3, and 4 at end of chapter.

The measurement of flow in head meters is dependent upon observations

## Fluid Flow

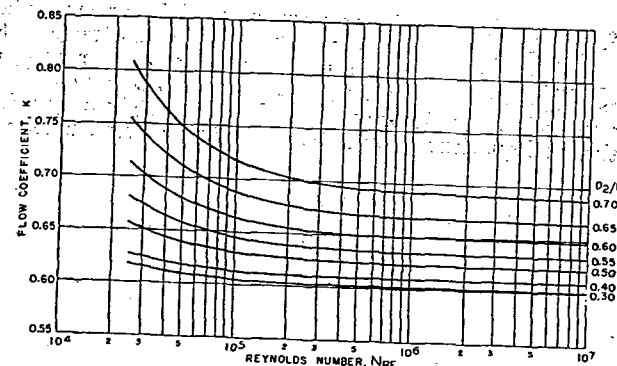


FIG. 9. FLOW COEFFICIENTS,  $K$ , FOR SQUARE-EDGED ORIFICE PLATES AND FLANGE TAPS IN SMOOTH PIPE

NOTE: From Table 6 of Reference 2.

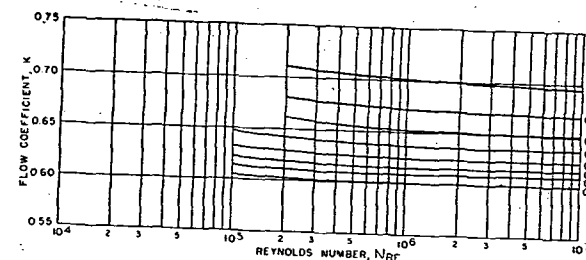


FIG. 10. FLOW COEFFICIENTS,  $K$ , FOR SQUARE-EDGED ORIFICE PLATES AND RADIUS TAPS IN SMOOTH PIPE

NOTE: From Fig. 36d of Reference 3.

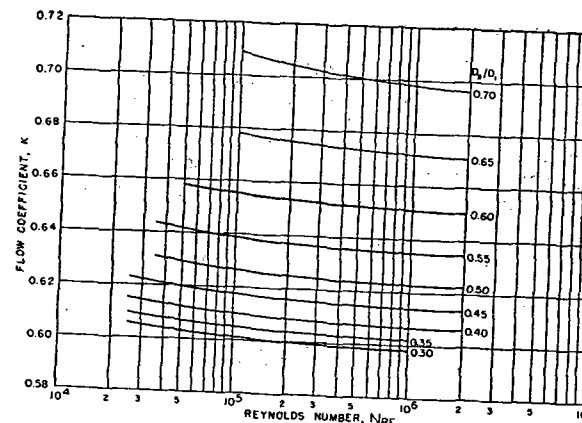


FIG. 11. FLOW COEFFICIENTS,  $K$ , FOR SQUARE-EDGED ORIFICE PLATES AND VENA CONTRACTA TAPS, IN SMOOTH PIPE

NOTE: From Table 7 of Reference 2.

of a static pressure difference between two parts of the system. Standard locations for these static pressure measurements are illustrated in Figs. 8 and 16. In general, there exists a reduction in area, either by a smooth contour as in the case of a Venturi or flow nozzle, or by a vena contracta following an orifice. In either case, the flow will be given by a suitable modification of Equations 47 and 48. Adding a correction term, these become

$$w = \frac{A_2 C}{\sqrt{1 - \beta^4}} \sqrt{2g\rho\Delta p} \quad (49)$$

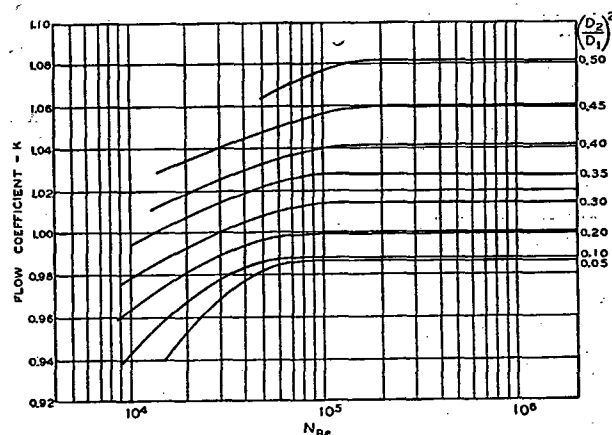


FIG. 12. FLOW COEFFICIENT FOR INTERNATIONAL STANDARDS ASSOCIATION FLOW NOZZLE SHOWN IN FIG. 8 AS A FUNCTION OF AREA RATIO  $(D_2/D_1)^2$  AND THE REYNOLDS NUMBER  $N_{Re}$ .

NOTE: From Reference 3. Used by permission of ASME

and

$$Q = \frac{A_2 C}{\sqrt{1 - \beta^4}} \sqrt{2gh_1} \quad (50)$$

In all cases,  $A_2$  refers to the minimum area of the Venturi, nozzle, or orifice. The correction factor  $C$  is introduced to account for any loss due to departure from isentropic flow, and for any deviation between the downstream measured pressure and the actual pressure at the minimum section. Since these corrections are usually dependent on configuration, as described by the ratio of upstream to minimum area  $A_1/A_2$ , it is often convenient to introduce a combined flow coefficient,  $K$  which is

$$K = \frac{C}{\sqrt{1 - \beta^4}} \quad (51)$$

so that

$$w = KA_2 \sqrt{2g\rho\Delta p} \quad (52)$$

and

$$Q = KA_2 \sqrt{2gh_1} \quad (53)$$

The coefficients  $K$  and  $C$  will be determined by the area ratio  $A_1/A_2$ , or by the diameter ratio  $D_1/D_2$  and the Reynolds number. Extensive data are available from various sources.<sup>2,4</sup> Figs. 9, 10, 11, 12 show representative values of  $K$  based on  $N_{Re}$ , the Reynolds number, and the ratio of diameter of the orifice or nozzle throat to pipe diameter.

In any specific application, numerical values for areas, densities, and pressure units can be substituted in Equations 52 and 53 to obtain compact working formulas. In planning flow measurements, standard flow meter

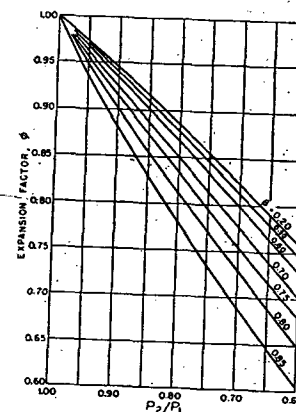


FIG. 13. RELATION OF EXPANSION FACTOR,  $\phi$ , FOR NOZZLES TO DIAMETER RATIO AND PRESSURE LOSS FOR AIR AND OTHER DIATOMIC GASES

dimensions and standard pressure tap locations should preferably be used so that published flow coefficients can be used for accurate determination of flow rates.

In measuring the flow of compressible fluids, the approximate Equations 52 and 53 must be corrected for density variations. The need for such correction is evident by comparing Equations 35 and 38 with Equation 47. Introducing a multiplicative correction factor  $\phi$  the equation for flow with no loss becomes:

$$w = \frac{A_2 \phi}{\sqrt{1 - \beta^4}} \sqrt{2g\rho_1(p_1 - p_2)} \quad (54)$$

By comparison with Equation 35,

$$\phi = \sqrt{\frac{k p_2 M_2^2 (1 - \beta^4)}{2 p_1 (p_1/p_2) - 1}} \quad (55)$$

From Equations 34 and 35,

$$M_1^2/M_2^2 = \beta^4(p_2/p_1)^{1/k} \quad (56)$$

Hence, by Equation 38 for a small value of  $M_1$ ,

$$\phi = \sqrt{\left(\frac{p_2}{p_1}\right)^{1/k} \left(\frac{k}{k-1}\right) \frac{\left(\frac{p_1}{p_2}\right)^{(k-1)/k} - 1}{\left(\frac{p_1}{p_2}\right) - 1} \frac{1 - \beta^4}{1 - \beta^4 \left(\frac{p_2}{p_1}\right)^{2k}}} \quad (57)$$

From Equations 37 and 56, if  $M_1$  is not too large,

$$\frac{2}{k} \frac{1}{M_1^2} \left(\frac{p_1}{p_2} - 1\right) \approx 1 - \beta^4 + \frac{1}{2} [1 - 2(k-2)\beta^4] M_1^2 \quad (58)$$

so that, approximately,

$$\phi \approx 1 - \frac{3}{8} \left[ 1 + \left(1 - \frac{2k}{3}\right) \beta^4 \right] M_1^2 \quad (59)$$

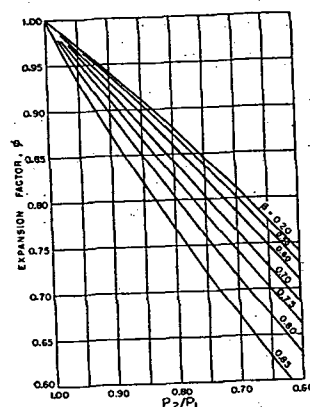


FIG. 14. RELATION OF EXPANSION FACTOR,  $\phi$ , FOR NOZZLES TO DIAMETER RATIO AND PRESSURE LOSS FOR STEAM, CARBON DIOXIDE AND NATURAL GAS

where to the same degree of approximation from Equation 36

$$M_1^2 = 2 \frac{p_1 - p_2}{k p_1} \quad (60)$$

Values of  $\phi$  are also given by Figs. 13 and 14.

While  $\phi$  may be used for smooth nozzles and Venturi tubes, it is necessary in the case of orifices, where the departure from ideal flow is significant, to replace  $\phi$  by an empirical factor  $Y$  obtained by the equation

$$Y = 1 - (0.41 + 0.35\beta^4) \left( \frac{p_1 - p_2}{p_1} \right) \quad (61)$$

When this correction is used, the flow will be given by the equation

$$w = K A_2 Y \sqrt{2 g \rho_1 (p_1 - p_2)} \quad (62)$$

#### Location of Head Meters and Pressure Taps

In the installation of Venturis, orifices, and nozzles, care must be taken in regard to upstream and downstream flow conditions. Recommended

practice, with reference to fittings and valves, is shown by Fig. 15. If these conditions cannot be met, some flexibility is possible by introducing straightening vanes, as described more fully in References 2 and 5.

The static pressure difference across the head meter is measured by suitably located static pressure taps. For orifices, the different sets of pressure taps are called flange taps, radius taps, vena contracta taps, and pipe or full-flow taps. The relative locations of the first three of these are shown in Fig. 16.

The flow coefficients in Figs. 9, 10 and 11 apply only to measurements made with these pressure tap locations. The need for applying suitable

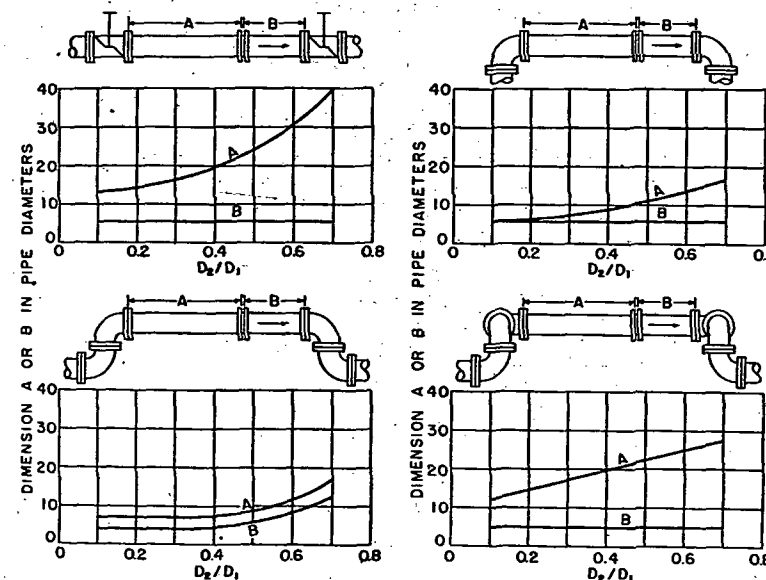


FIG. 15. MINIMUM CONDITIONS TO BE OBSERVED WHEN INSTALLING ORIFICES AND NOZZLES BETWEEN FITTINGS AND VALVES

coefficients to measurements obtained by means of the different taps, is indicated by the curve of change, in pressure of the flowing fluid, shown in the lower part of Fig. 16. Pipe taps are located  $2\frac{1}{2}$  pipe diameters upstream and 8 pipe diameters downstream (both distances being measured from the upstream face of the orifice plate) so that pressures are measured before the orifice plate has had any effect on the flow, and after the recovery in pressure has been completed. The use of pipe or full-flow taps has been limited to the metering of natural fuel gas in certain areas. As they are not suited to use in heating and ventilating work, no data for them are given in this chapter.

Still another type of pressure tap, the corner tap, is used in European practice. Pressures are taken from recesses in the flange connected to annular slits in the corners formed by the pipe wall and the orifice plate.

Coefficients for these taps have been adopted by the *International Standards Association*, but are not used commercially in America.

It will be noted that the location of the downstream pressure tap of the vena contracta arrangement is variable. Vena contracta is the term applied to the minimum cross-section of the jet from the orifice, where the static pressure is at a minimum. Its location, and the location of the downstream vena contracta tap, vary with the ratio of orifice to pipe diameter, and with rate of flow, as shown in Fig. 17; the tap is generally located in accordance with the mean curve in the figure.

Similar precautions are required when using flow nozzles and Venturi tubes. In many cases, these will be supplied ready for installation. In such cases, the manufacturer's instructions should be followed with care

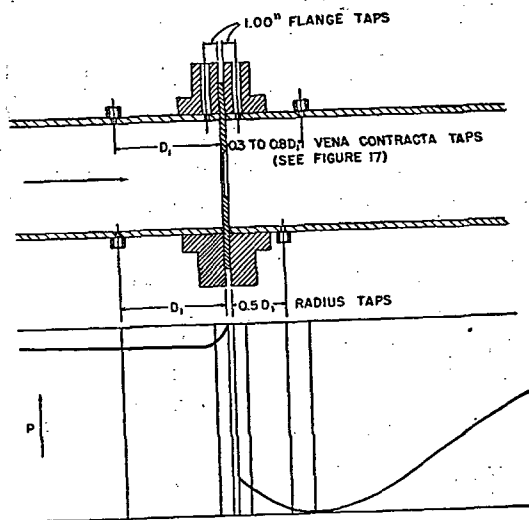


FIG. 16. RELATIVE LOCATION OF FLANGE, RADIUS AND VENA CONTRACTA TAPS

in order to avoid serious errors. Further information on such systems is given in References 2, 3, and 5.

#### Pitot Tube

In certain cases, such as in rectangular ducts, it is impracticable to use standard orifices, and consequently, either a specially designed orifice must be calibrated, or an independent flow device must be used. In either case, the Pitot tube is useful. It consists essentially of an inner bent tube with its open end pointing upstream so as to measure total pressure, and an outer tube having small holes on the side for communicating static pressure to a manometer. (See Fig. 3, Chapter 52). The difference in liquid level in the manometer will be proportional to the square of the velocity, for incompressible flow, so that in general

$$V = \sqrt{2gh_1} \quad (63)$$

For compressible flow, the differential head is to be divided by the correction  $F_c$  from Equation 64,

$$F_c = 1 + \frac{1}{2}M^2 + \frac{1}{4}M^4 \quad (64)$$

where

$$M^2 = 2 \frac{p_0 - p}{\rho p} \quad (65)$$

In the use of a Pitot tube system, care is required in obtaining correct total and static pressures. The total pressure tube must be smoothly constructed, and should point directly upstream. The static pressure tap must be located so that local flow interferences will not reduce the value. In any case, it is better to obtain an independent calibration, or use a specially designed and manufactured probe. A number of such Pitot tube probes are available, and can be used without calibration.

In using Pitot tubes to obtain flow rates, it is necessary to make a traverse of the pipe and thereby to obtain one of the profiles of Fig. 5.

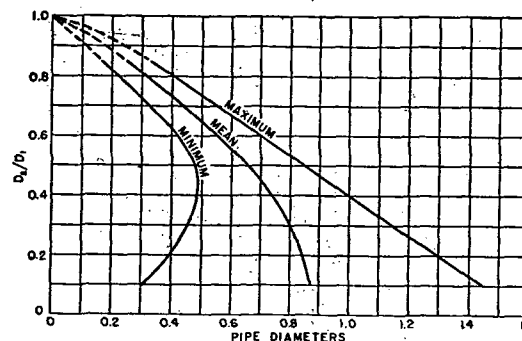


FIG. 17. LOCATION OF VENA CONTRACTA IN RELATION TO RATIO OF ORIFICE TO PIPE DIAMETER AND TO RATE OF FLOW

In rectangular ducts or near valves or fittings, a disturbed flow pattern would be obtained, and therefore, in such cases, a fairly complete survey should be made. The flow in such cases will be computed from the average of the local velocities, as obtained by Equation 63.

#### Variable Area Flow Meters

For permanent installations where high precision, ruggedness, and ease of operation are important, the variable area flow meter has proved very satisfactory. Its most frequent use is in measurement of liquids or gases in small diameter pipes. For ducts or pipes over 6 in. in diameter, the expense of this meter may not be warranted. In large systems, however, the meter might be placed in a by-pass line and used in conjunction with an orifice.

In its most common form, the variable area meter, Fig. 18, consists essentially of a float which is free to move vertically in a transparent tapered tube. The fluid to be metered enters at the narrow bottom end of the tube and moves upward, passing at some point through the annulus



formed between the float and inside wall of the tube. At any particular rate of flow, the float assumes a definite position in the tube, its location being indicated by means of a calibrated scale on the tube.

The position of the float is established by a balance between the fluid pressure forces across the annulus and the weight of the float itself. The buoyant force which must support the float,  $v_f(\rho_f - \rho)$ , is balanced by the pressure difference acting on the cross-section area of the float,  $A_f \Delta p$ , where  $\rho_f$ ,  $A_f$ ,  $v_f$ , are, respectively, the float density, float cross-section area, and float volume. Accordingly, the difference in head across the annulus is given by

$$h_f = \frac{\Delta p}{\rho} = \frac{v_f(\rho_f - \rho)}{A_f \rho} \quad (66)$$

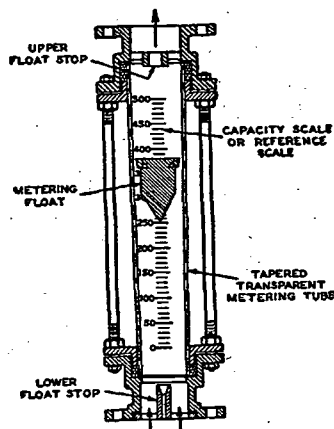


FIG. 18. SCHEMATIC DIAGRAM OF VARIABLE AREA FLOW METER

The volume flow follows from equation (53) as

$$Q = KA_2 \sqrt{2g v_f (\rho_f - \rho) / \rho A_1} \quad (67)$$

and the mass flow as

$$w = \rho Q = KA_2 \sqrt{2g v_f (\rho_f - \rho) \cdot \rho / A_1} \quad (68)$$

The flow for any selected fluid is, accordingly, very nearly proportional to the area, so that a convenient calibration of the tube may be obtained. The behavior of the flow coefficient,  $K$ , has been investigated<sup>6</sup> and the action of the flow meter as just outlined, experimentally confirmed. The flow coefficient variation for any float must be known in order to use the meter for different fluids. Some developments have been carried on in the design of the float to reduce the variation of the flow coefficient with Reynolds number, and also with regard to float materials, to reduce the dependence of mass flow calibration on fluid density.

This type of flow meter is usually furnished in standard sizes calibrated

for specific fluids by the manufacturer. The compactness, reliability, and ease of installation are particularly advantageous when many measurements of essentially the same type are to be made.

#### LETTER SYMBOLS USED IN CHAPTER 4

- $\beta$  = ratio, throat or orifice diameter to pipe diameter.
- $\mu$  = absolute viscosity, pounds per foot second.
- $\mu/\rho$  = kinematic viscosity, square feet per second.
- $\rho$  = density of flowing fluid, pounds per cubic foot.
- $\rho_m$  = proper mean density.
- $\rho_w$  = density of water at 60 F (62.37 lb per cubic foot).
- $\rho_f$  = density of float in variable area meters.
- $\phi$  = expansion factor for nozzles.
- $a$  = velocity of sound, feet per second.
- $A$  = cross-sectional area of flow, square feet.
- $C$  = correction factor (coefficient of discharge) for flow through orifice, nozzle or Venturi.
- $c_p$  = specific heat of gas at constant pressure.
- $c_v$  = specific heat of gas at constant volume.
- $D$  = diameter of fluid stream, feet.
- $d$  = internal diameter of pipe, feet.
- $d_H$  = hydraulic diameter, feet.
- $e$  = absolute roughness of pipe surface, feet.
- $F_c$  = correction factor for differential head in compressible flow.
- $f$  = dimensionless friction coefficient.
- $g$  = gravitational acceleration, feet per (second) (second).
- $g_c$  = gravitational conversion factor = 32.174 (pounds mass per pound force)  $\times$  feet per (second) (second).
- $h$  = enthalpy, Btu per pound of fluid.
- $h_f$  = loss of head, feet of fluid.
- $h_t$  = total head, feet of fluid.
- $J$  = mechanical equivalent of heat = 778 foot pounds per Btu.
- $K$  = flow coefficient (correction factor), including velocity of approach correction factor, for flow through orifice, nozzle or Venturi.
- $k$  = ratio of specific heat at constant pressure to specific heat at constant volume.
- $L$  = perpendicular distance from axis of pipe, feet.
- $l$  = length of pipe, feet.
- $M$  = Mach number.
- $N_{Re}$  = Reynolds number.
- $p$  = pressure, pounds per square foot.
- $p^0$  = stagnation pressure.
- $p_c$  = critical pressure.
- $Q$  = discharge rate, cubic feet per second.
- $q$  = heat transferred to the fluid per pound of fluid flowing.
- $R$  = gas constant.
- $r$  = radius of pipe in feet.
- $s$  = entropy of fluid in Btu per (pound) (Fahrenheit degree).
- $T$  = temperature, Fahrenheit degrees, absolute.
- $u$  = internal energy, Btu per pound of fluid.
- $V$  = velocity, feet per second.
- $V_c$  = critical velocity, feet per second.
- $v$  = specific volume, cubic feet per pound.
- $W$  = mechanical work, foot pounds per pound of fluid flowing.
- $w$  = mass flow of gas, pounds per second.
- $Y$  = expansion factor—correcting for expansion of gas under reduced downstream pressure.
- $z$  = elevation above some arbitrary datum, feet.

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## CHAPTER 5

## HEAT TRANSFER

Conduction, Convection, Radiation; Equations for Conduction, Convection, Radiation and Combined Convection and Radiation; Heat-Flow Resistance, in Series and Parallel; Practical Heat Transfer Problems; Periodic and Transient Heat Flow

HEAT is the form of energy that is transferred by virtue of an existing temperature difference. The temperature difference is the potential which causes the transfer, the latter in turn being resisted by the thermal properties of the material combined in a single term known as the resistance. Energy exchange associated with evaporation, condensation, etc., is treated elsewhere such as in the section on *cooling tower design* in Chapter 35. The objectives of this chapter are to:

1. Describe the mechanisms and present the rate equations for the different modes of heat transfer.
2. Illustrate the application of the basic concepts to steady-state problems (temperature independent of time or a cyclic variable thereof) by means of several typical solutions of heat transfer systems.
3. Present concise summaries of available methods of analysis for transient and periodic heat transfer problems.

Further applications to specific systems will be found throughout THE GUIDE.

## CONDUCTION, CONVECTION AND RADIATION

*Thermal conduction* is the term applied to the mechanism of heat transfer whereby the molecules of higher kinetic energy transmit part of their energy to adjacent molecules of lower kinetic energy by direct molecular action. Since the temperature is proportional to the average kinetic energy of the molecules, thermal transfer will occur in the direction of decreasing temperature. The motion of the molecules is random; there is no net material flow associated with the conduction mechanism. In the case of flowing fluids, thermal conduction is significant in the region very close to a solid boundary or wall, for in this region the flow is laminar, parallel with the wall surface, and there are practically no cross currents in the direction of the heat transfer across the solid fluid boundary. In solid bodies the significant mechanism of heat transfer is always thermal conduction.

Contrasted to the thermal conduction mechanism, *thermal convection* involves energy transfer by eddy mixing and diffusion<sup>1</sup> in addition to conduction. This is shown schematically in Fig. 1 which exhibits transfer from a pipe wall at surface temperature  $t_s$  to a colder fluid at a bulk temperature  $t_f$ . (Bulk temperature is that which would be attained if the fluid stream were drawn off at a certain section and mixed. It is therefore somewhat higher than the lowest temperature in the stream.) In the laminar sublayer, immediately adjacent to the wall, the heat transfer occurs by thermal conduction; in the *transition* region, which is called the buffer layer, eddy mixing as well as conduction effects are significant;

in the *eddy* or *turbulent* region the major fraction of the transfer occurs by eddy mixing.

In most commercial equipment the main body of the fluid is in turbulent flow, and the laminar film exists at the solid walls only, as shown in Fig. 1, but in cases of low-velocity flow in small tubes, or with viscous liquids such as heavy oil (low Reynolds numbers), the entire flow may be laminar. In these latter cases there is no transition or eddy region.

When the fluid currents are produced by sources external to the heat transfer region, as for example by a pump, the described solid to fluid heat transfer is termed *forced convection*. In contrast, if the fluid currents are generated internally, as a result of non-homogeneous densities arising from the temperature variations, the heat transfer is termed *free convection*.

In the conduction and convection mechanisms, the transfer of heat is associated with matter. For *radiant heat transfer*, however, a change in

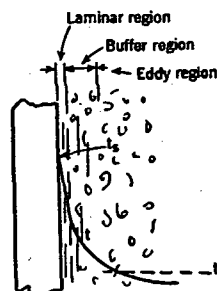


FIG. 1. THERMAL CONVECTION CONDITIONS

energy form takes place, from internal energy at the source to electromagnetic energy for transmission, then back to internal energy at the receiver.

The rate of heat transfer, corresponding to the three transfer mechanisms previously described, may be expressed by three rate equations. These are similar to Ohm's Law for electrical flow, the current flow through a resistance being proportional to the potential. The convection and radiation flow rate expressions may be approximated by a potential (temperature difference) and a resistance in order that heat transfer calculations may be effected more conveniently and rapidly.

#### Thermal Conduction Equation

Equation 1 states symbolically that the thermal conduction per unit transfer area normal to the flow,  $q/A$ , Btu per (hour) (square foot), is proportional to the temperature gradient  $(dt)/(dL)$ , Fahrenheit degrees per foot. The proportionality factor is termed the *thermal conductivity*,  $k$ , Btu per (hour) (square foot) (Fahrenheit degree per foot of thickness).

$$\frac{q}{A} = -k \frac{dt}{dL} \quad (1)$$

The minus sign on the right side of the equation is introduced to indicate positive transfer in the direction of decreasing temperature. Fig. 2 shows the physical significance of the indicated quantities.

It should be emphasized that the thermal conductivity used should be expressed in consistent units; either using the inch or foot throughout.

Expressions of conductivity used in the heating field are usually inconsistent in this sense, in that it is customary to refer to the conductivity *per square foot* but for one inch of thickness. This custom has been adopted for the reason that wall thicknesses are usually expressed in inches, whereas if expressed in feet, decimal or fractional thicknesses would result. When dealing with flat walls, no complication is involved in using the inconsistent expression of conductivity. However, where curved or spherical walls are concerned, considerable complication is involved. Therefore, in this discussion the consistent units of conductivity expressed in *Btu per (hour) (square foot) (Fahrenheit degrees per one foot thickness)* are used throughout. Conductivity values obtained from Chapter 9 or Table 1 in this chapter, must therefore be converted for use in the calculations of this chapter by dividing by 12. As an example, the conductivity of brick listed as 5.0 in Table 2 of Chapter 9, becomes 0.42 when used in the calculations of this chapter.

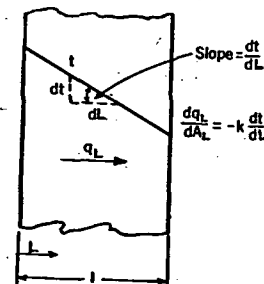


FIG. 2. THERMAL CONDUCTION IN A FLAT SLAB

Also, it should be emphasized that in order to make the calculations and applications consistent in this chapter, *all dimensions of thickness must be expressed in feet*.

#### Thermal Convection Equation

$$\frac{q}{A} = h_c(t_s - t_f) \quad (2)$$

This rate equation states that the thermal convection per unit transfer area ( $q/A$ ), Btu per (hour) (square foot) is proportional to the tem-

TABLE 1. APPROXIMATE UNIT THERMAL CONDUCTIVITIES\*

Conductivity,  $k = \text{Btu per (hr) (sq ft) (F deg per in.)}$

| MATERIAL              | k        | MATERIAL            | k        |
|-----------------------|----------|---------------------|----------|
| Air .....             | 0.168    | Lead .....          | 240.0    |
| Aluminum .....        | 1416.0   | Nickel .....        | 408.0    |
| Brass (70 - 30) ..... | 720.0    | Soil .....          | 2.4-12.0 |
| Cast-Iron .....       | 336.0    | Steel, mild .....   | 312.0    |
| Copper .....          | 2640.0   | Water, liquid ..... | 4.08     |
| Glass .....           | 3.6-7.32 |                     |          |

\* Thermal conductivities depend to some extent on temperature. The above magnitudes are approximate only. Refer to Chapter 9, and Reference 4 for additional data.

perature difference ( $t_s - t_f$ ) which is the temperature of the surface less that of the fluid. The particular fluid temperature to use for a given system will be noted under the discussion of that system. The proportionality factor is termed the *unit thermal convective conductance* (sometimes called the film coefficient for convection),  $h_c$ , Btu per (hour) (square foot) (Fahrenheit degree). Fig. 1 shows the conditions associated with convection.

The heat transmission by free or natural convection for objects surrounded by air can be conveniently expressed as in Equation 2a:

$$\frac{q}{A} = C \left( \frac{1}{D} \right)^{0.3} \left( \frac{1}{T_{av}} \right)^{0.181} (t_s - t_f)^{1.17} \quad (2a)$$

where

$\frac{q}{A}$  = heat transmission by convection, Btu per (square foot) (hour).

$C$  = a constant depending upon the shape of the surface.

$D$  = diameter of pipe or circular duct or height of vertical wall, inches. (Effect of diameter or height becomes constant at 24 in.)

$T_{av}$  = average of wall surface and surrounding air temperature, Fahrenheit degrees absolute.

$t_s - t_f$  = temperature excess between wall surface and surrounding air, Fahrenheit degrees.

For horizontal cylinders, the value of  $C = 1.02$  has been well established by various investigations. For vertical plates, the value of  $C = 1.39$  has been fairly well established. Suggested values<sup>2</sup> of  $C$  for horizontal plates warmer than the surrounding air are 1.79 when facing upward, and 0.89 when facing downward.

Problems in either forced convection or natural convection may be solved by the simple first-power equation if the convection coefficient is expressed as a unit conductance:

$$q = h_c A (t_1 - t_2) \quad (2b)$$

where

$q$  = heat transmission by convection, Btu per hour.

$A$  = surface area, square feet.

$t_1 - t_2$  = temperature difference between the surface and the fluid, Fahrenheit degrees.

$h_c$  = unit convective conductance, from Table 2, Btu per (square foot) (hour) (Fahrenheit degree temperature difference).

### Thermal Radiation Equation

The relation given by Equation 3 is applicable to systems in which radiant exchange takes place between the surfaces of solids, as schemati-

$$q_r = \sigma A_1 F_A F_E (T_1^4 - T_2^4) \quad (3)$$

cally shown in Fig. 3. Gaseous and luminous radiation are not considered in this discussion. Equation 3 states that the net radiation per unit transfer area of surface 1,  $q_r/A$  Btu per (hour) (square foot), which sees surface 2 through a non-absorbing medium, is proportional to the difference of the

TABLE 2. APPROXIMATE UNIT CONDUCTANCES FOR THERMAL CONVECTION FOR SEVERAL FLOW SYSTEMS

Expressed in Convenient Empirical Form

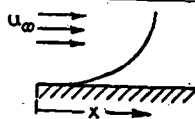
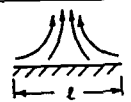
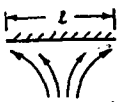
| CASE              | SYSTEM                                                                                                                                        | HEAT TRANSFER EQUATION* AND ITS LIMITS OF APPLICATION                                                                                                                                                                       | REFERENCE |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| FORCED CONVECTION |                                                                                                                                               |                                                                                                                                                                                                                             |           |
| 1                 | <br>Longitudinal flow in a circular cylinder. <sup>b</sup> | General Equation<br>$\frac{h_c D}{k} = 0.0225 \left( \frac{DG}{\mu} \right)^{0.3} \left( \frac{c_p \mu}{k} \right)^{0.3}$<br>where $x > 4.4D$<br>and $\left( \frac{DG}{\mu} \right) > 2200$                                 | 3         |
| 2                 | Same as Case 1. <sup>b</sup>                                                                                                                  | Equation for Air<br>$h_c = 5.4 \times 10^{-4} (T_f)^{0.3} \frac{G^{0.8}}{D^{0.2}}$<br>where $x > 4.4D$<br>and $\left( \frac{DG}{\mu} \right) > 2200$                                                                        | 3         |
| 3                 | Same as Case 1. <sup>b</sup>                                                                                                                  | Equation for Liquid Water (32-400 F)<br>$h_c = 13.5 (t_f)^{0.44} \frac{u_m^{0.5}}{D^{0.2}}$<br>where $x > 4.4D$<br>and $\left( \frac{DG}{\mu} \right) > 2200$                                                               | 3         |
| 4                 | <br>Flow normal to a single cylinder.                      | General Equation<br>$\frac{h_c D}{k} = 0.26 \left( \frac{DG}{\mu} \right)^{0.6} \left( \frac{c_p \mu}{k} \right)^{0.3}$<br>where $1000 < \frac{DG}{\mu} < 50,000$                                                           | 4         |
| 5                 | Same as Case 4.                                                                                                                               | Equation for Air<br>$h_c(\text{average}) = 0.211 (T_f)^{0.43} \frac{(u_m \rho)^{0.3}}{D^{0.4}}$<br>where $1000 < \frac{DG}{\mu} < 50,000$                                                                                   | 4         |
| 6                 | Same as Case 4.                                                                                                                               | Equation for Liquid Water (32-400 F)<br>$h_c(\text{average}) = 34.0 (t_f)^{0.38} \left( \frac{(u_m \rho)^{0.4}}{D^{0.4}} \right)$<br>where $1000 < \frac{DG}{\mu} < 50,000$                                                 | 4         |
| 7                 | <br>Flow along a flat plate.                             | General Equation (Turbulent Flow)<br>$\frac{h_{cx} x}{k} = 0.0296 \left( \frac{xG}{\mu} \right)^{0.3} \left( \frac{c_p \mu}{k} \right)^{0.3}$<br>where $\left( \frac{xG}{\mu} \right) > 500,000$ and<br>$h_c = 1.25 h_{cx}$ | 3         |
| 8                 | Same as Case 7.                                                                                                                               | Equation for Air (Turbulent Flow)<br>$h_{cx} = 0.51 (T_f)^{0.3} \frac{(u_m \rho)^{0.3}}{(x)^{0.2}}$<br>where $\left( \frac{xG}{\mu} \right) > 500,000$<br>$h_c(\text{average}) = 1.25 h_{cx}$                               | 3         |

TABLE 2. APPROXIMATE UNIT CONDUCTANCES FOR THERMAL CONVECTION FOR SEVERAL FLOW SYSTEMS (Concluded)

| CASE                         | SYSTEM                                                                                                                                               | HEAT TRANSFER EQUATION <sup>a</sup> AND ITS LIMITS OF APPLICATION                                                                                                                                                                                           | REFERENCE |
|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| FORCED CONVECTION            |                                                                                                                                                      |                                                                                                                                                                                                                                                             |           |
| 9                            | Same as Case 7.                                                                                                                                      | General Equation (Laminar Flow)<br>$\frac{h_{cx}}{k} = 0.332 \left( \frac{xG}{\mu} \right)^{0.5} \left( \frac{c_p \mu}{k} \right)^{0.25}$ For $\left( \frac{xG}{\mu} \right) < 500,000$<br>$h_c \text{ (average)} = 2h_{cx}$                                | 3         |
| 10                           | Same as Case 7.                                                                                                                                      | Equation for Air (Laminar Flow)<br>$h_{cx} = 0.0562(T)^{0.4} \left( \frac{u \rho}{x} \right)^{0.5}$ For $\left( \frac{xG}{\mu} \right) < 500,000$                                                                                                           | 3         |
| FREE CONVECTION <sup>a</sup> |                                                                                                                                                      |                                                                                                                                                                                                                                                             |           |
| 11                           | <br>Free convection past a heated horizontal cylinder.              | Equation for Air<br>$h_c = 0.271 \left( \frac{P}{P_o} \right)^{0.4} \left( \frac{\Delta t}{D} \right)^{0.25}$ $10^3 < N_{Gr} < 10^7$                                                                                                                        | 5         |
| 12                           | <br>Free convection past a single vertical surface.                 | Equation for Air<br>$h_c = 0.354 \left( \frac{P}{P_o} \right)^{0.4} \left( \frac{\Delta t}{l} \right)^{0.25}$ $10^3 < N_{Gr} < 10^7$<br>$h_c = 0.420 \left( \frac{P}{P_o} \right)^{0.4} \left( \frac{\Delta t}{l} \right)^{0.25}$ $10^8 < N_{Gr} < 10^{10}$ | 6         |
| 13                           | <br>Free convection past a heated horizontal surface (face up).    | Equation for Air<br>$h_c = 0.478 \left( \frac{P}{P_o} \right)^{0.4} \left( \frac{\Delta t}{l} \right)^{0.25}$ $10^3 < N_{Gr} < 10^7$                                                                                                                        | 5         |
| 14                           | <br>Free convection past a heated horizontal surface (face down). | Equation for Air<br>$h_c = 0.239 \left( \frac{P}{P_o} \right)^{0.4} \left( \frac{\Delta t}{l} \right)^{0.25}$ $10^3 < N_{Gr} < 10^7$                                                                                                                        | 5         |

<sup>a</sup> Fluid properties should be evaluated at the arithmetic mean fluid temperature,  $t_f = (t_{\text{surface}} + t_{\text{fluid}}) / 2$ .

<sup>b</sup> These expressions are suitable approximations to longitudinal flow in other than right circular cylinders provided the hydraulic diameter is employed as the conduit dimension parameter. For non-circular cross sections, the hydraulic diameter is equal to four times the cross-sectional area divided by the wetted perimeter.

<sup>c</sup> For low rates of heat transfer by free convection the exponent decreases towards zero, and for higher rates, increases towards 0.33. The above equations employing an exponent equal to 0.25 are applicable in the intermediate range indicated.

## NOMENCLATURE AND DIMENSIONS FOR TABLE 2

$c_p$  = heat capacity at constant pressure, Btu per (pound) (Fahrenheit degree)  
 $D$  = cylinder diameter, feet.  
 $f$  = subscript denoting film.

$g$  = body force per unit mass, feet per hour per hour. (For static system on earth,  $g = 32.2 \times 3600^2$  feet per hour per hour.)

$G = 3600 u_{mp}$  = mass flow per unit cross-sectional area normal to flow, pounds per (hour) (square foot of flow cross-section).

$N_{Gr}$  = Grashof modulus, dimensionless ( $N_{Gr} = D^3 \rho^2 g \Delta t / \mu^2$ ).

$h_o$  = average unit thermal convective conductance from the leading edge of surface to the position  $x$ , Btu per (hour) (square foot) (Fahrenheit degree).

$h_{cx}$  = local unit thermal convective conductance, at the position  $x$  from the leading edge of surface, Btu per (hour) (square foot) (Fahrenheit degree).

$k$  = thermal conductivity, Btu per (hour) (square foot) (Fahrenheit degree per foot thickness).

$l$  = a dimension of the system, feet.

$m$  = a subscript denoting mean.

$P$  = pressure, atmospheres.

$P_o$  = pressure (atmospheric) atmospheres.

$t$  = temperature, Fahrenheit.

$T$  = temperature, Fahrenheit, absolute.

$u$  = fluid velocity, feet per second.

$V$  = volume, cubic feet.

$x$  = a dimension of the system, feet.

$\beta$  = coefficient of cubical expansion ( $\beta = \frac{1}{V} \left( \frac{dV}{dT} \right) \rho$ ); for perfect gases  $\beta = 1/T$ .

$\Delta t$  = difference between wall and fluid temperatures, Fahrenheit degrees.

$\mu$  = fluid viscosity, pounds per (hour) (foot).

$\rho$  = density, pounds per cubic foot.

$\infty$  = infinity, referring the quantity to a point not directly affected by the phenomenon in question.

TABLE 3. RADIATION FACTORS OR EMISSIVITIES,  $e^*$   
For the determination of factor  $F_E$  in Equation 3

| CLASS | SURFACES                                                                                            | FRACTION OF BLACK-BODY RADIATION |              | ABSORPTIVITY FOR SOLAR RADIATION |
|-------|-----------------------------------------------------------------------------------------------------|----------------------------------|--------------|----------------------------------|
|       |                                                                                                     | At 50-100 F                      | At 1000 F    |                                  |
| 1     | A small hole in a large box, sphere, furnace, or enclosure                                          | 0.97 to 0.99                     | 0.97 to 0.99 | 0.97 to 0.99                     |
| 2     | Black non-metallic surfaces such as asphalt, carbon, slate, paint, paper                            | 0.90 to 0.98                     | 0.90 to 0.98 | 0.85 to 0.98                     |
| 3     | Red brick and tile, concrete and stone, rusty steel and iron, dark paints (red, brown, green, etc.) | 0.85 to 0.95                     | 0.75 to 0.90 | 0.65 to 0.80                     |
| 4     | Yellow and buff brick and stone, firebrick, fire clay                                               | 0.85 to 0.95                     | 0.70 to 0.85 | 0.50 to 0.70                     |
| 5     | White or light-cream brick, tile, paint or paper, plaster, whitewash                                | 0.85 to 0.95                     | 0.60 to 0.75 | 0.30 to 0.50                     |
| 6     | Window glass                                                                                        | 0.90 to 0.95                     | .....        | Transparent <sup>a</sup>         |
| 7     | Bright aluminum paint; gilt or bronze paint                                                         | 0.40 to 0.60                     | .....        | 0.30 to 0.50                     |
| 8     | Dull brass, copper, or aluminum; galvanized steel; polished iron                                    | 0.20 to 0.30                     | 0.30 to 0.50 | 0.40 to 0.65                     |
| 9     | Polished brass, copper, monel metal                                                                 | 0.02 to 0.05                     | 0.05 to 0.15 | 0.30 to 0.50                     |
| 10    | Highly polished aluminum, tin plate, nickel, chromium                                               | 0.02 to 0.04                     | 0.05 to 0.10 | 0.10 to 0.40                     |

<sup>a</sup> Emissivities of other materials may be found in Reference 4. <sup>\*</sup> Reflects about 3 percent.

fourth powers of the absolute surface temperatures ( $T_1^4 - T_2^4$ ). The proportionality factor ( $\sigma F_A F_E$ ) may be conveniently separated into three parts (excepting in some problems involving interreflections, where it is not possible to divide the product ( $F_A F_E$ ) into separate terms):

$\sigma$  = the Stefan-Boltzmann radiation constant =  $1730 \times 10^{-12}$  Btu per (hour) (square foot) (Fahrenheit degree absolute temperature to the fourth power).  
 $F_A$  = the geometrical factor which is dimensionless and  $\leq 1$ . This factor accounts for the shape and relative position of the two surfaces. The value of  $F_A = 1$  may be used in the cases of large parallel planes, long concentric cylinders or smaller bodies in large enclosures.

$F_E$  = the emissivity factor which is also dimensionless and  $\leq 1$ . This factor accounts for the absorption and emission characteristics of the surfaces for the

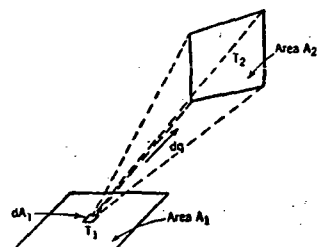


FIG. 3. RADIATION BETWEEN SURFACES

radiation which exists. Emissivities or absorptivities ( $\epsilon$ ) for many common surfaces, are given in Table 3. The value of  $F_g$  for large parallel planes, long concentric cylinders, or large enclosed bodies is  $1 + (1/\epsilon_1 + 1/\epsilon_2 - 1)$ .

The radiation under black-body conditions, or for an emissivity of 1.0, is given in Table 4<sup>7</sup> for cold surfaces as low as -39 F to warmer surfaces as high as 139 F. Some net radiation exchange solutions for several common radiation systems are given in Table 5.

There are several methods by which the geometrical factors  $F_A$  can be determined. One method involves the use of a mechanical geometrical integrator (Reference 8). Photographic and other methods are given in References 9 and 10.

#### Equivalent Conductance for Radiation

Although Equation 3 is a suitable equation for describing radiant exchange, it is not convenient for computations where other modes of energy transfer are operative. For such cases, it is convenient to define an equivalent conductance for radiation by the equation:

$$q_r = h_r A (t_1 - t_2) \quad (4)$$

TABLE 4. HEAT TRANSMISSION BY RADIATION FOR BLACK-BODY CONDITIONS<sup>a</sup>  
Expressed in Btu per (square foot) (hour)

| TEMP<br>F<br>DEG | 0    | -1   | -2   | -3   | -4   | -5   | -6   | -7   | -8   | -9   |
|------------------|------|------|------|------|------|------|------|------|------|------|
| -30              | 59.3 | 58.7 | 58.2 | 57.7 | 57.2 | 56.7 | 56.2 | 55.7 | 55.2 | 54.7 |
| -20              | 65.2 | 64.7 | 64.1 | 63.5 | 62.9 | 62.3 | 61.7 | 61.1 | 60.5 | 59.9 |
| -10              | 71.4 | 70.8 | 70.1 | 69.5 | 68.9 | 68.3 | 67.7 | 67.1 | 66.4 | 65.8 |
| 0                | 78.0 | 77.4 | 76.7 | 76.0 | 75.4 | 74.7 | 74.0 | 73.4 | 72.7 | 72.1 |
|                  | 0    | +1   | +2   | +3   | +4   | +5   | +6   | +7   | +8   | +9   |
| 0                | 78.0 | 78.7 | 79.4 | 80.1 | 80.8 | 81.5 | 82.2 | 82.9 | 83.6 | 84.3 |
| 10               | 85.0 | 85.7 | 86.5 | 87.2 | 88.0 | 88.7 | 89.4 | 90.2 | 90.9 | 91.7 |
| 20               | 92.4 | 93.3 | 94.0 | 94.8 | 95.6 | 96.4 | 97.2 | 98.0 | 98.8 | 99.6 |
| 30               | 100  | 101  | 102  | 103  | 104  | 105  | 106  | 107  | 108  | 109  |
| 40               | 109  | 110  | 111  | 112  | 113  | 114  | 115  | 116  | 117  | 118  |
| 50               | 118  | 119  | 120  | 121  | 122  | 123  | 124  | 125  | 126  | 127  |
| 60               | 127  | 128  | 129  | 130  | 131  | 132  | 133  | 134  | 135  | 136  |
| 70               | 137  | 138  | 139  | 140  | 141  | 142  | 143  | 144  | 145  | 146  |
| 80               | 148  | 149  | 150  | 151  | 152  | 153  | 154  | 155  | 156  | 157  |
| 90               | 159  | 160  | 161  | 162  | 163  | 164  | 165  | 166  | 167  | 168  |
| 100              | 170  | 171  | 173  | 174  | 175  | 176  | 177  | 178  | 179  | 180  |
| 110              | 183  | 184  | 185  | 187  | 188  | 189  | 191  | 192  | 193  | 195  |
| 120              | 196  | 197  | 199  | 200  | 201  | 203  | 204  | 206  | 207  | 209  |
| 130              | 211  | 212  | 214  | 215  | 217  | 218  | 220  | 221  | 222  | 224  |

<sup>a</sup> Example: Radiation from walls of room at 32 F to surface at -25 F for effective emissivity of 0.95 (102 - 62.3) 0.95 = 37.7 Btu per (square foot) (hour).

TABLE 5. NET RADIATION SOLUTIONS

| SYSTEM                                                                                                                      | SOLUTION                                                                                                                                                 | REMARKS                                                          |
|-----------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| <br>Two infinite parallel planes.                                                                                           | $\frac{q_r}{A} = \frac{1}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} \sigma (T_1^4 - T_2^4)$                                                       | Considering interreflections. (Reference 5)                      |
| <br>One radiation shield between two infinite parallel planes.                                                              | $\frac{q_r}{A} = \left( \frac{1}{2} \right) \frac{1}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} \sigma (T_1^4 - T_2^4)$                            | Considering interreflections. (Reference 5)                      |
| <br>n radiation shields between two infinite parallel planes.                                                               | $\frac{q_r}{A} = \frac{1}{n+1} \left( \frac{q_r}{A} \right)_0$ where $\left( \frac{q_r}{A} \right)_0$ is the net radiation exchange without the shields. | Considering interreflections. (Reference 5)                      |
| <br>Two concentric spheres or two infinitely long cylinders.                                                                | $\frac{q_r}{A_1} = \frac{1}{\frac{1}{\epsilon_1} + \frac{A_1}{A_2} \left( \frac{1}{\epsilon_2} - 1 \right)} \sigma (T_1^4 - T_2^4)$                      | Considering interreflections and diffuse surfaces. (Reference 5) |
| <br>Two areas $dA_1$ and $dA_2$ .                                                                                           | $\frac{dq_r}{dA_1} = \epsilon_1 \sigma F_A (T_1^4 - T_2^4)$                                                                                              | Surface diffuse, neglecting interreflection. (Reference 5)       |
| <br>Tube of infinite length parallel to an infinite wall.                                                                   | $\frac{q_r}{2\pi RN} = \left( \frac{1}{2} \right) \epsilon_1 \sigma (T_1^4 - T_2^4)$ where $N$ is the length of cylinder from which $q_r$ is exchanged   | Neglecting interreflections. (Reference 5)                       |
| <br>Surfaces are perfect radiators.                                                                                         | See Fig. 4                                                                                                                                               | (Reference 4)                                                    |
| <br>Surface element $dA$ and rectangle above and parallel to it, with one corner of rectangle contained in normal to $dA$ . | See Fig. 5                                                                                                                                               | (Reference 4)                                                    |
| <br>Adjacent rectangles in perpendicular planes.                                                                            | See Fig. 6                                                                                                                                               | (Reference 4)                                                    |
| <br>Opposed parallel rectangles and disks of equal size.                                                                    | See Fig. 6                                                                                                                                               | (Reference 4)                                                    |

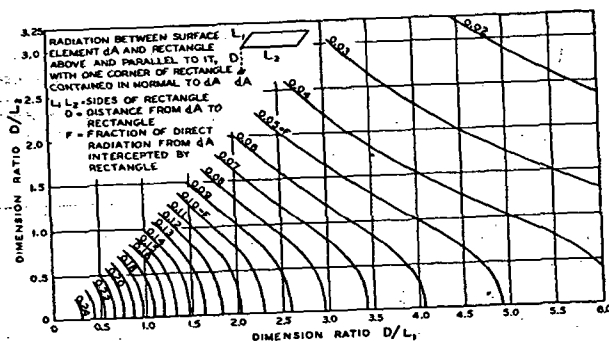


FIG. 4. GEOMETRICAL FACTOR  $F$  FOR DIRECT RADIATION BETWEEN AN ELEMENT  $dA$  AND A PARALLEL RECTANGLE\*

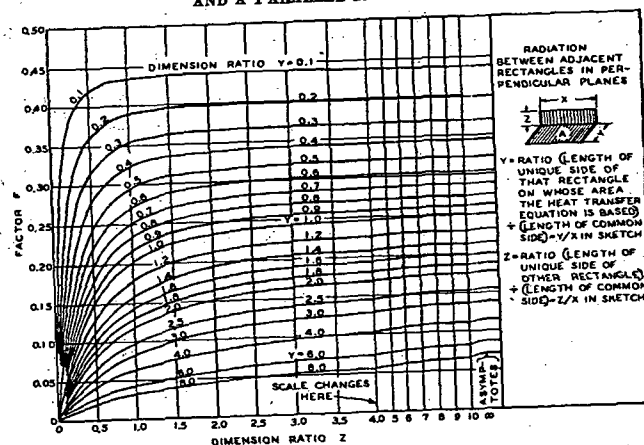


FIG. 5. GEOMETRICAL FACTOR  $F$  FOR DIRECT RADIATION BETWEEN ADJACENT RECTANGLES IN PERPENDICULAR PLANES\*

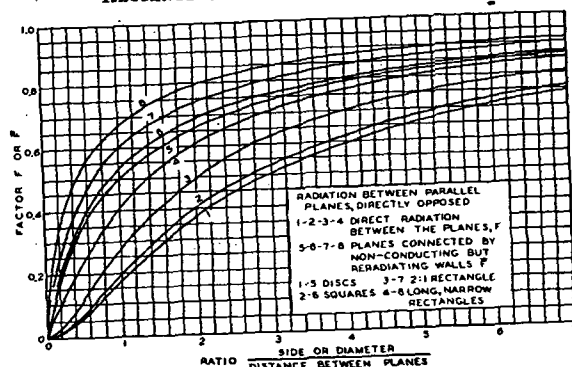


FIG. 6. GEOMETRICAL FACTOR  $F$  FOR DIRECT RADIATION BETWEEN OPPOSED PARALLEL RECTANGLE AND DISCS OF EQUAL SIZE\*

\* From Radiant Heat Transmission, by H. C. Hottel (Mechanical Engineering, July 1930, pp. 700 to 702)

The conductance  $h_r$ , thus defined is a function of the shape-emissivity factor, as well as the temperatures of the radiator and receiver. Fig. 7 shows a plot of the equivalent conductance for two black bodies (i.e., with emissivities equal to unity) which exchange energy only with one another.

### Combined Convection and Radiation

It should be noted that the previous equations and tables give the heat transfer by convection and by radiation computed separately. In many practical cases it is desirable to treat convection and radiation as a single combined process, using a first-power equation:

$$q_{rc} = h_{rc} A (t_1 - t_2) \quad (5)$$

where  $q_{rc}$  is the total heat flow due to radiation and convection, in Btu per hour. Values of  $h_{rc}$ , the surface or film conductance for combined

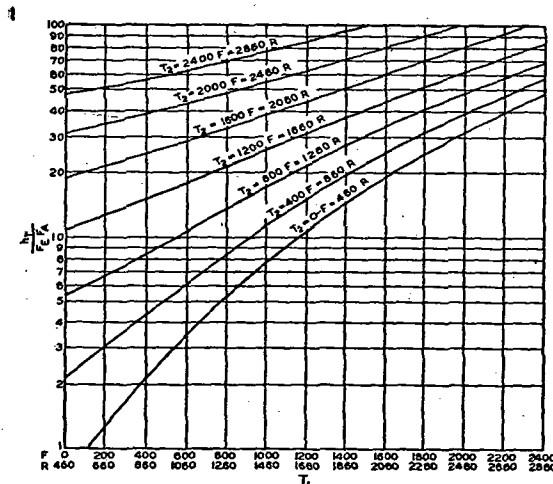


FIG. 7. EQUIVALENT CONDUCTANCE FOR RADIATION BETWEEN TWO BLACK BODIES EXCHANGING ENERGY ONLY WITH ONE ANOTHER

radiation and convection, are given in Chapter 9, (Table 1 and Fig. 4). Complete tables for the combined heat transfer of steam and hot water radiators, pipes, coverings, etc., will be found in the appropriate chapters.

### HEAT-FLOW RESISTANCE

In most of the steady-state heat transfer problems encountered in air conditioning applications, more than one of the heat transfer mechanisms are effective, and the thermal current flows through several resistances in series or in parallel. In using the resistance concept, the calculations involved are analogous to the application of Ohm's Law in electricity, viz., the heat flow or thermal current is directly proportional to the thermal potential or temperature difference, and inversely proportional to the thermal resistance:

$$q_{rc} = \frac{t_1 - t_2}{R} \quad (6)$$



Following the electrical analogy, when there is a thermal current flowing through several *resistances in series*, the resistances are additive:

$$R_T = R_1 + R_2 + R_3 + \dots + R_n \quad (7)$$

Similarly, conductance is the reciprocal of resistance, and for heat flow through several *resistances in parallel*, the conductances are additive:

$$C_T = \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \quad (8)$$

### Practical Heat Transfer Problems

The use of these relations for resistance and conductance makes possible the solution of many practical heat transfer problems. As discussed in Chapters 9, 28 and 36, the practical analyses of heat transfer in building walls, in fin-tube coils and in pipe coverings, are usually computed by this method. The same resistance analysis may be applied to complicated

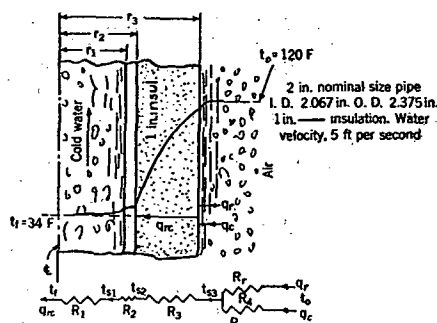


FIG. 8. HEAT TRANSFER CONDITIONS IN AN INSULATED COLD WATER LINE

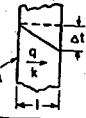
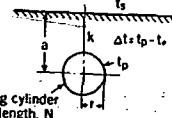
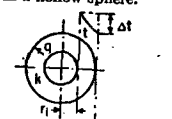
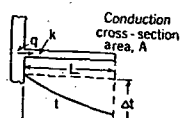
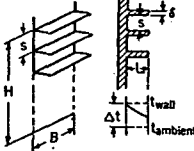
steady-state *conduction* problems. Table 6 gives the resistances in six common cases of steady-state conduction.

A complete analysis by the resistance method is well illustrated by considering the heat transfer from the air outside to the cold water inside of an insulated pipe. The temperature gradients and the nature of the resistance analysis are indicated by the two sketches of Fig. 8.

Since air is sensibly transparent to radiation, there will be some heat transfer by both radiation and convection to the outer insulation surface. The mechanisms act in parallel on the air side. The total transfer by radiation and convection then passes through the insulating layer and the pipe wall by thermal conduction, and thence by convection and radiation into main cold water streams. (Radiation is not significant on the water side as liquids are sensibly opaque to radiation, although water transmits energy in the visible region). The contact resistance between the insulation and the pipe wall is presumed to be equal to zero.

Referring to Fig. 8, the heat transferred for a given length  $N$  of pipe,  $q_{re}$ , Btu per hour, may be thought of as flowing through the parallel resistances  $R_i$  and  $R_o$ , associated with the insulation surface radiation and convection transfer. Then the flow is through the resistance offered to thermal conduction by the insulation,  $R_s$ , through the pipe wall resistance,

TABLE 6. SOLUTIONS FOR SOME STEADY-STATE THERMAL CONDUCTION PROBLEMS<sup>a, b</sup>

| No. | SYSTEM                                                                                                                                                                                   | Expressions for the resistance $R$ entering into the equation:<br>$q = \Delta t / R$ (Btu per hour)                                                                                                                                                                                                                                                                            |
|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.  | Flat wall or curved wall if curvature is small (wall thickness less than 0.1 of inside diameter).<br> | $R = \frac{L}{kA}$                                                                                                                                                                                                                                                                                                                                                             |
| 2.  | Radial flow through a right circular cylinder.<br>                                                    | $R = \frac{\log_e \frac{r_o}{r_i}}{2\pi kN}$<br>(See footnote c).                                                                                                                                                                                                                                                                                                              |
| 3.  | The buried cylinder.<br>                                                                              | $R = \frac{\log_e \left( \frac{a + \sqrt{a^2 + r^2}}{r} \right) \cosh^{-1} \left( \frac{a\sqrt{1 + \frac{r^2}{a^2}}}{r} \right)}{2\pi kN}$<br>For $\frac{a}{r} \geq 3$ , satisfactory approximation is:<br>$R = \frac{\log_e \frac{2a}{r} \cosh^{-1} \frac{a}{r}}{2\pi kN} = \frac{1}{2\pi kN}$                                                                                |
| 4.  | Radial flow in a hollow sphere.<br>                                                                   | $R = \frac{\frac{1}{r_i} - \frac{1}{r_o}}{4\pi k}$                                                                                                                                                                                                                                                                                                                             |
| 5.  | The straight fin or rod heated at one end.<br>                                                      | $R = \frac{m}{h_p \tanh mL}$ (see footnotes d and e).<br>For $mL > 2.3$ , $\tanh mL \approx 1$<br>$m = \sqrt{h_p/kA}$<br>$A$ = conduction cross-section area.<br>$p$ = perimeter of cross-section $A$ .<br>$h_s$ = unit conductance to the surroundings from the fin surface.<br>$k$ = thermal conductivity fin material.<br>$\Delta t$ = wall temperature—ambient temperature |
| 6.  | Finned surface of area $HB$ .<br>                                                                   | $R = \frac{(s + \delta)}{h_s \left( \frac{2}{m} \tanh mL + s \right) HB}$<br>$m = \sqrt{\frac{h_p k}{kA}} = \sqrt{\frac{2h_s}{k\delta}}$<br>$\Delta t$ defined as in Case 5 above.                                                                                                                                                                                             |

<sup>a</sup> The dimensions to be employed in these solutions are: length of dimension  $p$ ,  $L$ ,  $r$  = feet; units of  $k$  = Btu per (hour) (square foot) (Fahrenheit degree for one foot thickness); units of  $h$ , Btu per (hour) (square foot) (Fahrenheit degree); units of area,  $A$  = square feet.

<sup>b</sup> The thermal conductivity,  $k$ , in these solutions should be taken at the average material temperature.

<sup>c</sup>  $\log_e x = 2.303 \log_{10} x$ .

<sup>d</sup> This expression can also be employed as an approximation for tapered fins or of annular fins by employing average magnitudes of  $A$  and  $p$ .

<sup>e</sup>  $\tanh$  is the hyperbolic tangent.



$R_2$ , and into the water stream through the convection resistance,  $R_1$ . Note the analogy to the direct current electrical circuit problem. A temperature (potential) drop is required to overcome these resistances to the flow of thermal current. The total resistance to heat transfer,  $R_t$ , hour Fahrenheit degrees per Btu, is the summation of the individual resistances:

$$R_t = R_1 + R_2 + R_3 + R_4 \quad (9)$$

where the resultant parallel resistance  $R_4$  is obtained from

$$\frac{1}{R_4} = \frac{1}{R_r} + \frac{1}{R_o} \quad (10)$$

Provided the individual resistances may be evaluated, the total resistance can be obtained from this relation. Then the heat transfer for the length of pipe ( $N$ , ft) can be established by the relation

$$q_{re} \text{ (Btu per hour)} = \frac{(t_o - t_i)}{R_t} \quad (11)$$

For a unit length of the pipe the heat transfer rate is

$$\frac{q_{re}}{N} \text{ Btu per (hour) (foot)} = \frac{(t_o - t_i)}{R_t N} \quad (12)$$

The temperature drop,  $\Delta t$ , through an individual resistance may then be calculated from the relation:

$$\Delta t = R q_{re} \quad (13)$$

where  $R$  is the resistance in question.

The problem is now reduced to one of evaluating the individual resistances of the system. This entails suitable manipulation of the rate Equations 1, 2 and 3 to produce expressions of the form:

$$q = \frac{\Delta t}{R} \quad (14)$$

where  $q$  is the heat transfer rate, and  $\Delta t$  is the potential drop or temperature difference through the resistance  $R$ . Table 6 lists such solutions for six different conduction systems. Table 2 in Chapter 9 and Table 1 of this chapter indicate the magnitudes of the thermal conductivities,  $k$ , to be employed in the expressions of Table 6, after dividing  $k$  by 12.

The solution applicable to the problem depicted in Fig. 8, for the calculation of  $R_2$  and  $R_3$ , is case 2 in Table 6. Thus for a 1 ft length of 2 in. nominal size pipe (I. D. = 2.067 in., O. D. = 2.375 in.) insulated with 1 in. of material having a conductivity of 0.025:

$$R_2 = \frac{\log_e \frac{1.188}{1.033}}{2\pi \times 26 \times 1} = 8.5 \times 10^{-4} \text{ (hr) (F deg) per Btu.}$$

$$R_3 = \frac{\log_e \frac{2.188}{1.188}}{2\pi \times 0.025 \times 1} = 3.9 \text{ (hr) (F deg) per Btu.}$$

The convection resistances to heat transfer from the pipe wall to the cold water,  $R_1$ , and from the air to the surface of the insulating material,  $R_o$ , are dependent on the flow conditions prevailing at these surfaces, and on the thermal properties of the fluids. These resistances are also directly dependent upon the temperature distribution, and for this reason it is necessary first, to guess on the basis of the problem statement, a temperature distribution upon which to base the initial calculations. Since the values of  $h_o$  for heat transfer between water and pipe walls are relatively high in this temperature range, it is logical to assume only a small temperature difference between the temperature of the fluid body and the temperature of the pipe wall. For the purpose of an initial guess, this temperature difference will be assumed to be 2 deg. On the other hand,  $h_o$  for heat transfer from air to a body is relatively small, and a higher temperature difference would be expected between these masses. The value initially assumed here will be 20 deg. In summary, the temperature distribution in the system is assumed as follows:

Fluid temperature = 34 F.

Inner pipe wall temperature = 36 F.

Outer insulation surface temperature = 100 F.

Ambient air temperature = 120 F.

With these assumptions and the problem statement, it is now possible to calculate values for the convective resistances. If it is found in the ultimate solution of the problem that the temperature distribution is different from that assumed, it will then be necessary to repeat the solution procedure.

If reference now be made to Table 2, it is found that Case 3 of this table is a system similar to that encountered in the convection between the water and the pipe wall. The equation for this case is the following:

$$h_o = 13.9(t_o)^{0.44} \frac{u_m^{0.8}}{D^{0.2}} \quad (15)$$

where

$$u_m = 5 \text{ fps}$$

$$D = \frac{2.067}{12} = 0.1725 \text{ ft}$$

$$t_i = \frac{34 + 36}{2} = 35 \text{ F}$$

$$h_o = \frac{13.9 \times 6.9 \times 3.62}{0.703} = 494 \text{ Btu per (hr) (sq ft) (F deg).}$$

This heat transfer rate is through the inner surface of the pipe and it is, therefore, this area that determines the resistance  $R_1$ .

$$A = \pi D = 0.542 \text{ sq ft per unit length of pipe,}$$

and therefore

$$R_1 = \frac{1}{h_o A} = \frac{1}{494 \times 0.542}$$

$$R_1 = 3.73 \times 10^{-4} \text{ (hr) (F deg) per Btu.}$$

Case 11 of Table 2 fits the conditions of the problem if only free convection heating of the pipe is assumed. The equation in this case is as follows:

$$h_c = 0.271 \left( \frac{P}{P_o} \right)^{0.5} \left( \frac{\Delta t}{D} \right)^{0.25} \quad (16)$$

where

$$\begin{aligned} \Delta t &= 20 \text{ F} \\ D &= 0.364 \text{ ft} \\ P &= P_o = \text{one atmosphere} \end{aligned}$$

therefore,

$$\begin{aligned} h_c &= 0.271 \left( \frac{20}{0.364} \right)^{0.25} \\ h_c &= 0.737 \text{ Btu per (hr) (sq ft) (F deg).} \end{aligned}$$

Using the surface area of the insulation, the value of the resistance per unit length is determined.

$$A = \pi \left( \frac{4.375}{12} \right) \times 1 = 1.14 \text{ sq ft}$$

$$R_c = \frac{1}{h_c A} = \frac{1}{0.737 \times 1.14}$$

$$R_c = 1.19 \text{ (hr) (F deg) per Btu.}$$

This result may not be deemed conservative inasmuch as the expression is for still air. If, however, the air is not still, but flows at approximately 5 mph or 7 fps, the heat transfer equation for forced convection would apply. This equation is Case 5 of Table 2.

$$h_{c(\text{average})} = 0.211 (T_f)^{0.4} \frac{(u_{\infty} \rho)^{0.5}}{D^{0.4}} \quad (17)$$

$$T_f = \frac{100 + 120}{2} + 460 = 570 \text{ Rankine (Fahrenheit absolute)}$$

$$u_{\infty} = 7 \text{ fps}$$

$$\rho = 0.076 \left( \frac{520}{570} \right) = 0.0694 \text{ lb per cu ft}$$

$$D = 0.364 \text{ ft}$$

$$h_{c(\text{average})} = \frac{0.211(570)^{0.4}(7 \times 0.0694)^{0.5}}{(0.364)^{0.4}}$$

$$h_{c(\text{average})} = 2.73 \text{ Btu per (hr) (sq ft) (F deg)}$$

and

$$R_c (\text{Forced Convection}) = \frac{1}{h_c A} = \frac{1}{2.73 \times 1.14}$$

$$R_c = 0.321 \text{ (hr) (F deg) per Btu.}$$

The radiation resistance,  $R_r$ , which acts in parallel with the resistance just calculated, can be computed with the aid of Fig. 7. The pipe wall, assumed at 100 F sees the surroundings at 120 F. If these two tempera-

tures are used with Fig. 7, a value for  $\frac{h_r}{F_A F_E}$  is determined directly.

$$\frac{h_r}{F_A F_E} = 1.4 \text{ Btu per (hr) (F deg) (sq ft).}$$

The angle factor,  $F_A$ , is unity, and for an estimated surface emissivity of 0.95 (see Table 3),  $F_E = 0.95$ . Therefore,

$$h_r = 1.4 F_A F_E = 1.4 \times 1 \times 0.95$$

$$h_r = 1.33 \text{ Btu per (hr) (F deg) (sq ft)}$$

and the radiation resistance,  $R_r$ , is then the following:

$$R_r = \frac{1}{h_r A} = \frac{1}{1.33 \times 1.14}$$

$$R_r = 0.659 \text{ (hr) (F deg) per Btu.}$$

The resultant resistance of  $R_c$  and  $R_r$  acting in parallel (see Fig. 8) can now be evaluated as:

$$\frac{1}{R_t} = \frac{1}{R_c} + \frac{1}{R_r} = \frac{1}{0.321} + \frac{1}{0.659} = 4.54 \text{ Btu per (hr) (F deg)}$$

$$R_t = 0.216 \text{ (hr) (F deg) per Btu.}$$

The overall resistance,  $R_T$ , surroundings to cold water, is the sum of  $R_1 + R_2 + R_3 + R_t = 4.12 \text{ (hr) (F deg) per Btu}$  for 1-ft length of pipe. Note that the controlling resistances are  $R_3$  and  $R_t$ , and that neglect of both  $R_1$  and  $R_2$  would not significantly influence the total resistance,  $R_T$ .

On the basis of this resistance calculation, the heat transfer from the surroundings to the cold water may be evaluated as:

$$\frac{q_{rc}}{N} = \frac{t_o - t_i}{R_T} = \frac{120 - 34}{4.12} = 20.8 \text{ Btu per (hr) (ft)}$$

or about 0.175 tons of refrigeration per 100 ft of pipe.

Since the calculation is based on a 1-ft pipe length,

$$q_{rc} = 20.8 \text{ Btu per hr.}$$

The temperature drops through the various resistances are now readily evaluated by Equation 14 as:

$$\Delta t = qR$$

$$t_o - t_{a3} (\text{air to insulation surface}) = qR_4 = 20.8 \times 0.216 = 4.49 \text{ F deg}$$

$$t_{a3} - t_{a2} (\text{through the insulation}) = qR_3 = 20.8 \times 3.9 = 81.2 \text{ F deg}$$

$$t_{a2} - t_{a1} (\text{through the pipe wall}) = qR_2 = 20.8 \times 8.5 \times 10^{-4} = 0.018 \text{ F deg}$$

$$t_{a1} - t_i (\text{pipe wall to cold water}) = qR_1 = 20.8 \times 3.73 \times 10^{-3} = 0.078 \text{ F deg}$$

This solution was obtained on the temperature distribution assumptions initially made. It is apparent that a better solution could be obtained if the whole problem were reiterated using the temperature distribution just calculated.

## PERIODIC AND TRANSIENT HEAT FLOW

The foregoing data and examples dealt with steady-state heat transfer (not varying with time). In most practical heat transfer problems the heat flow depends upon time. Such cases can usually be divided into two classes: periodic and transient. Periodic heat transfer repeats periodically in time. Transient heat transfer exhibits no periodicity. Graphical, analytical and numerical methods are available for solving transient or periodic heat flow problems.<sup>4,5,10,11,12</sup> Graphical and numerical methods are the most versatile, and can be applied with minimum mathematical training.

A large number of analytical solutions for the case of heat conduction in variously shaped solids are available in the literature. Table 7 gives a

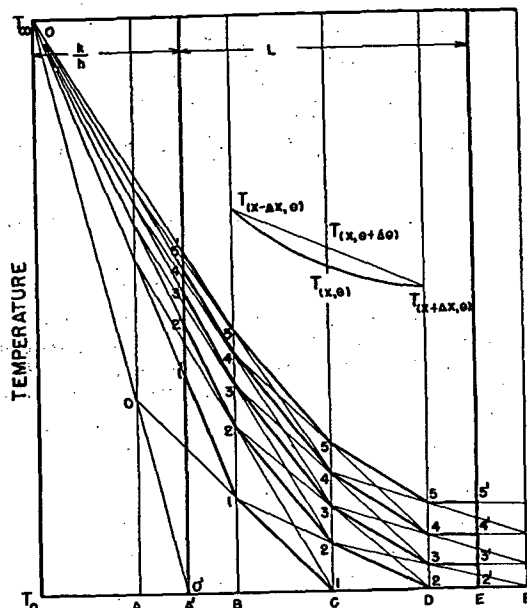


FIG. 9. EXAMPLE OF A GRAPHICAL SOLUTION TO A PROBLEM IN TRANSIENT HEAT CONDUCTION.

summary of the cases reported and tabulated. Many more analytical solutions are available in the form of infinite series,<sup>11,12,18,19</sup> but are not tabulated. Certain complex cases may be treated by combining the simple analytical solutions as discussed in Reference 17. (See also Reference 20).

Frequently, transient heat flow problems in one dimension have boundary conditions which make the problem difficult to treat analytically. In such cases, recourse may be made to a graphical method of solution sometimes called the Schmidt method.<sup>4,10,19,21,22</sup> This method will be briefly outlined for the case of transient heat flow in a slab insulated on one face, and suddenly exposed on the other face through a fixed thermal resistance to a higher temperature. The technique is general, however, and methods may be devised for any boundary conditions<sup>5,21</sup> and also, for one dimensional (radial) heat flow in spheres and cylinders.<sup>22,23</sup>

TABLE 7. ANALYTICAL SOLUTIONS FOR HEAT CONDUCTION IN VARIOUSLY SHAPED SOLIDS

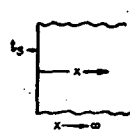
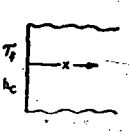
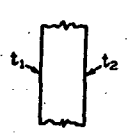
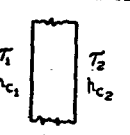
| SHAPE OF SOLID                                                                                                                                                              | BOUNDARY CONDITIONS                                                                                                                                                                                                                                                                                   | DATA AVAILABLE IN GRAPHS                                                                                                                        |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Semi-infinite<br>                                                                        | Surface temperature suddenly changed.                                                                                                                                                                                                                                                                 | Temperature distribution in solid as a function of time.<br>References: (4) p. 37, (5) p. V-23; (10) p. 254; (13) p. 46.                        |
|                                                                                                                                                                             | A steady flow of heat is suddenly applied to the surface.                                                                                                                                                                                                                                             | Heat flow from surface as a function of time.<br>References: (10) pp. 256, 267; (13) p. 47.                                                     |
|                                                                                                                                                                             | The surface temperature has been varying sinusoidally with time for a long time.                                                                                                                                                                                                                      | Temperature distribution as a function of time.<br>Reference: (10) p. 257.                                                                      |
| Semi-infinite with fluid at free surface.<br>                                            | The temperature of the fluid in contact with the surface has a sudden change in temperature. (The surface conductance is constant).                                                                                                                                                                   | Temperature distribution as a function of time.<br>References: (4) p. 37; (5) pp. V-45, 46, 47.                                                 |
|                                                                                                                                                                             | The temperature of the fluid in contact with the surface has been varying sinusoidally with time for a long time. (The surface conductance is constant).                                                                                                                                              | Temperature distribution as a function of time.<br>Reference: (10) p. 298.                                                                      |
|                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                       | Heat flow from the surface as a function of time.<br>Reference: (10) p. 298.                                                                    |
| Slab.<br>                                                                                | The temperatures $t_1$ and $t_2$ are suddenly changed from the initial uniform slab temperature to a new temperature. (The case where the surface on one side is insulated is treated by taking the case of a slab of twice the given thickness since the midplane has no heat flow due to symmetry.) | Temperature distribution as a function of time.<br>References: (3) p. V-12; (10) p. 265.                                                        |
|                                                                                                                                                                             | The temperatures $t_1$ and $t_2$ suddenly begin to increase as linear functions of time. The slab is initially at uniform temperature. (The case where one surface is insulated against heat flow is treated as noted above.)                                                                         | Temperature distribution as a function of time.<br>Reference: (10) p. 268.                                                                      |
|                                                                                                                                                                             | The temperature at both surfaces has been varying sinusoidally for a long time.                                                                                                                                                                                                                       | Temperature distribution as a function of time.<br>Reference: (10) p. 300.                                                                      |
| Slab immersed in a fluid with constant conductance between fluid and slab surface.<br> |                                                                                                                                                                                                                                                                                                       | Heat flow from the surface.<br>Reference: (10) p. 303.                                                                                          |
|                                                                                                                                                                             | The temperature of the fluid is suddenly changed from the initial uniform slab temperature. (If one surface is insulated against heat flow, see above.)                                                                                                                                               | Temperature distribution as a function of time.<br>References: (4) pp. 32, 33, 34, 35; (5) pp. V-9, 10, 35, 42; (10) pp. 274, 284; (13) p. 106. |
|                                                                                                                                                                             | The temperature of the fluid at one surface varies as a periodic function of time while the temperature of the fluid at the other surface is constant. The conductances need not be the same on both sides. (The variations in temperature are expressible as a Fourier series.)                      | Heat flow from the surface as a function of time.<br>References: (5) p. V-10; (10) p. 274; (13) p. 107.                                         |
|                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                       | Temperature distribution as a function of time.<br>Reference 14.                                                                                |
|                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                       | Heat flow at the surface as a function of time.<br>Reference 14.                                                                                |

TABLE 7. ANALYTICAL SOLUTIONS FOR HEAT CONDUCTION IN VARIOUSLY SHAPED SOLIDS (Concluded)

| SHAPE OF SOLID                                                                                                                                 | BOUNDARY CONDITIONS                                                                                    | DATA AVAILABLE IN GRAPHS                                                                                                           |
|------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| Cylinder of infinite axial dimension.<br>                     | The surface temperature is suddenly changed from the initial (uniform) temperature.                    | Temperature distribution as a function of time.<br>Reference: (10) p. 265.                                                         |
|                                                                                                                                                | The surface temperature suddenly begins to increase linearly with time.                                | Heat flow from surface as a function of time.<br>Multiply temperature difference between surface and fluid by surface conductance. |
| Cylinder of infinite axial dimension immersed in a fluid.<br> | The surrounding fluid suddenly changes from the initial (uniform) temperature of the cylinder.         | Temperature distribution as a function of time.<br>References: (4) p. 38; (5) pp. V-16, V-35, V-43, V-48; (10) pp. 278, 286; (15). |
|                                                                                                                                                | The temperature of the surrounding fluid changes sinusoidally.                                         | Heat flow from the surface as a function of time.<br>References: (5) p. V-16; (10) p. 278.                                         |
| Sphere<br>                                                    | The temperature of the surface is suddenly changed from the initial uniform temperature.               | Temperature distribution as a function of time.<br>References: (5) p. V-23; (10) pp. 264, 265.                                     |
|                                                                                                                                                | The temperature at the surface suddenly begins to change as a linear function of time.                 | Temperature distribution as a function of time.<br>Reference: (10) p. 269.                                                         |
| Sphere immersed in fluid.<br>                                | The temperature of the surrounding fluid suddenly changes from the initial uniform sphere temperature. | Temperature distribution as a function of time.<br>References: (4) p. 38; (5) pp. V-21, V-35, V-44; (10) pp. 281, 282; (4).        |
| Rectangular bar of infinite length.                                                                                                            | Any of the above noted boundary conditions for a slab.                                                 | Heat flow as a function of time.<br>References: (5) p. V-21; (10) p. 281.                                                          |
| Parallelepiped (rectangular)                                                                                                                   | Any of the above noted boundary conditions for a slab.                                                 | Temperature distribution as a function of time.<br>Combine solutions as indicated in Refs. 16 and 17.                              |
| Cylinder of finite length.                                                                                                                     | Any of the boundary conditions given above for a cylinder and a slab.                                  | Temperature distribution as a function of time.<br>Combine solutions as indicated in Refs. 16 and 17.                              |
| Hollow cylinder of infinite exterior radius.                                                                                                   | The temperature of the surface suddenly changes from the initial (uniform) temperature.                | Temperature distribution as a function of time.<br>Combine solutions as indicated in Refs. 16 and 17.                              |
|                                                                                                                                                |                                                                                                        | Heat flow at the surface as a function of time.<br>Reference: (10) p. 267.                                                         |

Consider the slab to be divided, as shown in Fig. 9, by  $n$  equidistant planes parallel to the slab surface and a distance  $\Delta x$  apart. Let the temperature of the slab at any plane and any time ( $\theta$ ) be denoted by  $T_{x,\theta}$ . Then the temperature of the slab at the two adjacent planes at the same

time will be denoted as  $T_{(x+\Delta x,\theta)}$  and  $T_{(x-\Delta x,\theta)}$ . In a similar manner the temperature of the  $x$  plane at a time  $\Delta\theta$  later will be  $T_{(x,\theta+\Delta\theta)}$ .

In accordance with this nomenclature, the temperature at any plane  $x$  and time  $\theta + \Delta\theta$  is given as

$$T_{(x,\theta+\Delta\theta)} = \frac{T_{(x+\Delta x,\theta)} + T_{(x-\Delta x,\theta)}}{2} \quad (18)$$

which may be interpreted as follows. The temperature of the slab at any plane,  $x$ , and any time,  $\theta$ , is equal to the average temperature of the two adjacent planes obtained at the time  $(\theta - \Delta\theta)$ .

The time interval  $\Delta\theta$  is determined by the equation

$$\Delta\theta = \frac{\Delta x^2}{2a} \quad (19)$$

Omitting the graphical construction at the slab boundaries, reference to Fig. 9 demonstrates the graphical method by means of which the temperature at each plane is determined at successive intervals of time in accordance with Equation 18.

For the problem stated, the boundary condition at the insulated surface is specified by the equation

$$\frac{\partial T}{\partial x} = 0$$

and at the uninsulated face by the equation

$$h(T_\infty - T) = -k \frac{\partial T}{\partial x}$$

In terms of finite differences these two equations (employing nomenclature established by Fig. 9) become.

$$\frac{T_F - T_E}{\Delta x} = 0 \quad \text{or} \quad T_F = T_E \quad \text{at} \quad x = L$$

and

$$h(T_\infty - T_A) = -k \frac{(T_B - T_A)}{\Delta x} \quad \text{at} \quad x = 0$$

or

$$\frac{T_\infty - T_A}{k/h} = - \frac{T_A - T_B}{\Delta x}$$

The details of the graphical construction are best obtained by inspection of Fig. 9. Note that the line  $(0,0,0')$  used to initiate the graphical construction, is the only one drawn to the slab boundary  $A'$ . The numbered points indicate temperatures at the sub-slab boundaries at 1,2,3, etc., time intervals  $(\Delta\theta)$  after the slab is exposed to the high temperature.

For transient heat flow in two dimensions, and also, for steady state conduction, numerical methods of solution are available in the literature.<sup>5,10,12,19</sup> These numerical methods are applicable to three dimensional problems, although the calculations involved normally become too tedious for most applications of the method. An additional technique of solution for one and two dimensional problems in transient conduction results from

the analogy of electrical resistance-capacitance networks to thermal systems.<sup>24</sup>

For two dimensional problems in steady state conduction, additional techniques of solution are found in flux plotting,<sup>5,19</sup> and in the use of a potential tank.<sup>5,19</sup> These methods are of most direct use in problems in which the boundaries of the two dimensional shape are made up of isothermal and adiabatic surfaces.

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- <sup>22</sup> *Methods graphiques pour l'etude des installations de Chauffage et de refrigeration en regime discontinu*, by A. Nessi and L. Nissolle (Dunod, Paris, 1949).
- <sup>23</sup> *Transient Heat Conduction in Hollow Cylinders after Sudden Change of Inner-Surface Temperature*, by R. L. Perry and W. P. Berggren (*University of California Publications in Engineering* 5, Vol. 59, 1944).
- <sup>24</sup> *Method for Determining Unsteady-State Heat Transfer by Means of Electrical Analogy*, by V. Paschakis (*A.S.M.E. Transactions*, Vol. 64, 1942, p. 105).

## CHAPTER 6 PHYSIOLOGICAL PRINCIPLES

Chemical Vitiating of Air, Physical Impurities in Air, Thermal Interchanges Between the Body and Its Environment, High Temperature Hazards, Acclimatization, Upper Limits of Heat for Men at Work, Application of Physiologic Principles to Air Conditioning Problems, Effective Temperature Index and Comfort Zones

**V**ENTILATION is defined in part as *the process of supplying air to, or removing air from, any space by natural or mechanical means*. The word in itself implies quantity, but air must be of the proper quality also. The term *air conditioning* in its broadest sense implies control of any or all of the physical or chemical qualities of the air. The A.S.H.V.E. Code of Minimum Requirements for Comfort Air Conditioning<sup>1</sup> defines it "as the process by which simultaneously the temperature, moisture content, movement and quality of the air in enclosed spaces intended for human occupancy may be maintained within required limits. If an installation cannot perform all of these functions, it shall be designated by a name that describes only the function or functions performed."

### CHEMICAL VITIATION OF AIR

People living indoors bring about certain physical and chemical changes in the air about them. The oxygen content of the air diminishes and the carbon dioxide increases, but these changes are too slight to be significant except in air tight spaces as in submarines. Organic matter which is usually perceived as odors, comes from the body or clothes. Moisture and heat are given off by the body. There is no evidence of any toxic volatile material given off by man to the ambient air. Stale air may be offensive because of odors and may induce loss of appetite and loss of energy. Objectionable body odors have the same effects. These reasons, whether esthetic or physiological, usually make it desirable in the design of air conditioning systems to provide for the elimination or control of odors arising from occupancy, cooking, or other sources. This may be accomplished by introducing odor-free air in sufficient quantities to reduce odor concentrations by dilution to a level which is not objectionable. Odor-free air may be outdoor air or air which has been cleared of odors by sorption, washing, or other appropriate means.

In the case of vitiating by a few hazardous gases such as carbon monoxide from heating, cooking, and certain industrial processes, no satisfactory chemical treatment for the elimination of the impurity has been found. The only satisfactory solution is elimination at the source by local exhaust ventilation; or, if this is impossible, reduction to a safe concentration by dilution. (See Chapter 8.) In the case of contamination by other matter, including volatile vapors and gases, chemical treatment for the removal or reduction of the impurities has been made available through air cleaning methods, which are discussed in Chapter 34.

When the only source of contamination is the human occupant, and overheating is not a problem, the minimum quantity of outdoor air needed appears to be that required to remove objectionable body odors, or tobacco smoke. The concentration of body odor in a room, in turn, depends

upon a number of factors, including the dietary and hygienic habits of the occupants (frequently reflecting their socio-economic status), the outdoor air supply, air space allowed per person, odor adsorbing capacity of air conditioning processes, and temperature and relative humidity. The intensity of odor sensation has been found to vary as the logarithm of the concentration of the odoriferous substance in the air, or inversely with the logarithmic function of the amount of outdoor air supplied and the air space per person.

The relation between air supply and occupancy has been reported by the Harvard School of Public Health<sup>2</sup> (Table 1) and the A.S.H.A.E. Research Laboratory.<sup>3</sup> Outdoor air requirements for removal of objectionable tobacco smoke odors are not accurately known, but available information and current practice indicate the need of 15 cfm per person or more.<sup>4</sup>

The total quantity of outdoor air to be circulated through an enclosure is often governed chiefly by physical considerations for controlling temperature, air distribution, and air velocity. Other factors which must be taken into consideration, include the type and usage of the building, locality, climate, height of rooms, floor area, window area, extent of occupancy, and the operation of the system distributing the air supply. Frequently, some of these factors, particularly the need for air movement and good distribution, may be satisfied by recirculation of inside air rather than outside air.

It will be noted that, with adequate air space, the rate of air change indicated in Table 1 is from 4 to 30 cfm per person. In rooms occupied by only a few persons, such an air change will be automatically attained in cold weather by normal leakage around doors and windows, and can easily be secured in warm weather by the opening of windows. With a space allotment of 400 cu ft per person, only  $1\frac{1}{2}$  air changes per hour are necessary to provide a ventilation rate of 10 cfm per person.

Therefore, in the ordinary dwelling with adequate cubic space allotment, no special provision for controlling chemical purity of the air is necessary (aside from removal of fumes from heating appliances). For such conditions, the control of air temperature is the major consideration.

In more crowded rooms (large offices, large workrooms, auditoriums), where the cubic space per person is less and it is usually impossible to admit untempered outside air without creating drafts, mechanical ventilation is essential.

The present data regarding the effect of cubic space on outdoor air requirements are not universally accepted. The Code of Minimum Requirements for Comfort Air Conditioning<sup>1</sup> prescribes definite minimum requirements which should be familiar to the designing engineer. It should be emphasized, however, that the code fixes *minimum*, rather than *adequate* requirements. (See also Tables 1 and 3 of Chapter 13.)

Notwithstanding the rapid advance made in air conditioning, some persons still believe there is a stimulating quality in outdoor air (particularly country, mountain and seashore air) under ideal weather conditions, which is lacking in artificially conditioned air. It is apparent, however, that modern air conditioning insures control of the phenomena of nature for the service and comfort of man independently of weather conditions. Freedom of movement, action and thought, together with the variability of stimuli experienced by persons under ideal conditions in the country, mountains or seashore, undoubtedly has some stimulating effect. Various experimenters have attempted to duplicate the invigorating qualities of

## Physiological Principles

TABLE 1. MINIMUM OUTDOOR AIR REQUIREMENTS TO REMOVE OBJECTIONABLE BODY ODORS UNDER LABORATORY CONDITIONS<sup>2</sup>

| TYPE OF OCCUPANTS                                                                                                                                       | AIR SPACE PER PERSON CU FT | OUTDOOR AIR SUPPLY CFM PER PERSON |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|-----------------------------------|
| <i>Heating season with or without recirculation. Air not conditioned.</i>                                                                               |                            |                                   |
| Sedentary adults of average socio-economic status....                                                                                                   | 100                        | 25                                |
|                                                                                                                                                         | 200                        | 16                                |
|                                                                                                                                                         | 300                        | 12                                |
|                                                                                                                                                         | 500                        | 7                                 |
| Laborers.....                                                                                                                                           | 200                        | 23                                |
| Grade school children of average socio-economic status                                                                                                  | 100                        | 29                                |
|                                                                                                                                                         | 200                        | 21                                |
|                                                                                                                                                         | 300                        | 17                                |
|                                                                                                                                                         | 500                        | 11                                |
| Grade school children of lower socio-economic status....                                                                                                | 200                        | 38                                |
| Children attending private grade schools.....                                                                                                           | 100                        | 22                                |
| <i>Heating season. Air humidified by means of centrifugal humidifier. Water atomization rate 8 to 10 gph. Total air circulation 50 cfm per person.</i>  |                            |                                   |
| Sedentary Adults.....                                                                                                                                   | 200                        | 12                                |
| <i>Summer season. Air cooled and dehumidified by means of a spray dehumidifier. Spray water changed daily. Total air circulation 50 cfm per person.</i> |                            |                                   |
| Sedentary Adults.....                                                                                                                                   | 200                        | <4                                |

outdoor air by the use of ozone, ionization, or ultra-violet light, but results to date have been inconclusive or negative.<sup>6</sup>

Ozone in amounts of 0.01 to 0.05 ppm of air is allowable in comfort air conditioning. Above this limit there is a pungent, unpleasant odor and perhaps respiratory distress, depression, and stupor.<sup>6</sup>

## PHYSICAL IMPURITIES IN AIR

Dust particles of almost any type can produce irritation of the mucous membranes of the nose and throat, if present in high concentrations. Certain dusts may be very harmful, but coal dust is tolerated well. The effects of various industrial dusts, pollens, etc., are discussed in Chapter 8.

A certain part of the dissemination of disease in confined spaces may be due to pathogenic organisms floating in the air like dust particles. (See Chapter 7.)

While in some instances it may be possible to reduce the physical impurities of the air by dilution from a non-contaminated source, such a source is rarely available. Frequently, outdoor air contains a higher concentration of physical impurities than indoor air. Therefore, it is usually desirable to reduce the concentration of physical impurities by air cleaning methods. (See Chapter 34.)

## THERMAL INTERCHANGES WITH ENVIRONMENT

Body temperature depends upon the balance between heat production and heat loss. Heat resulting from oxidation in the body (metabolism)

maintains the body temperature well above that of the surrounding air in a cool or cold environment. At the same time, heat is constantly lost from the body by radiation, convection and evaporation. Since, under ordinary conditions, the body temperature is maintained at its normal level of about 98.6 F, the heat production must be balanced by the heat loss. During work, the body temperature may rise; in fact, afternoon temperatures of normal persons average 1 deg above the resting value of the morning whether working or not.

The fundamental thermodynamic processes concerned in heat interchanges between the body and its environment may be described by the equation:

$$M = \pm S + E \pm R \pm C \quad (1)$$

where

- $M$  = rate of metabolism, heat produced within the body.
- $S$  = rate of storage, change in intrinsic body heat.
- $E$  = rate of evaporative heat loss.
- $R$  = rate of radiative heat loss or gain.
- $C$  = rate of convective heat loss or gain.

The rate of metabolism,  $M$ , is always positive. The storage,  $S$ , may be either positive or negative, depending upon whether heat is being stored or depleted owing to a rise or fall in body temperature. Under ordinary circumstances (when the dew-point of the air is below the body surface temperature) the evaporation loss,  $E$ , is always positive; that is, heat from metabolism supplies this loss.  $R$  and  $C$  are positive when body surface temperature is above that of walls and air, and negative when it is below.

DuBois,<sup>7</sup> after careful calorimeter studies on a fasting, nude man, plotted the partition of body heat loss and heat production as a function of temperature. Fig. 1 shows some disparity between heat production and heat loss. This disparity is  $S$  in Equation 1. In the central range of the experiments  $S$  was quite low and no increase in heat loss by vaporization was apparent.

Within the range of 81-86 F air temperature, with still air, there is, for a resting nude man, a point at which his body has to take no particular action to maintain its heat balance. If he is clothed, or if he is active, this point will naturally lie at a lower level. At this point, which may be termed the *neutral point* for that individual, conditions are neither too hot nor too cold. If, through a fall in air temperature, or a rise in air movement, the rate of heat loss from the skin to the environment is increased, then the body must do something to counteract this heat loss. Over a certain range, the body can achieve this by decreasing the flow of blood through the skin. This will result in some cooling of the skin and subjacent tissues, but the temperature of the deep tissues will be preserved. The range of external conditions over which this may be achieved, may be termed the *zone of vaso-motor regulation against cold*. Beyond this range, the temperature of the superficial tissues will fall still further, and that of the deep tissues will fall as well, unless some other steps are taken. The body normally does react; it increases heat production by increasing muscular tension, by shivering, or by spontaneous increase in activity.<sup>8</sup> As long as these are adequate to meet the increased rate of heat loss to the environment, a fall in deep body temperature may be prevented. Such conditions may be said to lie in the *zone of metabolic regulation against cold*. Beyond

this point, the body enters the *zone of inevitable body cooling*. Once body temperature starts to fall, man is headed for disaster.

It will be seen that, in man, deep body temperature is preserved over an important range of cold external conditions, at the expense of (1) a fall in the temperature of the peripheral tissues, and (2) an increased expenditure of energy. As regards the first of these, the farther away superficial tissue lies from the central body mass, the more readily will its temperature fall.

On the hot side of the neutral point, there exists a *zone of vaso-motor regulation against heat*, corresponding to that against cold. The blood flow through the skin is increased when the opportunities for heat loss to the environment are restricted.<sup>9</sup> This increase in blood flow may double the conductance of the superficial tissues over that characteristic of the neutral point, and the temperature of the skin surface may rise until it is only three degrees below that of the deep tissues. If this increase in blood flow is

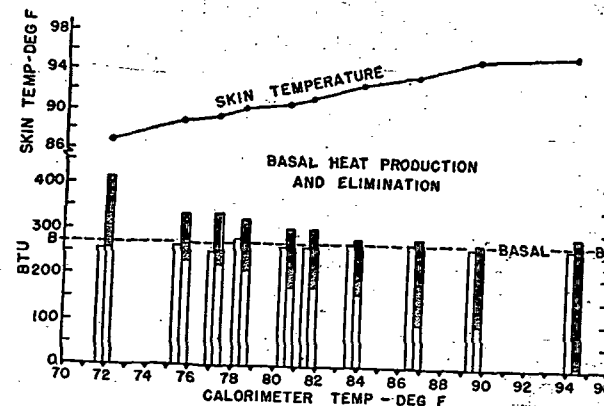


FIG. 1. HEAT LOSS FROM HUMAN BEING BY EVAPORATION, RADIATION, AND CONVECTION<sup>a</sup>

<sup>a</sup> Normal control, naked, in calorimeter at temperatures from 72.8 to 94.1 F. First column in each experiment represents heat production as determined by indirect calorimetry, the second column, heat elimination. The portion marked with vertical lines represents vaporization; the dotted area, convection; the unmarked area, radiation. The skin temperature represents the average reading of 18 spots on the surface.

unable to balance the restriction in heat loss, the body has entered the next zone. Once again, the normal body takes steps to prevent a change in its deep temperature; but they are not the counterpart of the steps taken under similar circumstances on the cold side. There is, in fact, very little change in heat production, beyond that resulting from a disinclination for exertion. The second line of defense, on the hot side, is a new and powerful method of promoting heat loss—the provision of water, by the operation of the sweat glands, for evaporative cooling. As long as evaporation is adequate to restore the desired heat loss, the body is in the *zone of evaporative regulation against heat*. When this ceases to be adequate, the body is in the *zone of inevitable body heating*. The body enjoys a little more latitude in this zone than it did in the corresponding zone on the cold side, but when the deep temperature rises more than 4 deg F, it loses its efficiency. All factors which affect the evaporation of water from the skin affect heat regulation in the zone of evaporative regulation. Atmospheric vapor pressure



and air motion are most important. With dry-bulb temperature above body temperature, air motion facilitates evaporative heat loss by removing hot humid air from contact with the skin and replacing it with relatively drier air.

Heat regulation in man requires an intact set of sensory nerves, a normal sympathetic nerve supply to sweat glands and blood vessels, a great many sweat glands, and a circulatory system capable of carrying heat from muscles and viscera to the skin by circulation of the blood.

Some of the phenomena of body temperature control are shown graphically in Fig. 2. The dotted curves, from a study at the John B. Pierce Laboratory of Hygiene,<sup>10</sup> are for subjects lightly clothed in a semi-reclining position, and give the relation between the dry-bulb temperature of the environment (with about 45 percent relative humidity) and the metabolic

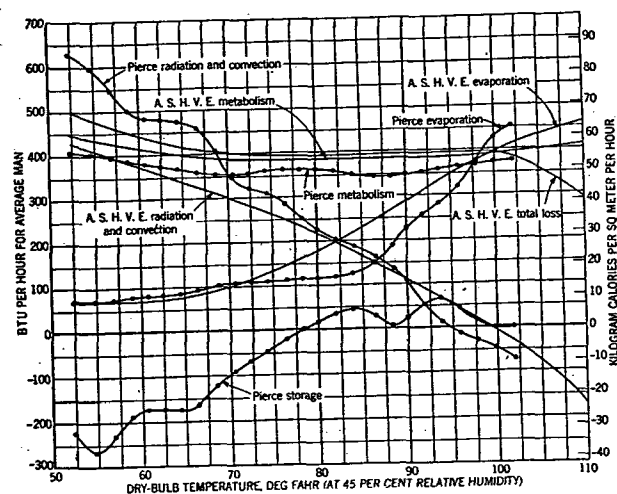


FIG. 2. RELATION BETWEEN METABOLISM, STORAGE, EVAPORATION, RADIATION PLUS CONVECTION, AND TEMPERATURE FOR THE CLOTHED SUBJECT

rate (heat production), the rate of heat dissipation by radiation and convection combined, and the latent heat loss due to evaporation from the skin and the respiratory tract. The smooth line curves from the work of the A.S.H.A.E. Research Laboratory<sup>11</sup> give the same relationships for healthy, male subjects (18 to 24 years of age), seated at rest and dressed in customary winter indoor clothing. The Pierce Laboratory data for the semi-reclining subjects also include the rate of heat storage (either positive or negative) due to a rise or fall in body temperature. For the normally clothed subjects, a curve gives the total heat loss (that is, the sum of the radiation, convection and evaporative losses). Here, storage is given by the difference between the metabolism and total heat loss.

The small difference between the metabolic rates for the two groups of subjects may be accounted for by difference in activity. Heat exchange between the body and the environment by radiation and convection is greater for the lightly clothed subject, both for cool conditions where there is excessive heat loss, and for very warm conditions where there is transfer of heat from the atmosphere to the body. The two curves for

evaporative loss serve to show how physiological control uses evaporation of sweat to maintain equilibrium at high temperatures. Below 75 F, for the normally clothed subject, and below 85 F for the lightly clothed subject, evaporation loss is minimal and constant. Burch<sup>12</sup> has shown that this insensible perspiration reflects the permeability of the skin to the moisture of the body. Above these temperatures, control is obtained by the availability of sweat for evaporation. The difference in the curves above 75 F is probably largely determined by the difference in clothing and activity.

In the zone of evaporative heat regulation, air movement facilitates heat loss if the temperature of the air is not above that of the skin.<sup>13</sup> Under hot, dry conditions air movement may be of little advantage, or even of disadvantage, if it increases the addition of heat to the skin by conduction more than it promotes the loss of heat from the skin by evaporation.

TABLE 2. PHYSIOLOGICAL RESPONSES TO HEAT OF MEN AT REST AND AT WORK\*

| EFFECTIVE TEMP | ACTUAL CHEEK TEMP (FAHR DEG) | MEN AT REST                           |                                               |                                                             | MEN AT WORK<br>90,000 FT-LB OF WORK PER HOUR |                                     |                                               |                                                         |
|----------------|------------------------------|---------------------------------------|-----------------------------------------------|-------------------------------------------------------------|----------------------------------------------|-------------------------------------|-----------------------------------------------|---------------------------------------------------------|
|                |                              | Rise in Rectal Temp (Fahr Deg per Hr) | Increase in Pulse Rate (Beats per Min per Hr) | Approximate Loss in Body Weight by Perspiration (Lb per Hr) | Total Work Accomplished (Ft-Lb)              | Rise in Body Temp (Fahr Deg per Hr) | Increase in Pulse Rate (Beats per Min per Hr) | Approximate Loss in Body Wt by Perspiration (Lb per Hr) |
| 60             | -----                        | -----                                 | -----                                         | -----                                                       | 225,000                                      | 0.0                                 | 6                                             | 0.5                                                     |
| 70             | -----                        | 0.0                                   | 0                                             | 0.2                                                         | 225,000                                      | 0.1                                 | 7                                             | 0.6                                                     |
| 80             | 96.1                         | 0.0                                   | 0                                             | 0.3                                                         | 209,000                                      | 0.3                                 | 11                                            | 0.8                                                     |
| 85             | 96.6                         | 0.1                                   | 1                                             | 0.4                                                         | 190,000                                      | 0.6                                 | 17                                            | 1.1                                                     |
| 90             | 97.0                         | 0.3                                   | 4                                             | 0.5                                                         | 153,000                                      | 1.2                                 | 31                                            | 1.5                                                     |
| 95             | 97.6                         | 0.9                                   | 15                                            | 0.9                                                         | 102,000                                      | 2.3                                 | 61                                            | 2.0                                                     |
| 100            | 99.6                         | 2.2                                   | 40                                            | 1.7                                                         | 67,000                                       | 4.0 <sup>b</sup>                    | 103 <sup>b</sup>                              | 2.7 <sup>b</sup>                                        |
| 105            | 104.7                        | 4.0                                   | 83                                            | 2.7                                                         | 49,000                                       | 6.0 <sup>b</sup>                    | 158 <sup>b</sup>                              | 3.5 <sup>b</sup>                                        |
| 110            | -----                        | 5.9 <sup>b</sup>                      | 137 <sup>b</sup>                              | 4.0 <sup>b</sup>                                            | 37,000                                       | 8.5 <sup>b</sup>                    | 237 <sup>b</sup>                              | 4.4 <sup>b</sup>                                        |

\* Data by A.S.H.A.E. Research Laboratory.

<sup>b</sup> Computed value from exposures lasting less than one hour.

## HIGH TEMPERATURE HAZARDS

Studies at the A.S.H.A.E. Research Laboratory<sup>14</sup> and elsewhere during the past two decades have made available much information dealing with the physiological effects of hot atmospheres on workers, and means of alleviating the distress and hazards associated therewith. Table 2 gives some of the physiological responses of men, at rest and at work, to hot environments. Frequent and continued exposure of workers to hot environments results in physiological derangement affecting the leucocyte count of the blood, and other factors dealing with man's mechanism of defense against infection.

Wherever *S* (Equation 1) becomes strongly positive and body temperature rises progressively, men will continue to work until body temperature reaches 103 F. When these body temperatures are exceeded, men work with declining efficiency and may be subject to heat stroke.

Heat exhaustion is a circulatory failure in which the venous return to the heart is reduced so that fainting results.<sup>15</sup> Early symptoms of heat exhaustion may include fatigue, headache, dizziness when erect, loss of appetite, nausea, abdominal distress, vomiting, shortness of breath, flushing of face and neck, pulse rate above 150, glazed eyes, and mental dis-



TABLE 3. UPPER LIMITS OF ENVIRONMENTAL CONDITIONS FOR ACCLIMATIZED, HEALTHY, YOUNG MEN IN MILITARY SERVICE

| ENVIRONMENT           | REACTIONS AT THE END OF 4 HR |            |
|-----------------------|------------------------------|------------|
|                       | Rectal Temp F                | Pulse rate |
| Relatively Easy ..... | Below 101                    | Below 130  |
| Difficult .....       | 101 to 102                   | 130 to 145 |
| Impossible .....      | Above 102                    | Over 145   |

turbances as apathy, poor judgment, and irritability which usually precede fainting (syncope). Recovery is usually prompt when the man is removed to a cool place and kept lying down for a time, unless he has some other illness such as heart disease.

Heat cramps are painful muscle spasms in extremities, back and abdomen due, at least in part, to excessive loss of salt in sweating. Formerly common in hot industries, this manifestation of illness due to heat is now greatly reduced by drinking water containing 0.1 percent salt, or by proper use of salt tablets. Heat cramps are readily alleviated by administration of salt solution intravenously.

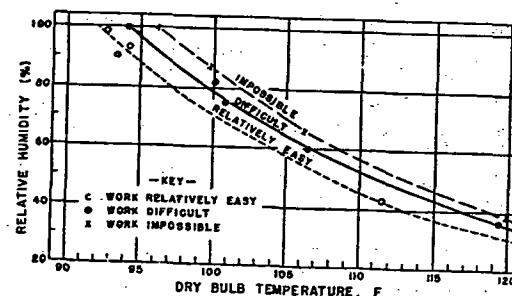
Heat stroke is a serious effect of exposure to great heat. The body temperature climbs rapidly to excessive levels often above 105 F when for unknown reasons free sweating suddenly stops. At such high temperatures, coma appears and death may be imminent. Emergency measures are required to reduce the excessive body temperature by cooling quickly to avoid irreparable damage to the brain.<sup>16</sup>

The deleterious physiologic effects of high temperatures exert a powerful influence upon physical activity, accidents, sickness and mortality. Both laboratory and field data show that physical work in warm atmospheres is a great effort, and that production falls progressively as the temperature rises.

### ACCLIMATIZATION

When men move to deserts or to jungles some adaptation to the climate takes place. If work is gradually increased day by day, and if the men can get plenty of water and salt, and can sleep each night, acclimatization may be complete in 7 to 10 days. The acclimatized man works with a lower heart rate, lower skin and rectal temperature, and more stable blood pressure than when unacclimatized. The process of acclimatization requires work in the heat.<sup>17</sup> During the recent war, white troops lived and did hard physical work for long periods in tropical conditions when disease hazards were controlled.

In recent tests made at the A.S.H.A.E. Research Laboratory,<sup>18</sup> subjects were required to perform light work under very hot conditions for a 4-hr period each day. It was found that the ability of a new subject to endure these conditions showed daily improvement for a period of at least 2 weeks. However, after acclimatization was completed, a recess of several days had no effect on the endurance of the subject. Individuals differ widely in their capacity to acclimatize. Acclimatized men lose most of these improvements in a few weeks of temperate climate, even though they are vigorously active. In the course of acclimatization, the sweat glands come to secrete fluid less rich in salt.<sup>19</sup> For all except those carrying out really hard work in hot, dry atmospheres, this effects an important saving in

FIG. 3. HEAT ENDURANCE OF ACCLIMATIZED SUBJECTS WORKING AT A SPECIFIC RATE<sup>20</sup>

salt loss, and makes all the difference between being exposed and not being exposed to the risk of heat cramps.

The adaptive level changes somewhat with the season. There are also marked differences between the sexes. In the cold zone the thickness of thermal insulating tissues of women is almost double that of men, although the sensory responses to cold are similar. In the hot zone, the threshold of sweating is higher for women. The thickness and insulating value of the clothing worn are also important factors in the determination of the comfort level.

### UPPER LIMITS OF HEAT FOR MEN AT WORK

In very hot conditions humidity is the limiting factor, and the wet-bulb temperature assumes great importance. In 1905 Haldane recognized that 88 F wet-bulb was the limit of endurance for coal miners, and later observers have concurred.

A study was made at the Armored Medical Research Laboratory<sup>20</sup> to determine the upper limits of environmental conditions under which a man can perform certain work. Thirteen enlisted men, thoroughly acclimatized to the hot conditions, served as subjects. During each test, the subjects were required to march for 4 hr at the rate of 3 mph, carrying

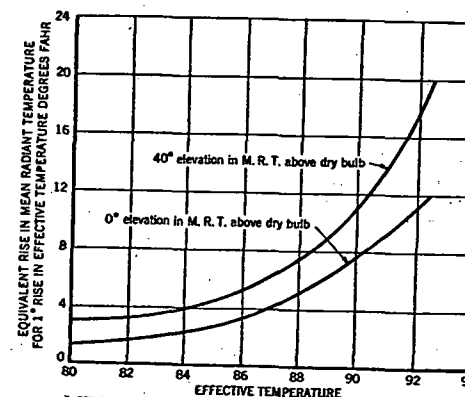


FIG. 4. EFFECT OF MRT ELEVATION IN TERMS OF EFFECTIVE TEMPERATURE

20 lb packs under a wide range of environmental conditions which were rated as relatively easy, difficult, and impossible, on the basis of the physiological reactions of the subjects at the end of the 4-hr period as shown in Table 3 and Fig. 3.

Recognition of the need of air conditioning for workers in hot industries is growing rapidly. The choice of the type of system to be used in any given instance, must be determined by the air conditioning engineer after a study of conditions. In some hot industries where few workers are

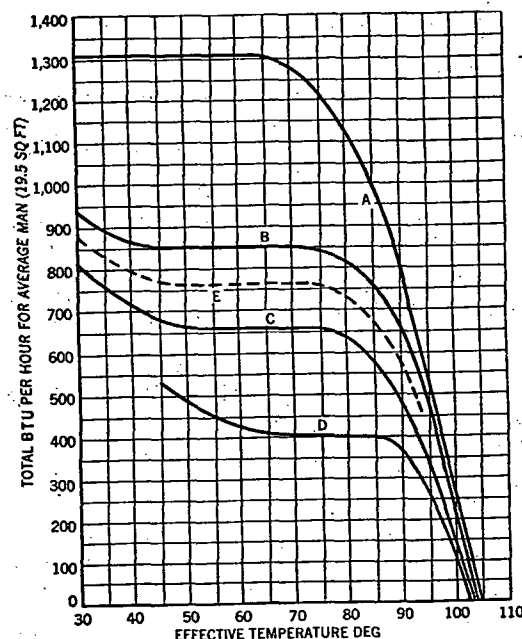


FIG. 5. RELATION BETWEEN TOTAL HEAT LOSS FROM THE HUMAN BODY AND EFFECTIVE TEMPERATURE FOR STILL AIR<sup>14</sup>

\* Curve A—Persons working, metabolic rate 1310 Btu per hour. Curve B—Persons working, metabolic rate 850 Btu per hour. Curve C—Persons working, metabolic rate 660 Btu per hour. Curve D—Persons seated at rest, metabolic rate of 400 Btu per hour. Curves B and D based on test data covering a wide temperature range. Curves A and C based on test data at an Effective Temperature of 70 and extrapolation of Curves B and D. All curves are averages of values for high and low relative humidities; variation due to humidity is small.

engaged in large spaces the worker himself, rather than the atmosphere, can be cooled by placing him in a small booth, and blowing cooled air over him, or by circulating cooled air through a loose-fitting suit.<sup>21</sup>

The A.S.H.A.E. Laboratory has studied the effects of walls of higher temperature than the air.<sup>18</sup> The findings are in part shown in Fig. 4. It will be seen that the importance of mean radiant temperature, as compared with that of the effective temperature, decreases as the effective temperature rises; and also, to a certain extent, as the mean radiant temperature itself rises. The lower of the two curves relates to conditions in which the MRT was kept approximately at the level of the DBT. If this curve is followed, it will be seen that, at 80 ET, a little more than 1 deg

rise in MRT produces the same effect as 1 deg rise in ET; but when the ET is 92 deg, it takes a rise of 11 F deg in the MRT to produce the same effect as 1 deg rise in ET. The upper curve relates to conditions in which the MRT was kept about 40 F deg higher than the DBT. It will be seen that under these conditions, a rise in MRT is less effective, even at low values of ET; and that it loses its relative effectiveness more rapidly as the ET rises. It should not be assumed, however, that MRT does not matter much. All that these comparisons indicate is that unit rise in MRT becomes less important as compared with unit rise in ET, as conditions get hotter. This may be due more to a growing importance of unit rise in ET than to a diminishing importance of unit rise in MRT. Under ordinary still air conditions the effects of air temperature and MRT appear to be interdependent. Various authorities give 0.3 to 1 deg increase of room temperature to compensate for 1 deg depression of the MRT.

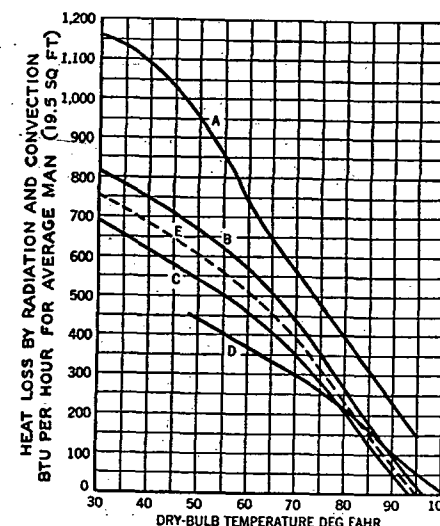


FIG. 6. RELATION BETWEEN RADIATION AND CONVECTION LOSS FROM THE HUMAN BODY AND DRY-BULB TEMPERATURE FOR STILL AIR<sup>14</sup>

\* See footnote a, Fig. 5.

### APPLICATION OF PHYSIOLOGIC PRINCIPLES TO AIR CONDITIONING PROBLEMS

In order to estimate cooling loads in occupied spaces it is necessary to know the metabolic rate (heat production) of man. This has been studied extensively, and found to remain relatively constant per unit of body surface area in a subject fasting and resting quietly after a good night's sleep. The rate is high in children, and diminishes gradually with age; it increases in certain diseases and in the presence of fever. The metabolic rate is somewhat lower in women. Heat production goes up sharply with work and varies widely in different persons doing the same work. Figs. 5, 6, and 7 and Table 25 of Chapter 13 give sufficient basic data for estimating heat production and heat loss under various conditions.

## EFFECTIVE TEMPERATURE INDEX AND COMFORT ZONES

There is no precise physiologic observation by which comfort can be evaluated. Mean skin temperature offers some promise. The zone of thermal neutrality differs with clothing, season, activity, and all the other factors controlling heat production (Table 4). The comfort zone is very similar to the zone of thermal neutrality.

Sensations of warmth or cold depend not only on the temperature of the surrounding air as registered by a dry-bulb thermometer, but also upon the temperature indicated by a wet-bulb thermometer, upon air movement, and upon radiation effects. Dry air at a relatively high temperature may feel cooler than air of lower temperature with a high moisture content. Air motion makes any moderate condition feel cooler. Radiation to cold or from warm surfaces is another important factor under certain conditions affecting the comfort reaction of the individual.

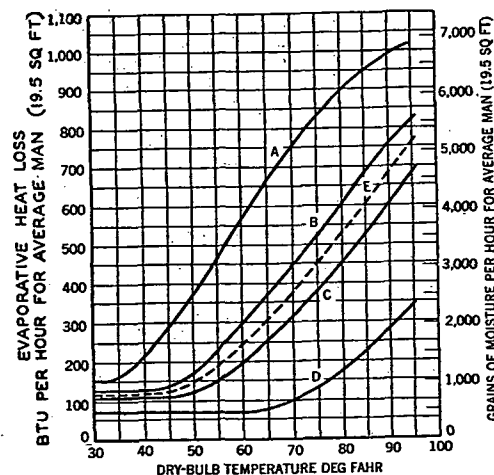


Fig. 7. EVAPORATIVE HEAT AND MOISTURE LOSS FROM THE HUMAN BODY IN RELATION TO DRY-BULB TEMPERATURE FOR STILL AIR CONDITIONS<sup>14</sup>

<sup>14</sup> See footnote a, Fig. 5.

Combinations of temperature, humidity, and air movement which induce the same feeling of warmth are called thermo-equivalent conditions. A series of studies<sup>22</sup> at the A.S.H.A.E. Research Laboratory established the equivalent conditions for practical use. This scale of thermo-equivalent conditions not only indicates the sensation of warmth, but also to a considerable degree determines the physiological effects on the body induced by heat or cold. For this reason, it is called the *effective temperature* scale or index, and it denotes sensory heat level.

*Effective temperature* is an empirically determined index of the degree of warmth perceived on exposure to different combinations of temperature, humidity, and air movement. It was determined by trained subjects who compared the relative warmth of various air conditions in two adjoining conditioned rooms by passing back and forth from one room to the other.

The numerical value of the index for any given air conditions is fixed by the temperature of slowly moving (15 to 25 fpm air movement) saturated

air which induces a like sensation of warmth or cold. Thus, any air condition has an effective temperature of 60 deg when it induces a sensation of warmth like that experienced in slowly moving air at 60 F saturated with moisture. The *effective temperature index* cannot be measured directly, but is determined from dry- and wet-bulb temperatures and air motion observations by reference to an Effective Temperature Chart (see Figs. 8, 9, and 10) or tables.

Fig. 8 gives the effective temperature for any combination of dry- and wet-bulb temperatures for *still air* (15 to 25 fpm) conditions. Charts similar to Fig. 8 for air velocities of 100 and 300 fpm have been presented in earlier editions of THE GUIDE, e.g. 1939. Fig. 9 is another form of effective temperature chart embodying all three variables: dry-bulb and wet-bulb temperatures, and air velocity.

TABLE 4. COMPARISON OF COMFORT RANGES WITH ZONE OF THERMAL NEUTRALITY

| INVESTIGATORS                      | EFFECTIVE TEMPERATURE |           | OPERATIVE TEMP | REMARKS                                                                |
|------------------------------------|-----------------------|-----------|----------------|------------------------------------------------------------------------|
|                                    | OPTIMUM LINE          | RANGE     | RANGE          |                                                                        |
| Comfort Zone                       |                       |           |                |                                                                        |
| Houghten and Yaglou.               | 66                    | 63-71     | .....          | Winter non-basal; at rest, normally clothed. Men and women.            |
| Yaglou and Drinker...              | 71                    | 66-75     | .....          | Summer non-basal; at rest and normally clothed. Men.                   |
| Yaglou.....                        | 72.5                  | 66-82     | .....          | Entire year; non-basal; at rest and stripped to waist. Men.            |
| Keeton et al.....                  | 75                    | 74-76     | .....          | Entire year; basal, nude. Steady state (9 hr exposure). Men and women. |
| Zone of Thermal Neutrality         |                       |           |                |                                                                        |
| DuBois and Hardy...                | 75                    | 73.2-76.9 | .....          | Basal; nude; men.                                                      |
|                                    | 71.8                  | 64.8-76.0 | .....          | Basal; clothed; men.                                                   |
| Winslow, Herrington and Gagge..... |                       |           | 84.0-87.8      | Non-basal; at rest; nude; men.                                         |
|                                    |                       |           | 74-84          | Non-basal; at rest; clothed; men.                                      |

As stated previously, effective temperature is an index of the degree of warmth experienced by the body. An effective temperature line is, therefore, a line defining the various combinations of conditions which will induce like sensations of warmth. It does not necessarily follow that like sensations of comfort will also be experienced along the entire length of an effective temperature line. Some degree of discomfort is likely to be experienced at very high or very low relative humidities, regardless of the effective temperature. It has also been found that the optimum effective temperature varies with the season, and is lower in winter than in summer.

Tests<sup>14</sup> made at the A.S.H.A.E. Research Laboratory in very hot conditions, with subjects doing light work, were in very close agreement with the effective temperature chart. Other work<sup>20</sup> under similar environmental conditions, but with subjects walking 3 mph and carrying 20 lb packs, indicated that the effective temperature lines should be more

nearly horizontal. It therefore appears that the slope of the ET lines may vary, depending upon the rate of work being performed.

Fig. 10 shows the A.S.H.A.E. Comfort Chart<sup>22</sup> as published since 1950. The areas and arrows indicating the summer and winter comfort zones on the previous charts have been removed. The summer comfort zone was removed because it extended to temperatures where too large a percentage of the people would be uncomfortable. The winter comfort zone was removed for the same reason, and because of inadequate data in later studies.

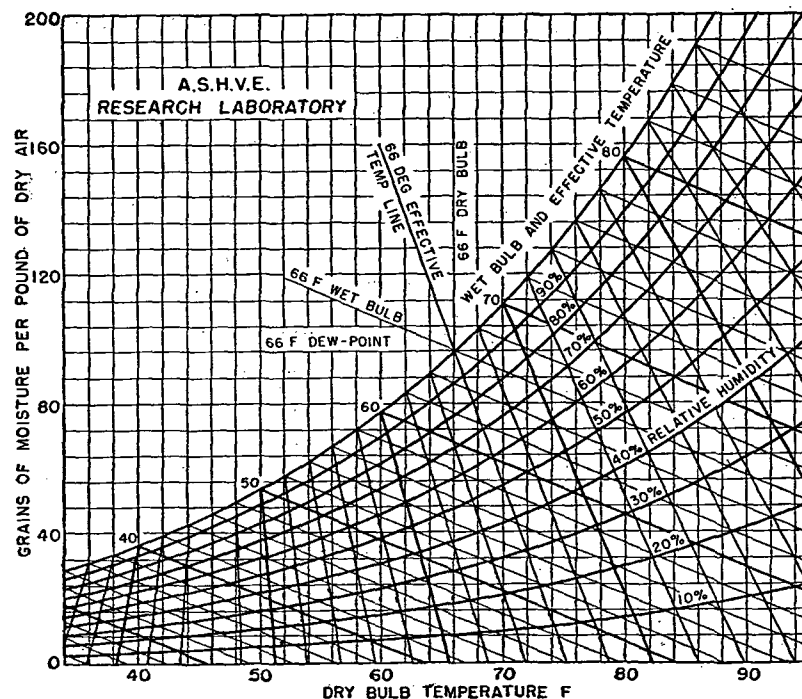


FIG. 8. PSYCHROMETRIC CHART, PERSONS AT REST, NORMALLY CLOTHED, IN STILL AIR

The distribution curve, showing the percent of people feeling comfortable at various effective temperatures in *summer*, indicates that a maximum of 98 percent of the people were comfortable at 71 ET. The study was conducted with relative humidities between 30 and 70 percent.

The distribution curve shown on the previously used chart, showing the percent of people feeling comfortable at various effective temperatures in the *winter*, was based on research prior to 1932. This curve indicated that at 66 ET a maximum number of people were comfortable. Later studies<sup>23</sup> by the A.S.H.A.E. Research Laboratory indicated that a maximum of 97.7 percent of the people were comfortable at 68 ET, and this finding has been confirmed by current practice.<sup>24</sup> However, adequate data from the later studies were available only for the ET range of 65 to 69,

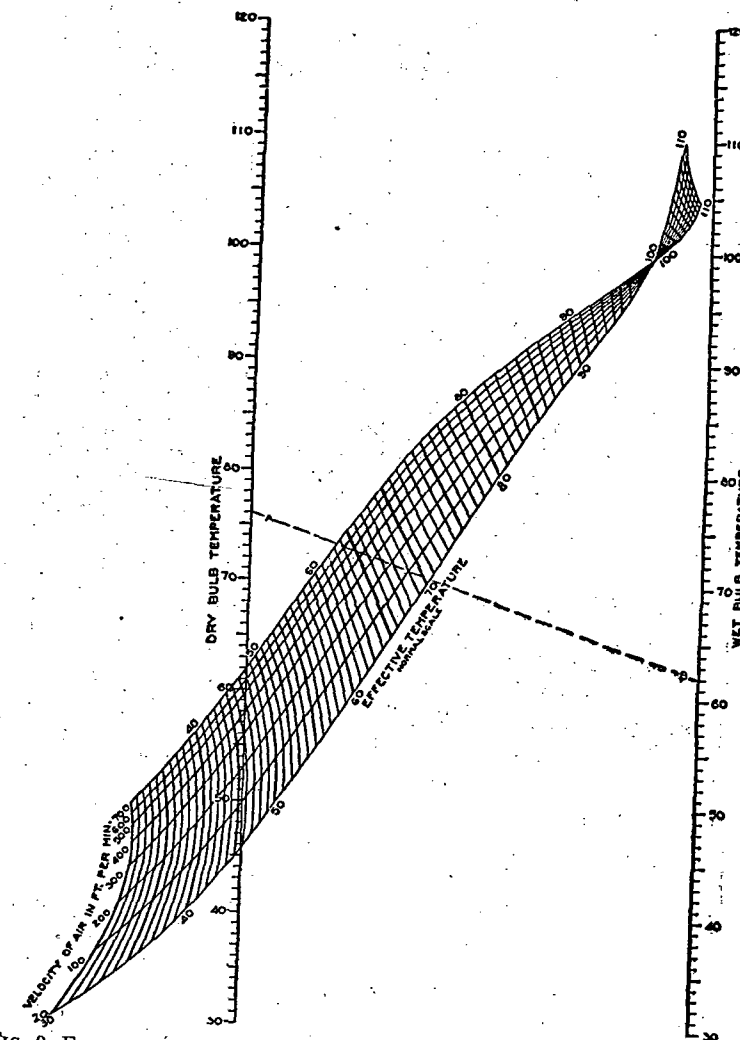


FIG. 9. EFFECTIVE TEMPERATURE CHART SHOWING NORMAL SCALE OF EFFECTIVE TEMPERATURE, APPLICABLE TO INHABITANTS OF THE UNITED STATES UNDER FOLLOWING CONDITIONS:

*A. Clothing:* Customary indoor clothing. *B. Activity:* Sedentary or light muscular work. *C. Heating Methods:* Convection type, i.e., warm air, direct steam or hot water radiators, plenum systems.

as presented in Fig. 10. The studies should be extended to cover a wider range. The lighter weight clothing, probably worn in the later studies, accounts for the higher desirable ET.

Radiation from occupants to room surfaces, and between the occupants, has an important bearing on the feeling of warmth, and may alter to some

measurable degree the optimum conditions for comfort previously indicated. Since the mean radiant temperature of a space is affected by cold walls and windows, as well as by the warm surfaces of heating units placed within the room or imbedded in the walls, these factors must be

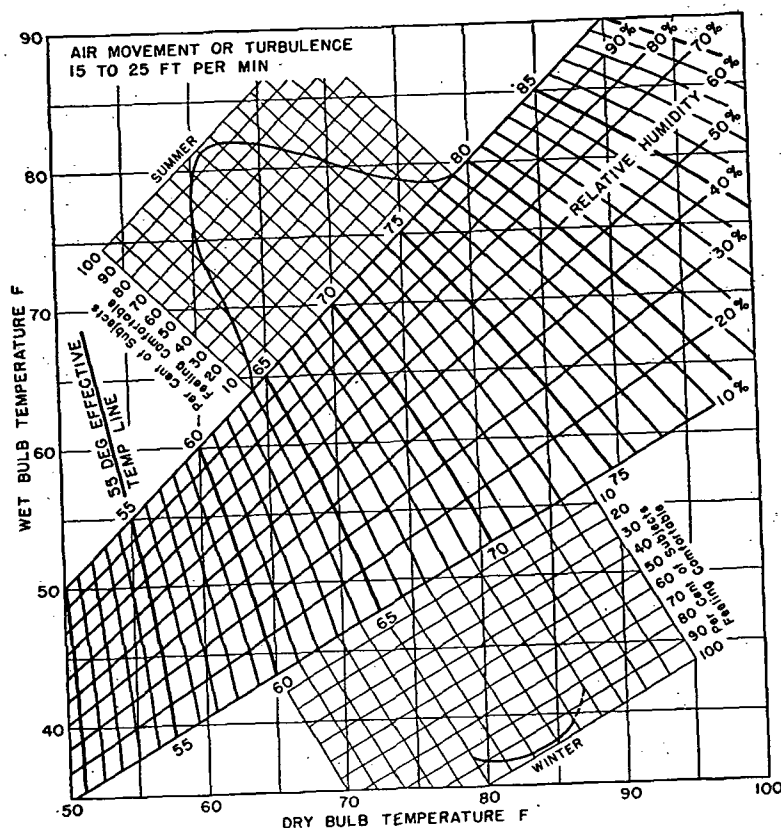


FIG. 10. A.S.H.A.E. COMFORT CHART FOR STILL AIR<sup>a,b</sup>

<sup>a</sup> Note.—Both summer and winter comfort lines apply to inhabitants of the United States only. Application of winter comfort line is further limited to rooms heated by central systems of the convection type. The line does not apply to rooms heated by radiant methods. Application of summer comfort line is limited to homes, offices and the like, where the occupants become fully adapted to the artificial air conditions. The line does not apply to theaters, department stores, and the like where the exposure is less than 3 hours. The line does not apply to theaters, department stores, and the like where the exposure is less than 3 hours. The line does not apply to theaters, department stores, and the like where the exposure is less than 3 hours. The line does not apply to theaters, department stores, and the like where the exposure is less than 3 hours.

<sup>b</sup> Dotted portion of winter comfort line was extrapolated beyond test data.

compensated. Likewise, in densely occupied spaces, such as classrooms, theaters and auditoriums, temperatures somewhat lower than those indicated by the comfort line may be desirable because of counter-radiation between the bodies of occupants in close proximity to each other. Such radiation will also elevate the mean radiant temperature of the room.

Many field studies<sup>22</sup> have been made to determine the optimum indoor effective temperature for both winter and summer in several metropolitan districts of the United States and Canada, in cooperation with the managements of offices employing large numbers of workers (Fig. 11). On the whole, women of all age groups studied prefer an effective temperature for comfort, 1.0 deg higher than men. All men and women over 40 years of age prefer a temperature 1 deg ET higher than that desired by persons below this age. The persons serving in all of these studies were representative of office workers dressed for air conditioned spaces in the summer season, and engaged in the customary office activity.

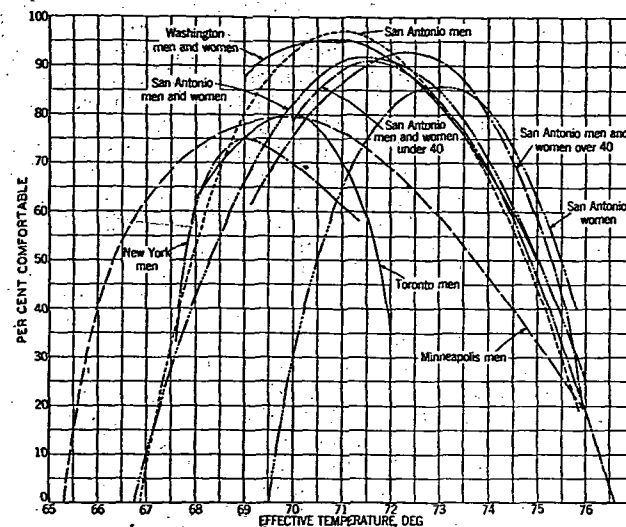


FIG. 11. RELATION BETWEEN EFFECTIVE TEMPERATURE AND PERCENTAGE OBSERVATIONS INDICATING COMFORT

On the basis of present knowledge, for different geographical regions and age groups, the most popular temperature varies from a low of 66 ET in winter to a high of 73 ET in summer. The spread for summer comfort is 69 to 73 ET.

A spread of 3 deg in the optimum effective temperature for summer cooling is ascribed to geographical location. However, variations in sensation of comfort among individuals may be greater for any given location than variations due to a difference in geographical location. The available information indicates that changes in weather conditions over a period of a few days do not alter the optimum indoor temperature.

Sudden chilling of persons entering a cooled and air conditioned space during the summer months, may at times be important. It is due to the rapid evaporation of perspiration which accumulated on the skin and in the clothing during previous subjection to hot and humid outside conditions and increased heat loss by radiation. While studies<sup>23</sup> have shown that for healthy individuals this chilling is not harmful, under some condi-

tions it may be unpleasant or even harmful. People entering and remaining in cooled spaces for short periods, 15 min or less, may be satisfied with less cooling. For long occupancy very little deviation from the optimum effective temperature is indicated.

Upon leaving an air-cooled space and re-entering a hot atmosphere, sudden warming occurs. Experiments at the A.S.H.A.E. Research Laboratory<sup>26</sup> and elsewhere<sup>25</sup> indicated no demonstrable harm to a healthy individual. Adaptation occurred as soon as normal perspiration was established. Mild exercise shortened the adaptation time.

A great number of persons seem to be fairly content in summer with a higher plane of indoor temperature. Studies by the University of Illinois<sup>27</sup> in cooperation with the A.S.H.A.E. Committee on Research indicate that effective temperatures as high as 74.5 ET are acceptable in the living quarters of a residence, and while this condition is not representative of optimum comfort, it provides sufficient relief in hot weather to be acceptable to the majority of users, in the interest of economy. Individual minority differences can be counteracted by clothing.

Satisfactory comfort conditions for persons at work<sup>28</sup> vary, depending upon the rate of work and the amount of clothing worn. In general, the greater the degree of activity, the lower the effective temperature necessary for comfort. Clothing has been evaluated for its overall insulation effects by a physical unit, the *clo* which equals 0.116 C deg per (kilogram calorie) (square meter) (hour).<sup>29</sup> Yaglou<sup>30</sup> criticizes the concept of overall insulation, and points out that different parts of the body require different amounts of insulation. The literature on effects of clothing is difficult to coordinate at the present time, as much of it is still in military service reports which are yet to be published and amplified.

For prematurely born infants, the optimum temperature varies from 100 to 75 F, depending upon the stage of development. The optimum relative humidity for these infants is placed at 65 percent.<sup>31</sup> No data are yet available on the optimum air conditions for full term infants and young children up to school age. Satisfactory air conditions for these age groups are assumed to vary from 75 to 68 F with natural indoor humidities. For children (having high metabolism) at school, in winter clothes, 70 F has been considered correct, with 55 F recommended for gymnasiums.

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## CHAPTER 7

## AIR CONDITIONING IN THE PREVENTION AND TREATMENT OF DISEASE

Sanitary Ventilation, Control of Airborne Infection, Value of Air Cooling Under Tropical Conditions, Treatment of Disease, Operating Rooms, Nurseries for Premature Infants, Fever Therapy, Cold Therapy, Allergic Disorders, Oxygen Therapy, General Hospital Air Conditioning

THE Second World War caused an increase of interest in the preventive aspects of air conditioning. It re-emphasized the importance of the control of airborne infection and demonstrated the value of air cooling under tropical conditions for the prevention of heat rash, for promoting proper rest and sleep, and in the convalescence of patients.

The problem of air conditioning or air purification in shelters, hospitals, or any buildings, following an atomic explosion has the attention of engineers, military personnel, public health authorities, private physicians, and the general public. The type and structure of shelters are important. In strategic areas likely to be bombed, they should be windowless, underground, strong enough to resist blast and have sufficient cover to protect against initial radiation. Suitable ventilation is a necessity, and could be provided by the use of pressurized installation in which any air taken from the outside is forced through a ventilator. Air conditioning and heating or cooling systems could then be kept in continuous operation for improving inside air conditions and controlling room temperature. Heat transmission through the walls, carbon dioxide accumulation, and the total number of people using the shelter, are factors in determining the necessity for using outside air. Such a shelter should be closed to outside air during the period immediately following a blast.

A surface or subsurface burst of an atomic bomb would result in a wide dispersion of airborne radioactive particles.<sup>1</sup> Windows of buildings within a three-mile radius from the point of detonation of a 20 KT bomb would be broken, and consequently, any protection however slight, obtainable through the use of conventional air-conditioning systems would not be accomplished. Beyond the three-mile radius many structures may be found with windows undamaged and otherwise capable of providing some degree of protection from airborne radioactive particles by the utilization of an air-conditioning system. However, conventional air-conditioning systems should not be relied upon for such protection in urban structures which may be utilized in the accomplishment of specific missions following an atomic detonation. There are special techniques and devices available which will provide this protection.

The smog incident in Donora, Pa., has focused the attention of health authorities and engineers on the problem of air contamination by toxic gases. The exact way in which such substances affect the human being is unknown.<sup>2</sup> There has been a great deal of speculation, but in reality there is little specific information concerning this problem. It is believed that in such cases the combination of contaminants, rather than any single substance, produces the toxic effects. It is known that low atmospheric pressure, with accumulation of toxic substances in increasingly higher

concentration, produced the condition in Donora. The U. S. Public Health team, in their investigation, found that this same city had experienced several previous incidences of lesser severity during the preceding 30 years. This was shown by much higher mortality rates during certain periods. A high percentage of the population of this city suffered to some extent during the recent *smog*. Older individuals were more seriously affected with cardio-respiratory symptoms.

Study of such a situation is rather difficult, as explained in the aforementioned report. The medical profession has much to learn about the effects of these substances on human beings, and until more precise knowledge is obtained, it is difficult to know when precise controls are really needed. Further research is urgently needed.<sup>8</sup>

### SANITARY VENTILATION

During the last 15 years great popular interest has been aroused in the spread of respiratory infection indoors, and control by ventilation or its sanitary equivalent by air disinfection. In Europe three important documents have appeared recently in English, Swedish, and French literature.<sup>4,5,6</sup> In the United States where the study began, the vast literature has been consolidated, and definitions, formulations, and factors of sanitary ventilation codified in a volume now being edited for publication.

The Council of Physical Medicine of the *American Medical Association* approved the radiant disinfection of air in 1943, and two sub-committees of the Committee on Research and Standards of the *American Public Health Association* have reported favorably upon the control of airborne infection by sanitary ventilation and on air sanitation respectively.<sup>7,8,9,10</sup> The work of a Technical Advisory Committee on Air Sterilization of the A.S.H.V.E. has from time to time since 1944 reported progress in *THE JOURNAL*, and has recommended a set of definitions, formulations and factors for joint adoption by the *American Public Health Association* and the Society.

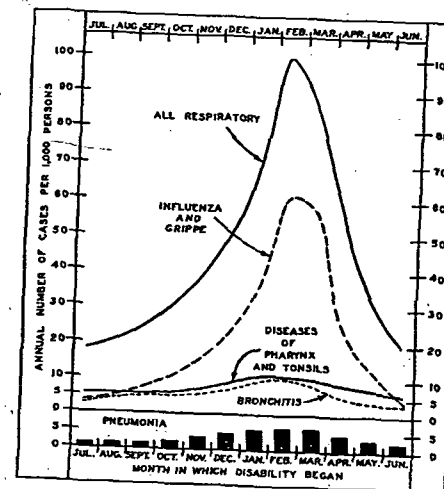
But this important new field of sanitary ventilation is just emerging from the research to the development stage. When consolidation and codification of present data have been completed, a more comprehensive treatment in *THE GUIDE* may be possible. The following section on Control of Airborne Infection gives some idea of the scope of the subject.

### CONTROL OF AIRBORNE INFECTION

The majority of airborne diseases are spread indoors where people gather. Any program of air sanitation is influenced by a number of factors. In the winter months, the closing of doors, windows and other means of access to the outside air to conserve warmth, as well as the crowding of persons indoors, provides conditions conducive to a high incidence of contagion. This seasonal phenomenon, illustrated in Fig. 1 which represents a study made by the U. S. Public Health Service, will concern the ventilating engineer insofar as air quality (determined by temperature, humidity, air replenishment and type of air movement and by freedom from contamination) is a major intrinsic factor. Apart from the seasonal picture of airborne contagion, are such extrinsic factors as rate of turnover of personnel, and the marked susceptibility of the recruit in comparison with permanent personnel<sup>11</sup> as shown in Fig. 2 by studies of military personnel housed in barracks. These extraneous variables and the factor of contact infection (direct spray) tend to complicate any evaluation of the effectiveness of air sanitation for elimination of micro-organisms in droplet-nuclei and droplet-dust. Thus, control measures may eliminate consistently 90 percent

of airborne organisms in laboratory tests, but cannot effect a decrease in actual incidence of infection exceeding 30 percent. Thirty percent may be the maximal reduction in infection possible by air treatment methods. The distinction should be clearly drawn, therefore, between the effectiveness of a procedure in laboratory tests and its effectiveness and applicability in actually reducing the incidence of airborne disease. On the other hand, recent studies suggest that inhalation of dust-borne bacteria is more important than direct inhalation of infectious droplets or droplet nuclei in the spread of respiratory tract infections.<sup>12</sup>

The following sequence of events has been postulated as occurring in a large proportion of intra-ward infections: (a) ejection of relatively large protected infective particles from patients; (b) rapid venting or settling of these particles so that those remaining airborne are in low con-



Occurrence of diseases causing disability for 8 consecutive days or longer in a group of 100,000 wage earners (10 percent women) in different industries.  
\* Graph obtained from Dean K. Brundage, U. S. Public Health Service.

FIG. 1. STUDY OF AVERAGE MONTHLY FREQUENCY (1921-1926 INCLUSIVE) OF SPECIFIED RESPIRATORY DISEASES\*

centration; (c) survival of infective particles to permit the accumulation of high concentrations on surfaces; (d) repeated reintroduction of infective particles into the air under the stimulus of ward activities or by air currents of the order of 50 fpm over the floor; and (e) extension of infective areas by air turbulence throughout the ward or hospital. The most important link in this probable infection chain has been demonstrated to be the reintroduction of particles into the air.<sup>13</sup>

Intensive studies on air disinfection have indicated two distinct control measures: (a) suppression of dust and lint, and (b) disinfection of droplet-nuclei. A third measure, control of relative humidity, is important. It has been shown that the viability of certain organisms sprayed into the atmosphere from a liquid suspension is dependent on relative humidity. The mortality rate of the organisms is very high at a relative humidity of 50 percent,<sup>14</sup> and decreases at humidities above and below this figure. It



has also been reported that the influenza virus loses much of its virulence when the relative humidity is 50 percent.<sup>15</sup>

Well controlled, large scale tests of the various methods of air sterilization conducted in barracks<sup>16, 17</sup> have confirmed the importance of dust control in minimizing the spread of airborne disease, a consideration which has guided the practices of ventilating engineers for a number of years. The importance of the dust factor has been emphasized by many engineers, and has been convincingly demonstrated by subsequent bacteriologic studies aboard ships.

Treatment of floors and bedclothes with oil emulsions has proved effective in reducing bacterial dispersion by as much as 90 percent in Army barracks and station hospitals.<sup>17</sup> The incidence of acute respiratory infections was from 10 to 30 percent lower in barracks with oiled floors and bedclothes than it was in control barracks which received no special treatment. More recent studies, however, have yielded inconsistent results.

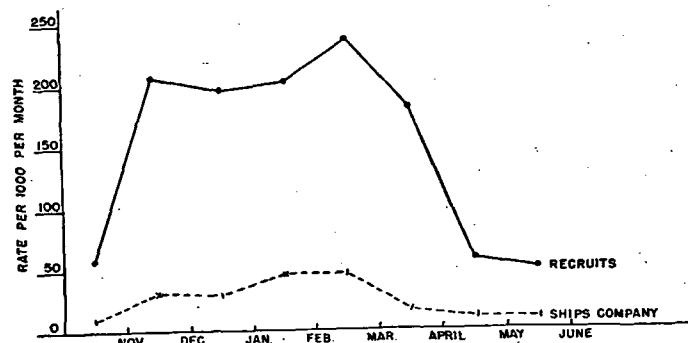


FIG. 2. MONTHLY INCIDENCE OF ACUTE RESPIRATORY ILLNESS AMONG NAVAL RECRUITS AND SHIP'S COMPANY (PERMANENT PERSONNEL)<sup>1</sup>

An emulsifying mixture, *Fixanol C* containing cetyl pyridinium bromide, when incorporated in the oil-in-water emulsion imparted a bactericidal action to the emulsion. Blankets treated with this substance and oil became bactericidal and retained this property for as long as three months. The possibility of hypersensitivity of an occasional individual to bromide drugs should be borne in mind when exposing large groups to treated garments or blankets.<sup>12</sup>

No simple method for disinfecting droplet-nuclei has yet been devised. Under favorable laboratory conditions, propylene glycol in concentrations of 0.07 to 0.14 milligrams per liter, and triethylene glycol in a concentration of 0.0045 milligrams per liter were highly germicidal for most airborne bacteria in clean air when the relative humidity was between 40 and 60 percent.<sup>18, 19, 20</sup> A humidity of 50 percent, without the use of glycol vapor, has been reported as destructive to some bacteria. However, maximum rates of bactericidal action of triethylene glycol vapor will be secured at humidities between 20 to 50 percent.<sup>21</sup>

In a recent report on the effect of triethylene glycol vapor in air disinfection, it is pointed out that the rate of ventilation, as determined by the number of air changes per hour, is important and that continuous vaporization is needed to maintain effective concentrations of glycol vapor.<sup>21</sup>

In the absence of an apparatus to measure the concentration of vapor in the room, a slight fog is an indication of adequate concentration. Absence of such a fog indicates a non-bactericidal concentration. The report stated: "However, under experimental conditions we have observed no apparent decomposition of triethylene glycol when temperatures up to 290 F were maintained at the site of vaporization, provided the vaporizing unit was designed so that heat was applied to liquid glycol only at the point of vapor formation. On the other hand, decomposition was frequently observed when the vaporizing temperature was raised above 290 F, or when liquid glycol was kept above 120 F for long periods of time. The precise nature of the decomposition products is as yet unknown, but they may well be irritant or toxic and their formation should be avoided. For this reason, it is felt that a limit of 290 F should be applied to the temperature employed in vaporization, and furthermore, that liquid glycol should not be heated above 120 F for long periods of time."

It was also recommended that a given vaporizer be capable of various outputs as measured by grams of liquid glycol vaporized per hour; for instance, from 0.5 g to at least 2.0 g per 1000 cu ft of volume treated, for small vaporizing units. Such high rates secure bactericidal concentration in less than an hour. Each room should be furnished with a single small vaporizer, and one vaporizer should not be expected to handle a volume greater than 4000 cu ft. Apparatus for the production of glycol vapor, and an independent duct system for carrying this vapor and diluting air for large rooms or spaces, and unit type vaporizers for small spaces, have been described recently.<sup>22</sup> There is also available a device for the automatic regulation of glycol vapor in the air called the glycostat. This instrument has been calibrated to measure the degrees of saturation of the air with glycol vapor by direct reading of the variations in the intensity of light reflected from the glycol condensing surface of the wheel of the instrument.<sup>23</sup>

Under practical conditions, particularly in the presence of dust in the air, glycol effectiveness is much reduced. The use of other chemical aerosols that have been tried is limited by their toxicity, odor, or destructiveness to fabrics and metals. A recently reported controlled experiment in the offices of the Metropolitan Life Insurance Company showed that under ordinary working conditions triethylene glycol vapor failed to reduce the number of airborne bacteria and the incidence rate of minor respiratory infections.<sup>24</sup>

Ultraviolet radiation of floors and upper air has been studied extensively at the Naval Training Center, Sampson, N. Y. In barracks housing naval recruits, hospital admissions for respiratory infections (mostly *catarrhal fever*) were 25 percent lower in a group of men exposed to ultraviolet radiation—2537 Angstrom Units, 1 to 7 ergs per (cm<sup>2</sup>) (sec) at bed level—than they were in adjacent control barracks without ultraviolet radiation.<sup>25</sup>

A controlled study over a six-year period on the evaluation of ultraviolet radiation of sleeping quarters as a supplement of accepted methods of respiratory disease control was recently reported.<sup>26</sup> The amount of radiation over the last two years of the period was believed to be about five times that recommended commercially. No significant effect in the incidence of disease could be detected in about 400 inmates during the six-year period. This conclusion may not be applicable to present ultraviolet equipment installed in accordance with manufacturers' recommendations. The data imply that air layers were not sufficiently mixed. However, more efficient mixing would have been obtained at the expense of increased

circulation of dust and lint. Sources of ultraviolet radiation should be so situated as to protect the eyes of the occupants of the room from direct or reflected rays. A combination of ultraviolet radiation and dust control measures is believed to be more effective than either one of the two used alone, but the proof for this has yet to come.

There is no doubt that these methods will reduce the number of bacteria in the air of an enclosed space, but there is still considerable question as to whether they are practical measures for reducing the total number of respiratory infections among personnel, since exposure by contact is an important factor. Bourdillon and his group concluded that there is justification for attempting to reduce the load of air-borne microorganisms by the methods now at our disposal.<sup>4</sup> They have explored the properties of a number of compounds, and their conclusions are in agreement with those of American investigators.

The present status is admirably reviewed by the Committee on Sanitary Engineering of the *National Research Council*,<sup>27</sup> and by a subcommittee of the *American Public Health Association*.<sup>9</sup> Both committees feel that the problem of air disinfection is still in the experimental stage. Knowledge concerning the effectiveness of glycol vapors has not kept pace with the development of vaporizing devices, and there is real danger that commercial exploitation of the various devices may discredit the method and discourage careful research in this important field.<sup>28</sup> More experimentation is needed for arriving at a definite conclusion concerning its use in industry and public buildings.

#### VALUE OF AIR COOLING UNDER TROPICAL CONDITIONS

The commissioning of a class of naval hospital ships with all wards, laboratories and living spaces air cooled is a notable achievement to provide better treatment of patients, especially those suffering from extensive burns, by control of environmental factors. Although statistics are not at hand to indicate the deaths or retarded recoveries of patients due to lack of air cooling in ships operating in tropical waters, it is generally agreed among competent observers that high temperature and humidity are major factors in prolonging disability and increasing mortality of the sick and injured. Physiologic data obtained on healthy men, moreover, show the large loss of body fluids and the stress on the cardiovascular system in terms of increased pulse rate when these men are continuously subjected to high temperatures. Even at rest about 50 cc of fluid per hour are lost as sweat<sup>29</sup> through intact skin. In burn patients the difficulty, encountered in temperate climates, of maintaining fluid and electrolyte balance is tremendously augmented by the additional evaporative fluid loss in hot environments.

Patients who have such varied conditions as heart disease, thyrotoxicosis, shock from any cause, severe hemorrhage, or those who have had an anesthetic, will invariably store heat when subjected to a hot, humid environment. The gradient between the body surface temperature and the environmental temperature is such that loss by radiation is slight. The heat loss by evaporation in a warm, humid environment is low whether the patient does or does not perspire. The heat regulatory center may be temporarily deranged following an anesthetic, brain injury, or after an overdose of barbiturate. Loss of fluids and electrolytes is another influencing factor. Cooling the body is the answer to this problem, and this can best be done in a cool room of low relative humidity where conditions for heat loss are ideal. This measure is also valuable in controlling temperature height of patients with various acute febrile diseases.<sup>30</sup>

Frequently from 50 to 75 percent of personnel aboard naval vessels operating in tropical waters are afflicted with heat rash to a degree that interferes with rest and sleep. In carefully controlled experiments<sup>29</sup> it was possible to produce a fulminating type of rash in all men living continuously at an effective temperature of 85 (90 F dry-bulb and 83 F wet-bulb). In the control group, 12 out of 24 hr were spent in a relatively cool atmosphere of 75 ET (80 F dry-bulb, and 70 F wet-bulb). These men either remained free from heat rash, or occasionally developed a mild form. Thus, intermittent cooling to a degree which prevented sweating in men at rest eliminated a serious handicap to good performance of duty.

In both laboratory tests and aboard hospital ships a relatively cool living environment of 76 to 78 ET provided an atmosphere conducive to rest and sleep without excessive sweating. Berthing spaces tended to have extremely low odor levels. Motivation, initiative and alertness, in contrast to the usual irritability and lack of incentive incident to residence in tropical climate, were maintained.<sup>31</sup>

Little has been done, however, to obtain practical methods for application of air conditioning under heavy heat loads and on the enormous scale that would be needed to modify life in the tropics. It is not improbable that cooled houses in a tropical climate, if used consistently for one generation, would modify the whole character of a population. The obvious advantages of part time cooling on personnel to promote rest and sleep in tropical areas would provide a prophylactic measure of great potential importance.

#### TREATMENT OF DISEASE

In the past few years considerable progress has been made in using air conditioning as an adjunct in the treatment of various diseases. Among the important applications are those in operating rooms, nurseries for premature infants, maternity and delivery rooms, children's wards, clinics for arthritic patients, heat therapy, cold therapy, oxygen therapy, X-ray rooms, the control of allergic disorders, and for the physiological effects in industry.

Normal individuals may be subjected to considerable strain in adjusting to hot, humid conditions. Heat loss by radiation is reduced, as is loss by evaporation of sweat. Individuals with certain disease processes are at a still greater disadvantage since they may also have difficulty in the transport of heat from the interior to the surface of the body via the circulation.

Patients with thyrotoxicosis tolerate hot, humid conditions or *heat waves* very poorly. Their metabolism is high, and therefore their heat production is excessive. They may be unable to eliminate heat from the body surface as rapidly as it is produced and transported to the skin. They develop hyperthermia or fever, and a tachycardia or rapid heart rate. The demand on the circulation for transport of heat from the interior of the body to the skin surface is increased. The increased body temperature leads to increased cell metabolism, and in turn to still greater heat production. This vicious cycle may threaten life if the cardio-vascular or transport mechanism breaks down. A cool, dry environment favors the loss of heat by radiation and evaporation from the skin, and may save the life of the patient with thyrotoxicosis.

Cardiac patients may be unable to maintain the circulation necessary to insure normal heat loss. Recently the importance of air conditioning hospital wards and rooms of cardiac patients, particularly those with congestive heart failure, has been stressed as a therapeutic measure.<sup>32</sup> It is more important in tropical or subtropical climates. Individuals with head

injuries, those subjected to brain operations, and those with barbiturate poisoning may have hyperthermia, especially in a hot environment, due to a disturbance in the heat regulatory center of the brain. Obviously, one of the most important factors in recovery is an environment in which the patient can lose heat by radiation and evaporation, namely, a cool room with dehumidified air.

The patient in shock, or the patient who has had a severe hemorrhage, may have an inadequate volume of circulating blood and be unable to maintain an adequate skin circulation. This may result in heat storage or fever. Patients with extensive skin burns may be unable to lose heat adequately from the limited uninvolved skin surface, and thus develop a fever. They need adequate fluid replacement, saline solution, plasma or blood to expand the circulating blood volume and thereby improve peripheral circulation. A cool environment is valuable in aiding heat loss after adequate skin circulation is established.

A hot, dry environment (89.6 F and 35 percent relative humidity) has been used over an extended period for the treatment of patients with rheumatoid arthritis, with reported improvement.<sup>33</sup>

### OPERATING ROOMS

The widest application of air conditioning in hospitals is in operating rooms. Complete air conditioning of operating wards is important because winter humidification helps reduce the danger of anesthetic gases; summer cooling with some dehumidification tends to eliminate excessive fatigue and to protect the patient and operating personnel; and finally, filtering aids the removal of allergens from the operating room air.

#### Reducing Explosion Hazard

Explosion hazards in operating rooms increased with the introduction of anesthetic gases and apparatus. Ether administered by the old drop method gives rise to an explosive mixture, but in practice this method is still regarded as comparatively safe. When ether is mixed with pure oxygen, or nitrous oxide in certain concentrations, the explosion hazard may be as great as with ethylene-oxygen, or cyclopropane-oxygen mixtures.

Of the anesthetic gases nitrous oxide alone does not explode but supports combustion. Ether, vinyl ether, ethylene, and cyclopropane are as potentially dangerous as gasoline or illuminating gas in the home.<sup>34</sup> Chloroform does not explode violently in contact with flame, but decomposes to liberate phosgene. All of the anesthetic gases and vapors, except ethylene, are heavier than air. Although the incidence of injury or death from explosion is negligible compared with other hazards in the operating room, the dramatic features surrounding an explosion justify continued investigation to eliminate the hazard.

During the course of ethylene anesthesia, the mixture, usually 80 percent ethylene and 20 percent oxygen, is so rich that the danger of explosion is slight in the immediate vicinity of the face mask, but leakage of ethylene into the air may accumulate to any lower concentration, and thus introduce a serious hazard. The most dangerous period is at the end of the operation when the patient's lungs and the anesthesia apparatus are customarily washed out with oxygen with or without the addition of carbon dioxide. Even when this procedure is omitted, it is difficult in practice to avoid dilution of the anesthetic gas with air during the normal course of breathing following the administration. In either case the mixture would pass through the explosion range and extraordinary precaution is necessary for the safety of the patient and operating personnel.

In a study<sup>35</sup> of 230 anesthetic explosions and fires, 70 percent of the explosions and 60 percent of the deaths were caused by igniting agents other than static sparks. The *National Fire Protection Association*<sup>36</sup> made certain recommendations for safe practice based on available information in Pamphlet No. 56, Recommended Safe Practice for Hospital Operating Rooms (July 1952). These recommendations outline in some detail ways and means for eliminating or correcting hazardous conditions which experience and investigation have shown to contribute to the hazards in question. They are divided into three parts: Part I, General, deals with the nature of the hazards, Part II, Construction and Equipment, deals with physical standards for features incorporated into the construction and equipment of the surgical suite, and Part III, Administration, contains precautions to be observed by hospital personnel. The requirements and recommendations are interdependent and each will be ineffective unless coordinated with the other. To approach complete success in the prevention of anesthetic explosions, all persons—the surgical staff, the nursing staff, the maintenance staff and administrative personnel—must be educated and periodically reminded of the explosive nature of combustible anesthetic agents.

Experience has shown that neither high humidity nor intercoupling devices have eliminated the danger from static electric discharge. The removal of gas concentrations from the operating table area, by means of specially devised exhaust ventilation, should be thoroughly tested. Portable duct systems as installed aboard ship should be acceptable. Serious explosions can occur in a closed system, but proper precautions will reduce this hazard to a minimum.

A comprehensive study of the explosion problem and of the general causes and prevention of operating room hazards, by the *University of Pittsburgh*, the *ASHAE Research Laboratory*, and the *U. S. Bureau of Mines* has led to a fruitful attempt to eliminate the explosive range of cyclopropane, one of the best but most difficult gases to handle. The use of helium as a diluent in the total gaseous mixture controls the oxygen concentration by displacement and, because of its flame quenching properties, it is the ideal gas for this purpose. In addition, a gaseous mixture containing helium is more difficult to ignite by electric discharges, and this quality also increases the safety factor of anesthetic administration.

#### Operating Room Conditions

Little is known about optimum air conditions for maintaining normal body temperatures during anesthesia and the immediate post-operative period. An anesthetized patient displays dilation of blood vessels in the skin resulting in profuse sweating and (it has been believed) inability to regulate body temperature. From this it was concluded that all anesthetized patients suffered considerable heat loss, although there may be little more than 0.8 F variation in the rectal temperature during the course of the operation.<sup>37</sup> The severe physiological effects, such as excessive sweating and rapid pulse, of high operating room temperatures on attendants and patients during the hot months signify the need for proper cooling. Statements of surgeons who operate in both air conditioned and non-air conditioned rooms strongly indicate that the recuperative power of the patient is greater when operated upon in air conditioned rooms.<sup>37</sup>

Although the comfortable air conditions for the operators are not identical with those for the patient, it is usually not difficult to compromise within a range of 55 to 60 percent relative humidity and 72 to 80 F temperature.

The work just cited reported that 68 to 70 F effective temperature not only furnished comfort for the operating room workers, but apparently prevented exhaustion of patients as evidenced by rapid convalescence in the recovery ward. Additional heat may be furnished to patients locally or by suitable covering, according to body temperature in individual cases.

In the control of airborne infection in the operating room, the prevention of dispersal of infectious materials into the air, control of dust, and proper ventilation supersede attempts to remove or kill pathogenic organisms. The bacterial content of conditioned operating rooms is generally lower than that of non-conditioned rooms.

Bacterial counts aboard an air-conditioned submarine were found to be exceptionally low and not cumulative with time, although all of the air was recirculated for more than 12 hours<sup>38</sup> without replenishment. The removal of bacteria by the process of air cooling and condensation of moisture out of air, merits further study.<sup>39</sup>

The degree of air contamination can be reduced by proper ventilation if velocity of air over the floor does not exceed 50 fpm. Research is in progress on the use of filtered air flowing through a system of mechanical cleaners which protect the patient against infection from attendants, and from bacteria-containing air in the corridor or ward.<sup>40</sup>

Operations are frequently postponed on allergic patients during asthmatic manifestations through fear of complications. The removal of airborne allergens, therefore, is in some cases an important function of the air conditioning system in preparing patients for operation.

Central system air conditioning plants and unit air conditioners producing between 8 and 12 air changes per hour of adequately filtered and properly conditioned air are generally acceptable to the medical profession for operating rooms. Opinions vary considerably on the use of all outside air *versus* recirculation for operating rooms. There is a current trend among eminent authorities on anesthesiology to recommend that a minimum of 50 percent outside air be introduced to the operating room, with a maximum of 50 percent recirculated filtered room air. A separate exhaust fan system is usually necessary to confine and remove the gases and odors. Double windows are desirable and often necessary to prevent condensation and frosting on the glass in cold weather, and to minimize drafts. The air flow of 8 to 12 air changes in operating rooms should: (1) reduce the concentration of the anesthetic to well below the pharmacologic threshold in the vicinity of the operating personnel; (2) remove the great amounts of heat and sometimes moisture, from sterilizing equipment if inside the operating room, from the powerful surgical lights, from solar heat, and from the bodies of the operatives; and (3) provide extra capacity for quickly preparing the room for emergency operations. Much can be gained by thermal insulation of sterilizing equipment, and by thorough exhaust ventilation of sterilizing rooms adjoining the operating rooms. An air conditioned recovery ward in connection with the air conditioned operating room, is of great value in stabilizing peripheral circulation, and in reducing excessive loss of fluids on hot humid days.

### NURSERIES FOR PREMATURE INFANTS

One of the most important requirements in the care of premature infants is the stabilization of body temperature. This is necessary because the infant's heat regulatory system is not fully developed, with the resultant tendency for environmental temperature to influence body temperature.

The younger the premature infant, the greater is the tendency. As the infant's metabolism is low, heat production is not adequate to maintain a normal body temperature in a cool environment. The resistance to infection is low, and the mortality rate is high. In general, the younger the age of the premature infant, the higher the mortality rate.

Nurseries constructed for metabolic research should be air conditioned so that conditions are reproducible. Results of such studies may be invalid if environmental conditions are not identical, since fluid and electrolyte loss may vary greatly with change in environmental conditions.

### Air Conditioning Requirements

The optimum air conditions for growth and development of premature infants were determined by extensive research<sup>41</sup> at the Children's Hospital, Boston, Mass., using four valid criteria, namely, stability of body temperature, gain in weight, incidence of digestive syndromes, and mortality. Individual temperature requirements varied widely (from 72 to 100 F) according to the constitutional state of the infants and body weights. The optimum relative humidity was about 65 percent, and the air movement less than 20 fpm.

A single nursery conditioned to 77 F and 65 percent relative humidity was found to fulfill satisfactorily the requirements of the majority of premature infants. Additional heat for weak (or debilitated) infants may be furnished in the cribs or by means of electric incubators placed inside the conditioned nursery, and the temperature adjusted according to individual requirements. In this way multiplicity of chambers and of air conditioning apparatus is obviated; the infants in the heated beds derive the benefit of breathing cool humid air, and the nurses and doctors need not expose themselves to extreme conditions.

**Importance of Humidity:** Although external heat is an important factor in the maintenance of normal body temperature, humidity appears to be of equal or greater importance. When the premature nurseries at the Children's Hospital were kept at relative humidity between 25 and 50 percent for two weeks or longer, the body temperature became unstable, gain in weight diminished, the incidence of gastro-intestinal disturbances increased, and the mortality rose. On the other hand, continuous exposure to air conditions with 55 to 65 percent relative humidity gave satisfactory results over a period of years. The initial physiologic loss of body weight (loss occurring within first four days of life) was found to vary inversely with the humidity. In the old nurseries with natural humidity it averaged 12.4 percent of the birth weight; in the conditioned nurseries it was 8.9 percent with 25 to 49 percent relative humidity, and 6.0 percent with 50 to 75 percent relative humidity. The number of days required to regain the birth weight was correspondingly maximum in the old nursery, and minimum in the conditioned nurseries under high humidity.

Maximum gains in body weight occurred in the conditioned nurseries under high humidity (55 to 65 percent) in infants weighing less than 5 lb. The gains were less under low humidity (25 to 50 percent) in the same nurseries, and in the old nurseries prior to use of air conditioning apparatus.

The incidence and severity of digestive syndromes, with diarrhea, persistent vomiting, diminishing gain or loss of body weight, and other symptoms, were generally from two to three times as high under low as under high humidity.

Summarizing, the best chances for life in premature infants are created by maintaining a relative humidity of 65 percent in the nursery, and by

providing a uniform environmental temperature just sufficiently high to keep the body temperature within normal limits. Medical and nursing care are, of course, factors of equal and sometimes of greater importance.

### Air Conditioning Equipment

Many of the installations now in use are of the central system type providing for filtration, for humidification and heating in cold weather, and for cooling and dehumidification in hot weather. A ventilation rate between 8 and 12 air changes per hour is desirable to remove odors and maintain uniformity of temperatures in extremes of weather. Recirculation should not be used in these wards owing to odors and the possibility of infection. There should be a frequent change in spray water.

### Control of Airborne Infection

The protection of the premature and older infant against infection is of the utmost importance. It was found in one installation equipped with air conditioning, germicidal lights and mechanical barriers that air conditioning alone did not prevent the spread of respiratory cross-infections.<sup>42</sup> Bacterial ultraviolet barriers, air conditioning and mechanical barriers are efficient. However, infections are brought in by, and often spread by, ward personnel in spite of these measures.

## FEVER THERAPY

Artificial production of high fever in man can be considered an imitation of nature's way of overcoming invading pathogenic organisms. The action may be direct and specific by destruction of the invading organism within the safe limit of human temperatures, or indirect in the case of heat resistant organisms, by general mobilization of the defensive mechanisms of the body.

Although the action may be direct and specific by destruction of the invading organisms within the safe human limits, fever therapy exerts much of its benefit through the improvement of the mechanism of bodily defense. A serious challenge to the theory on which fever therapy is based comes from the demonstration that high fever causes a reduction in the concentration of circulating antibodies in experimental animals.

Patients for fever therapy should be carefully selected. The most serious complications which may arise are heat stroke, heat exhaustion and circulatory collapse. The chief minor complications are heat cramps, fever blisters and mild dehydration.

The limits of induced systemic fever are usually between 104 and 107 F (rectal), and the duration from 3 to 8 hours at a time. The total period of fever treatment varies with the type of the organism involved.

The diseases which respond favorably to artificial fever therapy are gonorrhea and its complications (which include arthritis, pelvic infections in women, and involvement of the eye), syphilis and chorea.

The most striking results are seen in gonorrhea and syphilis, since the causative organisms can be destroyed at temperatures compatible with human life. However, the use of fever therapy has decreased since penicillin has been found so effective in the treatment of gonorrhea and syphilis. Mild fever, up to 101 F for one hour, has recently been used in the treatment of rheumatoid arthritis. This degree of fever is not bactericidal, but is believed to stimulate the body defense mechanism.

### Equipment for Production of Fever

Artificial fever can be induced by injections of various crystalloid or colloid substances, bacterial products of typhoid and malarial organisms, or by physical methods using hot baths, radiant heat cabinets, hot humidified air cabinets, or by short wave diathermy in combination with a cabinet.

The relative advantages of various methods have been evaluated clinically.<sup>43</sup> Among the devices for the production of fever by physical means, the one most widely used is the hot humid air or *air conditioned* cabinet. This apparatus was developed at the *Kettering Institute for Medical Research* at Miami Valley Hospital in Dayton, Ohio.

In the earlier studies of the Society, temperatures were elevated more easily using saturated atmospheres. A fever therapy apparatus<sup>44</sup> using these same principles has proved efficient as a means of inducing and maintaining fever in a body, with small likelihood of burns because of the comparatively low dry-bulb temperatures.

When heat is necessary in treating legs or arms, such media as short or long wave diathermy, micro-waves, infrared, water baths, etc., have been used extensively. A recent development, a saturated atmosphere heating unit, similar to one previously described has proven satisfactory, because heat may be administered over longer periods which render deep heating possible without fear of burns or shocks. Local heating has been somewhat satisfactory in relieving the painful symptoms of peripheral vascular disease.

This procedure, however, is not without danger. Elevation of tissue temperature increases cell metabolism and the need for oxygen. The inadequate blood supply and oxygen deficiency may lead to tissue death or gangrene. Application of heat to the trunk or abdomen, with consequent reflex dilatation of the vessels of the extremities, eliminates this danger of local heat application.

Short wave diathermy within the cabinet during the induction phase has been used. When the desired body temperature has been reached by electrical induction, the atmosphere of the enclosure is kept at saturation to prevent heat loss, thus maintaining the patient's temperature at the desired point. The two underlying principles in the production of fever by the hot, humid air cabinet are: (1) the transfer of heat by conduction from the circulating hot air to the body, and (2) prevention of heat loss. The latter is more important. In an atmosphere of high humidity, the heat loss by evaporation is markedly decreased.

## COLD THERAPY

Cold as an anesthetic agent was advocated by Allen several years ago.<sup>45</sup> Freezing of the tissue must be avoided. For certain patients, in whom amputation of an extremity is indicated, the application of a tourniquet with cooling of the affected extremity down to near freezing (5 C or 40 F) is of value. The patient, following this procedure can be prepared for surgery without the handicap of absorption of septic products and severe pain. This procedure has proven especially valuable in the neglected diabetic patient with an infected gangrenous extremity. Time for treatment of coma and hydration of the patient is gained. However, if amputation of an extremity is not indicated, the application of a tourniquet and pack-



ing in ice are dangerous procedures, since loss of the limb usually results. An extremity with inadequate blood supply can be readily cooled without the use of a tourniquet, but such an extremity is also usually eventually lost. Theoretically, cooling is said to reduce the metabolism of the tissue with suspension of the vital processes. It also reduces the blood flow to practically zero, and few extremities with inadequate blood supply remain viable or recover.

Packing in ice, or use of low temperatures, is contra-indicated in the treatment of patients with frostbite, immersion foot or trench foot. The affected extremities should be exposed to the air in a cool room and not rubbed with snow or packed in ice. The lowering of temperature by packing the body in ice for treatment of cancer has not proven successful.

The methods used for refrigeration, depending upon available facilities, are as follows:<sup>45</sup>

- (1) Cracked or shaved ice which is simple and has the advantage of not freezing tissues. However, it is cumbersome and sloppy to handle and is unsuited to prolonged treatments.
- (2) Use of ice in a pail for immersion of local parts.
- (3) Special boxes for holding ice with padded or curtained openings for the limb.
- (4) Bare ice bags and cloth bags for iced wet dressings for prolonged treatments and convenience.
- (5) A double chambered cabinet using dry ice has been constructed.
- (6) Electrical refrigerating apparatus, consisting of a compact noiseless unit that pumps fluid to various types of applications, is available. The applicators may be in the form of blankets containing rubber tubes suitable for covering the entire body, or all or part of a limb. Special applicators are available for insertion into various body cavities, and for inducing dental anesthesia.
- (7) An air chamber at regulated temperature for treatments of frostbite and immersion foot, and amputation stumps.

The electrical apparatus is costly, but has the advantages of thermostatic regulation, light weight, freedom of movement, and permits prolonged treatments with heat, as well as cold over the range of temperatures therapeutically desirable.

### ALLERGIC DISORDERS

Hay fever, asthma, eczema and contact dermatitis are classified as allergic disorders. The allergic individual responds to contact with a variety of substances, which are innocuous to a non-allergic person, with severe manifestations of hypersensitivity.

These substances are known as allergens and consist of airborne irritants such as dusts, molds, feathers, pollens, animal dander and others; of food protein such as milk, wheat, eggs, etc., or of simple chemicals brought in contact with the skin. They may enter the body by various routes of which inhalation is the most common type. Ingestion of offending food substances is not infrequent.

The offending substance reacts with the sensitized cells of the mucous membranes or skin. During this reaction, histamine or a histamine-like substance is released and causes (a) increased capillary permeability, (b) secretion of mucus and (c) muscular contraction. In the eyes and nose this produces itching, redness and lacrimation or rhinorrhea, in short, the symptoms of hay fever. In the lungs it causes, in addition to the secretory

response, a contraction of the smooth muscles of the bronchi resulting in bronchial asthma.

It is commonly known that non-specific environmental factors such as dust, irritating gases, change of temperature and humidity may precipitate asthmatic attacks in allergic subjects, even in the absence of exposure to specific allergens. It is assumed that the presence of frequent allergic bronchial constriction renders the smooth muscles of the bronchi so sensitive to various non-specific stimuli that the threshold of their response to such irritation is considerably lower than that of a non-allergic individual.

### Air Conditioning Apparatus

Of all the measures to relieve a specifically sensitive individual, elimination of exposure to the responsible allergen is the most efficient, though not always a practical, form of treatment. In recent years considerable effort has been made to accomplish such elimination by removal of respiratory allergens from enclosures by filtration or other air conditioning processes.

Paper or cloth filters, mounted in inexpensive window or floor units, prove quite satisfactory in many cases, but since dust and smoke frequently cause asthmatic attacks, it is desirable that an air filter, to be of full value in the treatment of asthma, should remove all possible dusts and pollens regardless of size or amount. Electrostatic air cleaners are more efficient than most commonly used types for capturing very fine dust.

Although the chief remedial factor in the treatment by conditioned air is the filtration of pollen, a certain amount of cooling and dehumidification appears to be desirable. A comfortable temperature between 70 and 75 F, and a relative humidity well below 50 percent proved satisfactory.<sup>46</sup> Direct drafts, overcooling or overheating are apt to initiate or aggravate the symptoms.

### Limitations of Air Conditioning Methods

The results obtained with air filtration, or other air conditioning processes, in the control of allergic conditions, are fairly comparable to those obtained by desensitization treatment, so long as the patients remain in the pollen-free atmosphere. For all practical purposes filtration gives only temporary relief. In mild cases sleeping in an air conditioned space may make it possible for the individual to pass more comfortable nights. With rare exceptions, the symptoms recur on exposure to pollen-laden air. Moreover, the usefulness of air conditioning methods is limited, because all cases are not caused by airborne substances. Cases of bacterial asthma do not respond to treatment with filtered air.

Despite these limitations, air conditioning methods possess definite advantages in the simplicity of treatment, convenience, and under certain conditions, almost immediate relief.<sup>47</sup> Pollen cases are usually relieved of most of their symptoms within 1 to 3 hr after exposure to properly filtered air. A pollen-free atmosphere is especially valuable when desensitization has given little or no relief, and when desensitization is not advisable owing to intercurrent illness.

### OXYGEN THERAPY

Oxygen therapy is used to prevent or relieve anoxia. Some of the more important clinical conditions in which oxygen treatment is beneficial include pneumonia, severe anemia, cardiac decompensation, pulmonary ate-

lectasis, asphyxia and asthma. The effectiveness of oxygen therapy is dependent on the concentration of the oxygen in the inspired air, or the partial pressure of oxygen in the pulmonary alveoli.

Oxygen is usually administered by nasal catheter, face mask or tent.<sup>48</sup> The necessity of air conditioning in oxygen therapy arises from the fact that oxygen is too expensive a gas to waste in the ventilation of oxygen tents and oxygen chambers. Air conditioning is applied to the oxygen tent or chamber through reconditioning of the atmosphere in a closed circuit. Excessive heat, moisture and carbon dioxide are removed.

### Oxygen Tents

In oxygen tents, the air enriched with oxygen is usually circulated by means of a small motor blower which sends the air over soda lime to remove carbon dioxide, and then over ice to remove excess heat and moisture. The concentration of oxygen in the tent is regulated by means of a pressure reducing valve and flow meter. In an inadequately cooled tent, high temperatures and humidities are inevitable, increasing the discomfort of the patient and imposing an added strain on an already overburdened heart. Oxygen therapy under such conditions may do more harm than good. An ice melting rate of approximately 10 lb per hour gives satisfactory results in patients with fever in a medium size oxygen tent.

Oxygen tents are confining to the patient. They may terrify the restless and delirious patient. Medical and nursing care is complicated, as the tent must be opened or removed with attendant loss of oxygen. Oxygen concentrations of 50 percent or more are difficult to maintain, and it is a problem to keep the temperature and humidity low enough in hot weather. However, with attention to details, the patient can be made quite comfortable. In fact, during hot, humid weather an oxygen tent may be very valuable in controlling a patient's temperature, since the upper part of the body within the cooled tent loses heat rapidly.

### Oxygen Chambers

The conventional oxygen chamber is an air-tight sheet metal enclosure of fire-proof construction, large enough to accommodate one or two patients. Trap doors or curtains are provided for the personnel, food and service, to avoid loss of oxygen. Glass windows in the ceiling and walls admit light from outside the chamber. The air conditioning system may be of the gravity type, or of the fan type using mechanical refrigeration or air drying agents.

The temperature and humidity requirement in oxygen therapy depends primarily upon the physical condition of the patient, and secondarily upon the type of disease. In pneumonias<sup>49</sup> prescribed conditions should be a temperature of 60 to 75 F, humidity 50 to 55 percent, moderate air movement, oxygen concentration of 50 percent, and carbon dioxide of less than one percent.

### Oxygen in Aviation

An important application of the principle of oxygen therapy is in aviation. At the present time all high altitude military airplanes in this country are provided with gaseous oxygen equipment, and military personnel are required to utilize oxygen at all times while in flight above 15,000 ft, or between 12,000 to 15,000 ft for longer than two hours, or between 10,000

to 12,000 ft for longer than six hours. The use of oxygen in commercial aviation will depend on the height and duration of the flights, as well as the state of health of the passengers. The necessity for portable, comfortable equipment, the possible fire hazards due to smoking, and the use of oxygen on sleeper planes are some of the difficulties facing civil airline operators. The pressure cabin airplane is a solution to the problem.

### GENERAL HOSPITAL AIR CONDITIONING

Complete conditioning of a large hospital involves a capital investment and running expenses which may not be justified. In clean and quiet districts, the requirements of almost all general and private wards during the cool season of the year can be satisfactorily fulfilled by the use of conventional heating equipment, in conjunction with window air supply and gravity or mechanical exhaust. Insulation against heat and sound is much more important than humidification in winter; it will also help in keeping the building cool in warm weather. Excessive outside noise and dust may require the use of silencers and air filters in the openings.

Cooling and dehumidification in warm weather are important. In new hospitals particularly, the desirability of cooling certain sections of the building should be given serious consideration. Financial reasons may preclude the cooling of the entire building, but the needs of the average hospital can be met by the use of built-in room coolers and a few portable units which can be wheeled from ward to ward when needed.

In the North, and certain sections of the Pacific Coast, cooling is needed but a few days during summer, while in the South, it can be used to advantage from May to October, and in tropical climates almost continuously throughout the year.

F. L. Grocott of the Anglo-Iranian Oil Co. states that in Iran, the medical staff after 10 years' experience with air conditioning, demand a uniform environment of 75 F and 50 percent relative humidity (70 ET) under all summer outside conditions for general wards and treatment rooms, and 70 F with 30 to 50 percent relative humidity (65-66 ET) for winter conditions. In the operating rooms, 70 F with 50 percent relative humidity (66 ET) is demanded all the year 'round, although the annual external range is 40 F to 120 F. No ill effects have been noted in the medical personnel, though they are exposed to changes from external to internal conditions many times daily. Temperature shock in either direction seems to create discomfort for a short interval, but if the individual is in good health, no injury results.<sup>50</sup>

Aside from comfort and recuperative power of the patients, cooling is of great assistance in the treatment of fevers in the new-born and in post-operative cases, in enteric disorders, fevers, heat stroke, heart failure, thyroid crisis, and in a variety of other ailments which often accompany summer heat waves.

### Problem of Odors

The evacuation of battle casualties in aircraft and their subsequent hospitalization have stimulated efforts to minimize odors arising from draining wounds, old odorous casts, and gangrenous wounds. For aircraft, chemical sprays and vapors, perfumes, oxidizing gases and simple exhaust methods are unsatisfactory. An ideal deodorant would purify the air by means of odor adsorption so that subsequently the air can be recirculated.

Based upon the effectiveness of activated carbon commercially and industrially to adsorb odors, individual adsorption units have been used successfully. In hospital wards the question of superiority of adsorption methods for elimination of odors over other methods remains to be answered. The present status of the problem is that the commercial aspect is highly controversial.<sup>51</sup>

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## CHAPTER 8

## AIR CONTAMINANTS

Classification of Air Contaminants; Sizes of Airborne Particles; Air Pollution by Smoke, Ash and Cinders; Smoke Abatement and Air Pollution Control; Odor Nuisance; Industrial Air Contaminants; Flammable Gases and Vapors; Combustible Dusts; Atmospheric Pollen; Airborne Bacteria; Radioactive Air Contaminants

THE normal constituents of the earth's atmosphere are oxygen, nitrogen, carbon dioxide, water vapor, argon, small or negligible amounts of other inert gases, hydrogen, variable traces of ozone, and small quantities of microscopic and submicroscopic solid matter, sometimes called *permanent atmospheric impurities*. From the viewpoint of the air conditioning engineer, all other airborne substances may be termed *contaminants*. This term is applied preferably, however, to undesirable or chance impurities, since the occasion may arise for adding to the air controlled amounts of solid or gaseous diluents for the prevention of explosions; germicidal vapors or mists (aerosols) for bacteria control; masking substances for odor control; or a substitute for one of the normal gases, as, for example, when helium is used to replace nitrogen in atmospheres for compressed air workers or divers.

Control of the chemical quality of air is one of the functions of complete air conditioning, and some knowledge of the composition, concentration and properties of air contaminants under various circumstances is therefore essential.

Air contaminants arise from the normal processes of wear, erosion, wind-storm, sea-spray evaporation, thermal disintegration, earthquake, volcanic eruption, combustion, manufacturing, transportation, agriculture, and the biochemical or biological processes of life. They are classified at various times as organic and inorganic, visible or invisible, microscopic or macroscopic, particulate or gaseous, toxic or harmless, beneficial or destructive. The following classification is based chiefly upon the origin or method of formation of air contaminants.

## CLASSIFICATION OF AIR CONTAMINANTS

Dust, Fumes, and Smokes are solid particulate air contaminants.

Dusts are solid particles projected into the air by natural forces, such as wind, volcanic eruption or earthquake, and by mechanical processes, such as crushing, grinding, milling, drilling, demolition, shovelling, conveying, screening, bagging and sweeping. Some of these forces produce dust from larger masses, while others simply disperse materials that are already pulverized. Generally, particles are not called dust unless they are smaller than about 100 microns. Dusts may be of mineral type, such as rock, ore, metal, sand; vegetable, such as grain, flour, wood, cotton, pollen; or animal, such as wool, hair, silk, feathers, leather.

Fumes are solid particles commonly formed by the condensation of vapors from normally solid materials such as molten metals. Metallic fumes generally occur as the oxides in air because of the highly reactive nature of finely divided matter. Fumes may also be formed by sublimation, distillation, calcination, or chemical reaction, whenever such processes create airborne particles predominately below the 1 micron size. Fumes permitted to age tend to flocculate into clumps or aggregates of larger size, thereby facilitating removal from air.

Smokes are the extremely small solid particles produced by incomplete combustion

of organic substances such as tobacco, wood, coal, oil, tar and other carbonaceous materials. The term *smoke* is commonly applied to the mixture of solid, liquid and gaseous products of combustion, although the technical literature prefers to distinguish between such components as soot or carbon particles, fly-ash, cinders, tarry matter, unburned gases, and gaseous combustion products. The finest particulate constituents are much less than 1 micron in size, often in the range of 0.1 to 0.3 micron.

Mists and Fogs are liquid particulate air contaminants.

Mists are very small airborne droplets of materials that are ordinarily liquid at normal temperatures and pressures. They may be formed by atomizing, spraying, splashing, mixing, violent chemical reaction, electrolytic evolution of gas from a liquid, or escape of a dissolved gas upon release of pressure. Very small droplets expelled or atomized into the air by sneezing constitute mists containing microorganisms that become air contaminants.

Fogs are limited by some classifications to airborne droplets formed by condensation from the vapor state. This arbitrary distinction between mist and fog is of minor importance, as both terms are used to indicate the particulate state of airborne liquids (occasionally termed *aerosols*). Fog nozzles are so named because of their ability to produce extra fine droplets as compared to the mist from ordinary spray devices. The highly volatile nature of some liquids quickly reduces their airborne droplets from the mist to the fog range, and eventually to the vapor phase until the air becomes saturated with that liquid. Many droplets in fogs or clouds are microscopic and submicroscopic in size, and may be conceived as the transition state between the larger mists and the vapors.

Vapors and Gases are non-particulate air contaminants.

Vapors are the gaseous phase of substances that are either liquid or solid in their commonly known state, examples being gasoline, kerosene, benzene, carbon tetrachloride, mercury, iodine, camphor. Vapors may be changed to the solid or liquid form by increasing the pressure, decreasing the temperature or applying both processes simultaneously. They are removed from the air by condensation with less difficulty than are the gases.

Gases are normally formless fluids which tend to occupy a space or enclosure completely and uniformly at ordinary temperatures and pressures. The following substances qualify as gases: oxygen, nitrogen, carbon dioxide, carbon monoxide, hydrogen, ammonia, sulfur dioxide. Gases, likewise, may be solidified or liquefied by the proper control of temperature and pressure.

The preceding classification is not suitable for the airborne living organisms, which range in size from the submicroscopic viruses to the largest pollen grains, not considering the smallest insect life. Bacteria range from about 0.2 to 5 microns in size, fungus spores from 1 to 10 microns, and pollen from 5 to 150 microns.

#### SIZES OF AIRBORNE PARTICLES

Fig. 1 is a graphic tabulation of the properties of airborne solids and liquids arranged according to size on the micron scale. There are 25,400 microns in 1 inch.

Particles larger than 10 microns are unlikely to remain suspended in air currents of moderate strength, but settle out by gravity at speeds dependent upon the shape, size and specific gravity of the particle, wind velocity, orientation of the collecting surface, and topography. These larger particles are of major interest to the engineer in the solution of nuisance problems, but it is usually the smaller particles, or those below 10 microns, that remain in the air long enough to be of hygienic as well as economic significance.

Industrial dust particles are predominantly of the order of 1 micron in size. Tremendous numbers are also present in the submicroscopic range below 0.5 micron, but those below 0.1 micron are not believed at present

to be of practical importance, possibly due to their exceedingly small mass in comparison with the balance of airborne matter. In fact, particles this small may become the *permanent* atmospheric impurities that have little, if any, opportunity of settling because of the continual motion imparted to them by air currents and the molecular activity of gases (Brownian Movement).

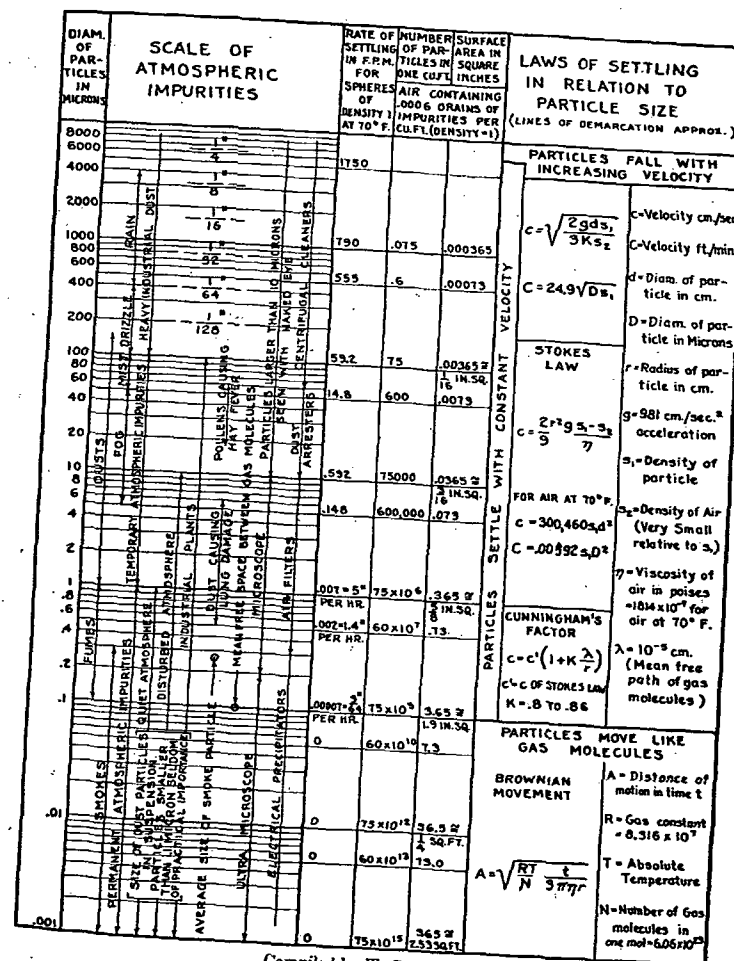


FIG. 1. SIZES AND CHARACTERISTICS OF AIRBORNE PARTICULATE MATTER

The survey<sup>1</sup> of atmospheric pollution in 14 American cities conducted from 1931 to 1933 indicated the average size of outdoor dust particles to be 0.5 micron, as collected by the Owens jet dust counter and measured under the microscope. Inability of the *light field* microscope to reveal

particles in the 0.1 micron vicinity may have influenced the determination of average particle size.

The lower limit of particle size visible to the naked eye cannot be stated definitely. It depends not only upon the individual eye, but also upon the shape and color of the particle, intensity and quality of the light, and nature of the background or opportunity for contrast. Under ideal conditions a particle of 10-micron size might be recognized, while under less favorable conditions it may be impossible to distinguish a particle smaller than 50 microns. The lower limit of visibility probably ranges from 10 to 50 microns.

Dusts, powders and granular materials are frequently classified by reference to the size of screens used for separation. Particles above 40 microns are said to be the *screen sizes* and those below, the *sub-screen* or microscopic sizes. Approximate or theoretical sizes of particles corresponding to the mesh scale of the U. S. Standard Sieve Series are given in Table 1.

Microscopic examination of screened dust indicates that the average diameter of a sample of irregular particles may be substantially larger

TABLE 1. RELATION OF SCREEN MESH TO PARTICLE SIZE

| U. S. Standard Sieve Mesh...     | 400 | 325 | 200 | 140 | 100 | 60  | 35  | 18   |
|----------------------------------|-----|-----|-----|-----|-----|-----|-----|------|
| Nominal Sieve Opening in Microns | 37  | 44  | 74  | 105 | 149 | 250 | 500 | 1000 |

than the openings of the screen through which it has passed, if the particle shapes deviate considerably from the spherical form.<sup>2</sup> The smallest dimension of many such particles will correspond with the maximum permissible distance between the wires of commercial screens made to ASTM Standard Specifications. Screening does not give sharp separation into size groups, and accordingly, such a classification is statistical rather than absolute.

### AIR POLLUTION BY SMOKE, ASH AND CINDERS

Total airborne solids settling in urban areas are usually reported as *soot fall* in tons per (square mile) (month). Such data published for the cities in this country range from 20 to 200 tons per (square mile) (month). To the air conditioning engineer this information may indicate the effectiveness of smoke abatement or fuel combustion control methods in his locality, but it does not provide a suitable index of the suspended dust that air cleaners in a ventilating system are expected to capture.<sup>3, 4, 5</sup> Gravimetric or weight data of the type given in Table 2 are preferable. In some cases airborne particle counts may be necessary, as for pollen, bacteria, spores, and insoluble dusts causing illness or lung disease.

Dust concentrations by weight cannot be converted readily to concentrations by particle count because of the variability of particle size, shape and specific gravity, and the inherent characteristics of dust counting and weighing procedures. One milligram of dust per cubic meter of air may represent dust counts from 1 million to 100 million particles per cubic foot of air (lightfield microscope technic) according to the size distribution of

the airborne dust sample. Information of this type for a specified application is best obtained by simultaneous sampling for both counting and weighing and noting carefully at the time all factors that might affect the reproducibility of the count-weight ratio.

### Smoke Abatement and Air Pollution Control

Successful abatement of atmospheric pollution caused by smoke requires the combined efforts of the combustion engineer, industrial executive, public health officer, city planning commission and the community at large. Electrification of industry and railroads, increases in the use of domestic oil and gas furnaces, and segregation of industrial districts are gradually providing effective aid in the solution of this problem. In the large cities where nuisance from smoke, fly-ash and cinders is more serious, limited areas obtain some relief by the use of district heating. (See Chapters 14, 15 and 16 for further discussion on fuel burning technic.)

TABLE 2. DUST CONCENTRATION RANGES

| LOCATION                             | GRAINS PER 1000 Cu Ft* | MILLIGRAMS PER CUBIC METER |
|--------------------------------------|------------------------|----------------------------|
| Rural and suburban districts         | 0.02-0.2               | 0.05-0.5                   |
| Metropolitan district                | 0.04-0.4               | 0.1-1.0                    |
| Industrial districts                 | 0.1-2.0                | 0.2-5.0                    |
| Ordinary factories or workrooms      | 0.2-4.0                | 0.5-10                     |
| Excessively dusty factories or mines | 4-400                  | 10-1000                    |
| Minimum explosive concentrations     | 4000-200,000           | 10,000-500,000             |

\* 1 grain per 1000 cu ft = 2.3 milligrams per cubic meter.

1 oz per cubic foot = 1 gram per liter = 1000 grams per cubic meter

Many present ordinances limit the number of minutes in any one hour that smoke of a specified density (determined by comparison with a Ringelmann Chart which is described in Chapter 52) may be discharged.

There is now considerable interest and activity in the control of air pollution factors in addition to smoke. Difficulty in the establishment of acceptable criteria for certain corrosive and irritant gases, such as fluorides and the oxides of sulphur and nitrogen discharged with the gases of combustion, and the frequently complicated technical and economic problems encountered in control, have delayed the drafting and enforcement of legislative measures. Recent reports of an increased incidence of diseases, such as pneumonia and lung cancer, in areas high in certain air contaminants, require further critical investigation before acceptance. The values finally adopted will undoubtedly be lower than the M.A.C. (Maximum Allowable Concentration) limits for use in industry, because the exposure is continuous compared with the 8-hour day, 5 or 6-day week upon which M.A.C. values are based, and because the exposed population contains individuals with greater variation in age and health status.

In foggy weather, or with an *inversion* of atmospheric conditions, accumulation of gaseous contaminants may cause irritation of eyes, nose, and respiratory passages, and possibly cause even more serious physiological effects. The Meuse Valley fog disaster (Belgium 1930) and the Donora smog (Pennsylvania 1948) are classic examples in the history of gaseous air pollution. In both instances it is believed that irritant gases, princi-

pally from industrial plants, accumulating during periods of exceptionally prolonged meteorological *inversion* and fog, contributed to the illness of many persons, and to the death of some who were especially susceptible.

### Absorption of Solar Radiation

Absorption of solar ultraviolet light by smoke and soot is recognized as a health problem in many industrial cities. Measurements of solar radiation in Baltimore<sup>6</sup> by actinic methods demonstrated that ultraviolet light intensity in the country was 50 percent greater than in the city. In New York City<sup>7</sup> a loss as great as 50 per cent in visible light was found by photoelectric measurements.

### ODOR NUISANCE

A problem companionate with smoke abatement is the control of odor nuisance in the neighborhood of industrial plants discharging noxious or offensive air contaminants. Community planning and zoning will avoid much of the difficulty in the future, but meanwhile many industrial cities must resort to corrective measures by requiring installation of air cleaning devices, alteration of manufacturing processes, or termination of the offensive operation in residential or commercial districts.

Control of outdoor odor nuisance is especially troublesome because of the extremely minute quantities of contaminant that are capable of offending through a wide area. New industrial chemicals with strange or unfamiliar odors tend to receive more attention from the neighborhood than the customary odors generated by well known processes and raw materials. Methods of odor control currently in use include charcoal adsorption, scrubbing towers and air washers, chlorination, condensation, masking, passage of the odorous air through combustion chambers, dispersion through a tall stack, and best of all, substitution of less offensive materials whenever possible.<sup>8, 9, 10, 11</sup>

Control of air quality within buildings ventilated for human occupancy is discussed in Chapter 6. Tobacco smoke odors, cooking odors and body odors are air contaminants of the nuisance type which now command a decisive position in the standards of air quality for indoor comfort. However, the engineer will find, at times, that odors originating *outside* buildings in industrial or business districts may determine the kind and capacity of equipment he must provide for a high quality air supply installation.

### INDUSTRIAL AIR CONTAMINANTS

Many industrial processes are sources of contaminants. Their control is an important function of the ventilating or air conditioning engineer, because the atmosphere within buildings is the medium whereby such finely divided matter is dispersed and transported from the source to remote locations where it may cause property damage, nuisance, fire, explosion, disease and even death.

Tables 3, 4 and 5 give maximum allowable concentration values for many industrial air contaminants. Some of these values have been proposed by ASA Sectional Committee Z37 on Allowable Concentrations of Toxic Dusts and Gases, and others by the Committee on Threshold Limits of the American Conference of Governmental Industrial Hygienists. The

values have been adopted by the *American Conference of Governmental Industrial Hygienists* and by many of the official industrial hygiene agencies.

It must be emphasized that these limits in the great majority of instances are only *suggested maximum working levels* since they are estimates, based in many cases upon incomplete environmental and medical studies. Where there is agreement between the ASA Standard Z37 and A.C.G.I.H. values, reliability of the ASA Standard is increased. The values are not fixed, but are subject to revision, upward or downward, with the development of new information. There is by no means complete agreement regarding these values among responsible industrial hygienists.

In applying these guide limits, the following factors must be considered:

1. The duration of exposure is 8 hr a day for 5 or 6 days a week.
2. The measurements are indicative of the concentration in the breathing zone of the exposed person.
3. The M.A.C. is usually accepted as the average exposure value when the upper limits do not greatly exceed the M.A.C. value. For example, it cannot be assumed that if 100 ppm is considered *safe* for 8-hour exposure, that 800 ppm for one hour will be permissible.
4. Two substances with similar M.A.C. values may be quite different as to physiological effects at other concentrations. In one instance the selection of a limit may be predicated upon a discomfort factor, with a wide margin of safety before systemic effects would be encountered, while in another case the value represents an appreciable fraction of the concentration which may be associated with severe and irreversible injury.
5. These values are *upper* limits; it is desirable to operate well below the levels if the engineering and economic factors permit. The prudent engineer will incorporate a reasonable margin of safety in his estimates of ventilation capacity.

In Table 3, Column 1 lists the ASA Sectional Committee Z37 M.A.C. values; Column 2, those of the A.C.G.I.H. Committee on Threshold Limits. Column 3 gives the value in grams per cubic meter or ounces per 1000 cu ft for the corresponding A.C.G.I.H. limits; Column 4 shows the liquid ounces of chemical, if liquid at 20 C (68 F), which, if equally dispersed in 1000 cu ft, would give the corresponding M.A.C.

In Table 4, Columns 1 and 2 are respectively the M.A.C. values from the ASA and A.C.G.I.H. Committees.

In Table 5, the M.A.C. values for industrial dusts as given were obtained from data of the A.C.G.I.H. Committee on Threshold Limits.

A.C.G.I.H. limits for either gamma or Roentgen radiations are 0.3 roentgens per week.

Information on the properties and effects, with respect to health, of specific industrial air contaminants is available in publications listed at the end of this chapter.

### FLAMMABLE GASES AND VAPORS

Adequate ventilation is a primary requirement for minimizing the hazard of fire or explosion due to gases and vapors. The need for good ventilation is not removed by the use of other precautions, such as the elimination of known ignition sources, segregation of hazardous operations, adoption of safe building construction, and installation of automatic alarms. Some safety engineers regard over-ventilation of an operation employing flammable liquids as a legitimate operating charge for the privilege or necessity of using a dangerous process. However, it is not possible to

TABLE 3. MAXIMUM ALLOWABLE CONCENTRATION OF GASES AND VAPORS

| SUBSTANCE                                  | ASA STANDARDS<br>M.A.C.<br>ppm<br>by volume | THRESHOLD LIMIT VALUES A.C.G.I.H.* 1954 |                                |                            |
|--------------------------------------------|---------------------------------------------|-----------------------------------------|--------------------------------|----------------------------|
|                                            |                                             | ppm                                     | Gm/cu m<br>or<br>Oz/1000 cu ft | Oz/1000 cu ft <sup>b</sup> |
| Acetaldehyde                               |                                             | 200                                     | 0.36                           | 0.43                       |
| Acetic acid                                |                                             | 10                                      | 0.02554                        | 0.02                       |
| Acetic anhydride                           |                                             | 5                                       | 0.02085                        | 0.02                       |
| Acetone                                    |                                             | 1000                                    | 2.4130                         | 2.42                       |
| Acrolein                                   |                                             | 0.5                                     | 0.1145                         | 0.013                      |
| Acrylonitrile                              |                                             | 20                                      | 0.04336                        | 0.05                       |
| Ammonia                                    |                                             | 100                                     | 0.069                          | 0.16                       |
| Amyl acetate                               |                                             | 200                                     | 1.054                          | 0.41                       |
| Amyl alcohol (iso)                         |                                             | 100                                     | 0.36                           | 0.02                       |
| Aniline                                    |                                             | 5                                       | 0.019                          | 0.02                       |
| Arsine                                     |                                             | 0.05                                    |                                |                            |
| Benzene (benzol)                           | 100                                         | 35                                      | 0.11393                        | 0.12                       |
| Bromine                                    |                                             | 1                                       | 0.00653                        | 0.03                       |
| 1,3-Butadiene                              |                                             | 1000                                    | 2.210                          | 3.3                        |
| n-Butanol                                  |                                             | 100                                     | 0.3030                         | 0.36                       |
| 2-Butanone                                 |                                             | 250                                     | 0.735                          | 0.88                       |
| n-Butyl acetate                            |                                             | 200                                     | 0.943                          | 1.04                       |
| Butyl "cellosolve" (2 butoxyethanol)       |                                             | 200                                     | 0.966                          | 1.02                       |
| Carbon dioxide                             |                                             | 5000                                    |                                |                            |
| Carbon disulfide                           | 20                                          | 20                                      | 0.0622                         | 0.05                       |
| Carbon monoxide                            | 100                                         | 100                                     |                                |                            |
| Carbon tetrachloride                       |                                             | 25                                      | 0.157                          | 0.095                      |
| "Cellosolve" (2-ethoxyethanol)             |                                             | 200                                     | 0.736                          | 0.76                       |
| "Cellosolve" acetate                       |                                             | 100                                     | 0.54                           | 0.53                       |
| Chlorine                                   |                                             | 1                                       |                                |                            |
| Chlorobenzene                              |                                             | 75                                      | 0.3465                         | 0.3                        |
| 2-Chlorobutadiene                          |                                             | 25                                      | 0.0905                         | 0.09                       |
| Chloroform                                 |                                             | 100                                     | 0.488                          | 0.31                       |
| 1-Chloro-1-nitropropane                    |                                             | 20                                      | 0.101                          | 0.08                       |
| Cresol                                     |                                             | 5                                       | 0.022                          | 0.02                       |
| Cyclohexane                                |                                             | 400                                     | 1.375                          | 1.69                       |
| Cyclohexanol                               |                                             | 100                                     | 0.406                          | 0.42                       |
| Cyclohexanone                              |                                             | 100                                     | 0.401                          | 0.41                       |
| Cyclohexene                                |                                             | 400                                     | 1.34                           | 1.58                       |
| Cyclopropane (propane)                     |                                             | 400                                     | 0.6875                         | 0.91                       |
| 1,2-Dibromoethane (ethylene dibromide)     |                                             | 25                                      |                                |                            |
| o-Dichlorobenzene                          |                                             | 50                                      | 0.3005                         | 0.24                       |
| Dichlorodifluoromethane                    |                                             | 1000                                    | 4.94                           | 3.18                       |
| 1,1-Dichloroethane                         |                                             | 100                                     | 0.405                          | 0.33                       |
| 1,2-Dichloroethane (ethylene dichloride)   |                                             | 100                                     | 0.4051                         | 0.31                       |
| 1,2-Dichloroethylene                       |                                             | 200                                     | 0.794                          | 0.59                       |
| Dichloroethyl ether                        |                                             | 15                                      | 0.0378                         | 0.08                       |
| Dichloromethane                            |                                             | 500                                     | 1.74                           | 1.25                       |
| Dichloromonoethane                         |                                             | 1000                                    | 4.20                           | 2.83                       |
| 1,1-Dichloro-1-Nitroethane                 |                                             | 10                                      | 0.0589                         | 0.4                        |
| 1,2-Dichloropropane (propylene dichloride) |                                             | 75                                      | 0.3265                         | 0.29                       |
| Dichlorotetrafluoroethane                  |                                             | 1000                                    | 6.93                           | 4.38                       |
| Diethyl amine                              |                                             | 25                                      | 0.045                          | 0.07                       |
| Dimethylaniline                            |                                             | 5                                       | 0.02475                        | 0.02                       |
| Dimethylsulfate                            |                                             | 1                                       | 0.00515                        | 0.003                      |
| Dioxane                                    |                                             | 100                                     | 0.36                           | 0.33                       |
| Ethyl acetate                              |                                             | 400                                     | 1.44                           | 1.52                       |
| Ethyl alcohol                              |                                             | 1000                                    | 1.881                          | 2.2                        |
| Ethyl amine                                |                                             | 25                                      |                                |                            |
| Ethyl benzene                              |                                             | 200                                     | 0.868                          | 0.96                       |
| Ethyl bromide                              |                                             | 200                                     | 0.892                          | 0.59                       |
| Ethyl chloride                             |                                             | 1000                                    | 2.64                           | 2.75                       |
| Ethylene chlorhydrin                       |                                             | 5                                       | 0.01645                        | 0.015                      |
| Ethylene oxide                             |                                             | 100                                     | 0.18                           | 0.09                       |
| Ethyl ether                                |                                             | 400                                     | 1.212                          | 1.67                       |
| Ethyl formate                              |                                             | 100                                     | 0.303                          | 0.315                      |
| Ethyl silicate                             |                                             | 100                                     | 0.851                          | 0.87                       |
| Fluorine                                   |                                             | 0.1                                     |                                |                            |
| Fluorotrichloromethane                     |                                             | 1000                                    | 5.62                           | 3.7                        |
| Formaldehyde                               | 10                                          | 5                                       | 0.006135                       |                            |
| Gasoline                                   |                                             | 500                                     | 2.045                          | 2.89                       |
| Heptane                                    |                                             | 500                                     | 2.05                           | 2.87                       |

TABLE 3. MAXIMUM ALLOWABLE CONCENTRATION OF GASES AND VAPORS (Concluded)

| SUBSTANCE                                  | ASA STANDARDS<br>M.A.C.<br>ppm<br>by volume | THRESHOLD LIMIT VALUES A.C.G.I.H.* 1954 |                                |                            |
|--------------------------------------------|---------------------------------------------|-----------------------------------------|--------------------------------|----------------------------|
|                                            |                                             | ppm                                     | Gm/cu m<br>or<br>Oz/1000 cu ft | Oz/1000 cu ft <sup>b</sup> |
| Hexane                                     |                                             | 500                                     | 1.76                           | 2.54                       |
| Hydrogen chloride                          |                                             | 5                                       | 0.00746                        | 0.004                      |
| Hydrogen cyanide                           |                                             | 10                                      | 0.01104                        | 0.015                      |
| Hydrogen fluoride                          |                                             | 3                                       | 0.00245                        | 0.003                      |
| Hydrogen selenide                          |                                             | 0.05                                    |                                |                            |
| Hydrogen sulfide                           | 20                                          | 20                                      |                                |                            |
| Iodine                                     |                                             | 1                                       | 0.01039                        | 0.0002                     |
| Isophorone                                 |                                             | 25                                      | 0.141                          | 0.15                       |
| Isopropyl alcohol                          |                                             | 400                                     | 1.022                          | 1.22                       |
| Isopropyl ether                            |                                             | 500                                     | 2.085                          | 2.75                       |
| Mesityl oxide                              |                                             | 50                                      | 0.2005                         | 0.22                       |
| Methyl acetate                             |                                             | 200                                     | 0.606                          | 0.62                       |
| Methyl alcohol                             | 200                                         | 200                                     | 0.2618                         | 0.32                       |
| Methylal                                   |                                             | 1000                                    | 3.11                           | 3.5                        |
| Methyl bromide                             |                                             | 20                                      | 0.0778                         | 0.04                       |
| Methyl butyl ketone (hexanone)             |                                             | 100                                     | 0.352                          | 0.41                       |
| Methyl "cellosolve" (2-methoxyethanol)     |                                             | 25                                      | 0.7775                         | 0.078                      |
| Methyl "cellosolve" acetate                |                                             | 25                                      | 0.1208                         | 0.11                       |
| Methyl chloride                            | 100                                         | 100                                     | 0.2086                         | 0.22                       |
| Methyl chloroform (1-1-1 trichloroethane)  |                                             | 500                                     |                                |                            |
| Methylcyclohexane                          |                                             | 500                                     | 2.005                          | 2.44                       |
| Methylcyclohexanol                         |                                             | 100                                     | 0.466                          | 0.49                       |
| Methylcyclohexanone                        |                                             | 100                                     | 0.458                          | 0.48                       |
| Methyl formate                             |                                             | 100                                     | 0.2554                         | 0.26                       |
| Methyl iso-butyl ketone                    |                                             | 100                                     | 0.409                          | 0.49                       |
| Monochlorobenzene                          |                                             | 75                                      | 0.3465                         | 0.3                        |
| Monofluorotrichloromethane                 |                                             | 1000                                    | 5.61                           | 3.59                       |
| Naphtha (coal tar)                         |                                             | 200                                     | 0.638                          | 0.71                       |
| Naphtha (petroleum)                        |                                             | 500                                     | 1.945                          | 2.6                        |
| Nickel carbonyl                            | 0.001                                       |                                         | 0.000007                       | 0.000006                   |
| Nitrobenzene                               |                                             | 1                                       | 0.00503                        | 0.004                      |
| Nitroethane                                |                                             | 100                                     | 0.307                          | 0.275                      |
| Nitrogen dioxide                           |                                             | 5                                       |                                |                            |
| Nitrogen oxides (other than nitrous oxide) |                                             | 25                                      |                                |                            |
| Nitroglycerine                             |                                             | 25                                      |                                |                            |
| Nitromethane                               |                                             | 0.5                                     | 0.00464                        | 0.003                      |
| 2-Nitropropane                             |                                             | 100                                     | 0.2495                         | 0.21                       |
| Nitrotoluene                               |                                             | 50                                      | 0.182                          | 0.17                       |
| Octane                                     |                                             | 5                                       | 0.028                          | 0.23                       |
| Ozone                                      |                                             | 500                                     | 2.33                           | 3.17                       |
| Pentane                                    |                                             | 0.1                                     |                                |                            |
| Pentanone (methyl propanone)               |                                             | 1000                                    | 2.94                           | 4.5                        |
| Phenol                                     |                                             | 200                                     | 0.704                          | 0.82                       |
| Phosgene                                   |                                             | 5                                       |                                |                            |
| Phosphine                                  |                                             | 1                                       |                                |                            |
| Phosphorus trichloride                     |                                             | 0.05                                    |                                |                            |
| Propyl acetate                             |                                             | 0.5                                     | 0.00281                        | 0.0018                     |
| Stibine                                    |                                             | 200                                     | 0.834                          | 0.885                      |
| Stoddard solvent                           |                                             | 0.1                                     |                                |                            |
| Styrene monomer                            |                                             | 500                                     | 2.845                          | 3.4                        |
| Sulfur monomer                             | 400                                         | 200                                     | 0.85                           | 0.89                       |
| Sulfur chloride                            |                                             | 1                                       | 0.00552                        | 0.003                      |
| Sulfur dioxide                             |                                             | 10                                      |                                |                            |
| 1,1,2,2-Tetrachloroethane                  |                                             | 5                                       | 0.343                          | 0.02                       |
| Tetrachloroethylene (perchloroethylene)    |                                             | 200                                     | 1.358                          | 0.810                      |
| Toluene                                    |                                             | 200                                     | 0.752                          | 0.83                       |
| Toluidine                                  |                                             | 5                                       | 0.0219                         | 0.02                       |
| Trichloroethylene                          | 200                                         | 200                                     | 1.072                          | 0.79                       |
| Turpentine                                 |                                             | 100                                     | 0.556                          | 0.58                       |
| Vinyl chloride                             |                                             | 500                                     | 1.28                           | 1.33                       |
| Xylene                                     | 200                                         | 200                                     | 0.868                          | 0.96                       |

\* A.C.G.I.H. = American Conference of Governmental Industrial Hygienists.

<sup>b</sup> Liquid ounces (at 20 C) of chemical in 1000 cu ft.<sup>c</sup> From 1953 list.

apply a reasonable safety factor to the ventilation estimate without consideration of the concentrations of gases or vapors that approach the danger point. Safety engineers prefer to limit the concentration to  $\frac{1}{4}$  or  $\frac{1}{5}$  of the lower explosive limit, and this fact should be given full weight in determining the capacity and design of ventilating equipment. Rarely should consideration be given to operation above the upper explosive limit in the open areas of buildings or rooms—even though unoccupied—because the danger of temporary drop of gas concentration to a point within the explosive range is too great.

Ability of a flammable liquid to form explosive mixtures is determined largely by its vapor pressure, volatility, or rate of evaporation. *Flash*

TABLE 4. LIMITS FOR TOXIC DUSTS, FUMES AND MISTS

| SUBSTANCE                                             | A.S.A. STANDARDS,<br>M.A.C.<br>mg/cu m | THRESHOLD LIMIT<br>VALUES, A.C.G.I.H.<br>1954<br>mg/cu m |
|-------------------------------------------------------|----------------------------------------|----------------------------------------------------------|
| Antimony                                              |                                        | 0.5                                                      |
| Arsenic                                               |                                        | 0.5                                                      |
| Barium                                                |                                        | 0.5                                                      |
| Cadmium                                               | 0.1 (W)                                | 0.1                                                      |
| Chlorodiphenyl                                        |                                        | 1                                                        |
| Chromic acid & chromates as CrO <sub>3</sub>          | 0.1                                    | 0.1                                                      |
| Cyanide as CN                                         |                                        | 5                                                        |
| Dinitrotoluene                                        |                                        | 1.5                                                      |
| 0-Dinitroresol                                        |                                        | 0.2                                                      |
| Fluorides                                             |                                        | 2.5                                                      |
| Iron Oxide fume                                       |                                        | 15                                                       |
| Lead                                                  | 0.15                                   | 0.15                                                     |
| Magnesium oxide fume                                  |                                        | 15                                                       |
| Manganese                                             | 8                                      | 8                                                        |
| Mercury                                               | 0.1                                    | 0.1                                                      |
| Parathion (O,O-diethyl-O-p-nitrophenyl thiophosphate) |                                        | 0.1                                                      |
| Pentachloronaphthalene                                |                                        | 0.5                                                      |
| Pentachlorophenol                                     |                                        | 0.5                                                      |
| Phosphorus (yellow)                                   |                                        | 0.1                                                      |
| Phosphorus pentachloride                              |                                        | 1                                                        |
| Phosphorus pentasulfide                               |                                        | 1                                                        |
| Selenium as Se                                        |                                        | 0.1                                                      |
| Sulfuric acid                                         |                                        | 1                                                        |
| Tellurium                                             |                                        | 0.1                                                      |
| Tetryl                                                |                                        | 1.5                                                      |
| Trichloronaphthalene                                  |                                        | 5                                                        |
| Trinitrotoluene                                       |                                        | 1.5                                                      |
| Uranium (soluble compounds)                           |                                        | 0.05                                                     |
| Uranium (insoluble compounds)                         |                                        | 0.25                                                     |
| Zinc oxide fumes                                      |                                        | 15                                                       |

point is a convenient method of expressing this property in terms of the temperature scale. It may be defined as the temperature to which a combustible liquid must be heated to produce a flash when a small flame is passed across the surface of the liquid. The higher the flash point, the more safely can the liquid be handled. Liquids with flash points under 70 F should be regarded as highly flammable.

Upper and lower limits of flammability of gases and vapors, and the flash points of the corresponding liquids are given in Table 6.

Methods for estimating the flammable limits of mixtures of gases or vapors must be applied with caution; the reader is referred to other publications for this information.<sup>12, 13</sup>

Design of equipment for the control of combustible anesthetics is outlined in Chapter 7. Construction of equipment for handling air contain-

ing flammable substances, or operating in atmospheres so contaminated, is discussed in Chapter 46.

It is customary to report the concentrations of flammable gases or vapors in percent by volume, or *volume percent*. Comparison with concentrations on the *part per million* scale used in chemical, medical or industrial hygiene literature is readily made by the conversion: 1 percent = 10,000 ppm (parts of contaminant per million parts of air, by volume, or in other words, cubic feet of contaminant per million cubic feet of air). It will be noted in Table 6 that nearly all of the substances listed have lower explosive limits above 1.0 percent, while the *maximum allowable concentrations* for gases and vapors in Table 3 are below 1000 ppm or 0.1 percent in most cases. Therefore, control of toxic or injurious vapors to levels below their maximum allowable concentrations for health usually requires much more effective ventilation than for the prevention of a fire hazard.

### COMBUSTIBLE DUSTS

A dust explosion is essentially a sudden pressure rise caused by the very rapid burning of airborne dust. The primary explosion often originates

TABLE 5. LIMITS FOR MINERAL DUSTS

| SUBSTANCE                                       | THRESHOLD LIMIT VALUES<br>A.C.G.I.H. 1954<br>mppcf* |
|-------------------------------------------------|-----------------------------------------------------|
| Aluminum                                        | 50                                                  |
| Asbestos                                        | 5                                                   |
| Carborundum                                     | 5                                                   |
| Cement                                          | 50                                                  |
| Dust (nuisance, no free silica)                 | 50                                                  |
| Mica (below 5% free silica)                     | 20                                                  |
| Silica—high (above 50% free SiO <sub>2</sub> )  | 5                                                   |
| Silica—medium (5 to 50% free SiO <sub>2</sub> ) | 20                                                  |
| Silica—low (below 5% free SiO <sub>2</sub> )    | 50                                                  |
| Slate (below 5% free SiO <sub>2</sub> )         | 50                                                  |
| Soapstone (below 5% free SiO <sub>2</sub> )     | 20                                                  |
| Talc                                            | 20                                                  |
| Total dust (below 5% free SiO <sub>2</sub> )    | 50                                                  |

\* mppcf—million particles per cubic foot of air, standard light field count.

from a small amount of dust in suspension exposed to a source of ignition and the pressure and vibration it creates may be sufficient to dislodge large accumulations of dust on horizontal ledges or surfaces of the building and equipment, thereby creating a secondary explosion of great force. Thus the air conditioning engineer is involved for two reasons: (1) to obtain a movement of dust-laden air into exhaust hoods or openings, and through ventilating or pneumatic conveying ducts, in a manner that will prevent accumulation of highly flammable dust at points where it could ignite inside the equipment; and (2) to so design *process ventilation* as to prevent the escape of dust which might settle on horizontal surfaces and become a potential source of disaster at some distance from the dusty operation. (See Chapter 46).

Intensity of a dust explosion depends upon: chemical and thermal properties of the dust; particle size and shape; concentration in air; proportion of inert dust in the air; moisture content and composition of the air; size and temperature of the ignition source; and degree of dispersion of the dust cloud. Investigations on the explosibility of dusts require determination of the maximum pressure developed during explosion of a known air concentration, as well as determination of the rate of pressure rise. In-



TABLE 6. APPROXIMATE LIMITS OF FLAMMABILITY OF SINGLE GASES AND VAPORS IN AIR AT ORDINARY TEMPERATURES AND PRESSURES\*

| GAS OR VAPOR                | LOWER LIMIT<br>PERCENT BY<br>VOLUME | UPPER LIMIT<br>PERCENT BY<br>VOLUME | Closed Cup <sup>b</sup><br>FLASH POINT<br>FAHRENHEIT | NBFU<br>CLASSIFI-<br>CATION <sup>c</sup> |
|-----------------------------|-------------------------------------|-------------------------------------|------------------------------------------------------|------------------------------------------|
| Acetaldehyde                | 4.0                                 | 57                                  | -17                                                  | I                                        |
| Acetone                     | 2.5                                 | 12.8                                | 0                                                    | I                                        |
| Acetylene                   | 2.5                                 | 80                                  | 70                                                   | II                                       |
| Allyl alcohol               | 2.5                                 | 26.6                                | ...                                                  | ...                                      |
| Ammonia                     | 15.5                                | ...                                 | 100                                                  | III                                      |
| Amyl alcohol                | 1.2                                 | ...                                 | ...                                                  | ...                                      |
| Amyl chloride               | 1.6                                 | ...                                 | ...                                                  | ...                                      |
| Amylene                     | 1.6                                 | 7.7                                 | 12                                                   | I                                        |
| Benzene (benzol)            | 1.3                                 | 6.8                                 | 140                                                  | III                                      |
| Benzyl chloride             | 1.1                                 | ...                                 | ...                                                  | ...                                      |
| Butane                      | 1.8                                 | 8.4                                 | 84                                                   | III                                      |
| Butyl acetate               | 1.4                                 | 15.0                                | ...                                                  | ...                                      |
| Butyl alcohol               | 1.7                                 | 9.7                                 | ...                                                  | ...                                      |
| Butylene                    | 2.0                                 | 50                                  | -22                                                  | I                                        |
| Carbon disulfide            | 1.2                                 | ...                                 | ...                                                  | ...                                      |
| Carbon monoxide             | 12.5                                | 74.2                                | ...                                                  | ...                                      |
| Crotonaldehyde              | 2.1                                 | 15.5                                | 65                                                   | II                                       |
| Cyclohexane                 | 1.3                                 | 8.4                                 | 1                                                    | I                                        |
| Cyclopropane                | 2.4                                 | 10.5                                | 115                                                  | III                                      |
| Decane                      | 0.67                                | 2.6                                 | ...                                                  | ...                                      |
| Dichloroethylene (1, 2)     | 9.7                                 | 12.8                                | 57                                                   | II                                       |
| Diethyl selenide            | 2.5                                 | ...                                 | ...                                                  | ...                                      |
| Dioxane                     | 2.0                                 | 22.2                                | 54                                                   | II                                       |
| Ethane                      | 3.1                                 | 12.5                                | 49                                                   | I                                        |
| Ether (diethyl)             | 1.8                                 | 36.5                                | ...                                                  | ...                                      |
| Ethyl acetate               | 2.2                                 | 11.5                                | 28                                                   | II                                       |
| Ethyl alcohol               | 3.3                                 | 19.0                                | 54                                                   | II                                       |
| Ethyl bromide               | 6.7                                 | 11.3                                | ...                                                  | ...                                      |
| Ethyl cellosolve            | 2.6                                 | 15.7                                | 104                                                  | III                                      |
| Ethyl chloride              | 4.0                                 | 14.8                                | -53                                                  | I                                        |
| Ethylene                    | 2.7                                 | 28.6                                | ...                                                  | ...                                      |
| Ethylene dichloride         | 6.2                                 | 15.9                                | 56                                                   | II                                       |
| Ethyl formate               | 2.7                                 | 16.5                                | -4                                                   | I                                        |
| Ethyl nitrite               | 3.0                                 | 50                                  | -31                                                  | ...                                      |
| Ethylene oxide              | 3.0                                 | 80                                  | ...                                                  | ...                                      |
| Furfural (125 C)            | 2.1                                 | ...                                 | 140                                                  | III                                      |
| Gasoline (variable)         | 1.4-1.5                             | 7.4-7.6                             | -50                                                  | I                                        |
| Heptane                     | 1.0                                 | 6.0                                 | 25                                                   | I                                        |
| Hexane                      | 1.2                                 | 6.9                                 | -15                                                  | ...                                      |
| Hydrogen cyanide            | 5.6                                 | 40.0                                | ...                                                  | ...                                      |
| Hydrogen                    | 4.0                                 | 74.2                                | ...                                                  | ...                                      |
| Hydrogen sulfide            | 4.3                                 | 45.5                                | ...                                                  | ...                                      |
| Illuminating gas (coal gas) | 5.3                                 | 33.0                                | 82                                                   | III                                      |
| Isobutyl alcohol            | 1.7                                 | ...                                 | ...                                                  | ...                                      |
| Isopentane                  | 1.3                                 | ...                                 | ...                                                  | ...                                      |
| Isopropyl acetate           | 1.8                                 | 7.8                                 | 43                                                   | II                                       |
| Isopropyl alcohol           | 2.0                                 | ...                                 | 53                                                   | II                                       |
| Methane                     | 5.0                                 | 15.0                                | ...                                                  | ...                                      |
| Methyl acetate              | 3.1                                 | 15.5                                | 14                                                   | I                                        |
| Methyl alcohol              | 6.7                                 | 38.5                                | 52                                                   | II                                       |
| Methyl bromide              | 13.5                                | 14.5                                | ...                                                  | ...                                      |
| Methyl butyl ketone         | 1.2                                 | 8.0                                 | ...                                                  | ...                                      |
| Methyl chloride             | 8.2                                 | 18.7                                | ...                                                  | ...                                      |
| Methyl cyclohexane          | 1.1                                 | ...                                 | 25                                                   | II                                       |
| Methyl ethyl ether          | 2.0                                 | 10.1                                | -35                                                  | I                                        |
| Methyl ethyl ketone         | 1.8                                 | 9.5                                 | 30                                                   | II                                       |
| Methyl formate              | 5.0                                 | 22.7                                | -2                                                   | I                                        |
| Methyl propyl ketone        | 1.5                                 | 8.2                                 | ...                                                  | ...                                      |
| Natural gas (variable)      | 4.3                                 | 13.5                                | ...                                                  | ...                                      |
| Naphtha (benzene)           | 1.1                                 | 6.0                                 | 20-110                                               | III                                      |
| Naphthalene                 | 0.9                                 | ...                                 | 176                                                  | III                                      |
| Nonane                      | 0.83                                | 2.9                                 | 88                                                   | III                                      |
| Octane                      | 0.95                                | 3.2                                 | 56                                                   | II                                       |
| Paraldehyde                 | 1.3                                 | 7.8                                 | ...                                                  | ...                                      |
| Pentane                     | 1.4                                 | ...                                 | ...                                                  | ...                                      |

TABLE 6. APPROXIMATE LIMITS OF FLAMMABILITY OF SINGLE GASES AND VAPORS IN AIR AT ORDINARY TEMPERATURES AND PRESSURES\* (Concluded)

| GAS OR VAPOR         | LOWER LIMIT<br>PERCENT BY<br>VOLUME | UPPER LIMIT<br>PERCENT BY<br>VOLUME | Closed Cup <sup>b</sup><br>FLASH POINT<br>FAHRENHEIT | NBFU<br>CLASSIFI-<br>CATION <sup>c</sup> |
|----------------------|-------------------------------------|-------------------------------------|------------------------------------------------------|------------------------------------------|
| Propane              | 2.1                                 | 10.1                                | ...                                                  | ...                                      |
| Propyl acetate       | 1.8                                 | 8.0                                 | 58                                                   | II                                       |
| Propyl alcohol       | 2.1                                 | 13.5                                | 59                                                   | II                                       |
| Propylene            | 2.0                                 | 11.1                                | ...                                                  | ...                                      |
| Propylene dichloride | 3.4                                 | 14.5                                | 60                                                   | II                                       |
| Propylene oxide      | 2.0                                 | 22.0                                | ...                                                  | ...                                      |
| Pyridine             | 1.8                                 | 12.4                                | 74                                                   | III                                      |
| Toluene (toluol)     | 1.3                                 | 7.0                                 | 40                                                   | II                                       |
| Turpentine           | 0.8                                 | ...                                 | 95                                                   | III                                      |
| Vinyl ether          | 1.7                                 | 27.0                                | ...                                                  | ...                                      |
| Vinyl chloride       | 4.0                                 | 21.7                                | ...                                                  | ...                                      |
| Water gas (variable) | 6.0                                 | 70                                  | ...                                                  | ...                                      |
| Xylene (xylol)       | 1.0                                 | 6.0                                 | 63                                                   | II                                       |

\* Adapted from: Fire and Explosion Hazards of Combustible Gases and Vapors, by G. W. Jones; Chapter 13, Industrial Hygiene and Toxicology, edited by F. A. Patty (Interscience Publishers, 1948); Properties of Flammable Liquids, Gases and Solids (Associated) Factory Mutual Fire Ins. Cos., January (1940); and National Fire Codes for Flammable Liquids, Gases, Chemicals and Explosives—1945 (National Fire Protection Association).

<sup>b</sup> Closed cup refers to the equipment used in flash point determinations.

<sup>c</sup> From Standards for Storage, Handling and Use of Flammable Liquids (National Board of Fire Underwriters, No. 30, July 1954).

investigators frequently experience difficulty in obtaining dust suspensions of uniform dispersion, and this should be kept in mind when comparing results from several sources.<sup>14</sup>

Minimum explosive concentrations of airborne dusts already tested range from 0.01 to 0.5 oz per cubic foot, or 10 to 500 grams per cubic meter of air. Maximum pressures generated have been reported as high as 500 psi, although they are more likely to be of the order of 50 psi. Investigations on the flammable characteristics of dusts are currently made at 0.1 and 0.5 oz. per cubic foot.<sup>15-21</sup>

### ATMOSPHERIC POLLEN

Properties of pollen grains discharged by weeds, grasses and trees and responsible for hay fever, are of special interest to designers of air cleaning equipment (see Allergic Disorders in Chapter 7, and Air Cleaning, Chapter 34). Whole grains and fragments transported by the air range chiefly between 10 and 50 microns in size, but some have been measured as small as 5 microns, and others over 100 microns in diameter. Ragweed pollen grains are fairly uniform in size within the range of 15 to 25 microns. Pollen grains can be removed from the air more readily than the particles of dust prevalent in outdoor air or produced by dusty processes, since the latter predominate in the range of 0.1 to 10 microns in size.

Most grains are quite hygroscopic and therefore vary in weight with the humidity. Illustrations and data on individual pollen grains are available in the botanical literature.<sup>22, 23, 24</sup> Geographical distribution of plants known to produce hay fever is also recorded.<sup>25, 26</sup>

The quantity of pollen grains in the air is generally estimated by exposing an adhesive-coated glass plate outdoors for 24 hr, and then counting calibrated areas under the microscope. Methods are available for determining the number of grains in a measured volume of air,<sup>25, 27, 28</sup> but their greater accuracy has not caused them to replace the more simple *gravity slide method* used for most pollen counts. Counting technics vary somewhat, but the daily pollen counts reported in local newspapers during the

hay fever season usually represent the number of grains found on 1.8 sq cm of a 24-hr gravity slide.

Hay fever sufferers may notice the first symptoms when the pollen count is 10 to 25, and in some localities the maximum figures for the seasonal peak may approach 1000 for a 24-hr period, depending upon the sampling and reporting methods of the laboratory. Translation of gravity counts by special formulas to a volumetric basis, or the number of grains per cubic yard or per cubic foot of air, is unreliable because of the complexity of the modifying factors. When such information is important, it is best obtained directly by a volumetric instrument. The number of pollen grains per cubic yard of air evidently varies from 2 to 20 times the number found on 1 sq cm of a 24-hr gravity slide, depending on grain diameter, shape, specific gravity, wind velocity, humidity and physical placement of the collecting plate.<sup>29, 30, 31</sup>

### AIRBORNE BACTERIA

Study of the occurrence and significance of micro-organisms in the atmospheres of the indoor world is absorbing the energies of a substantial number of physicians, bacteriologists, aerobiologists, physicists, public health workers, engineers and hospital personnel. Some data are available on the types and quantities of bacteria found in a variety of spaces, but it is not possible at present to use this information as a conclusive index of the potential health hazard of a given environment. The reported number of airborne organisms may vary from 1 to 1000 per cubic foot of air, influenced somewhat by the method of testing.<sup>32</sup> Many are attached to the dust particles present in the air.

Where it seems advisable or desirable to control the bacterial content of rooms, public conveyances or buildings, highly effective methods are available (see Chapter 7), and their extended use may do much to assist the workers in this field in accumulating the necessary mass of evidence that will decide the practical value of air sterilization for the control of communicable disease. It is now well established that ultraviolet radiation is feasible for the protection or preservation of pharmaceuticals, cosmetics, and food products.

### RADIOACTIVE AIR CONTAMINANTS<sup>33</sup>

Radioactive air contaminants are physically similar to ordinary industrial and chemical plant contaminants. They differ from ordinary contaminants, however, in that they may be highly toxic when ingested and may present a direct radiation hazard when accumulated in appreciable quantities. Another factor which must be considered in the filtration of these materials is the possibility of their being concentrated in plant and animal life in the area of contamination. Concentrations resulting from absorptions by plants and subsequent feeding of animals in the magnitude of several thousand times, is not unusual. Tolerances for radioactive contaminants have been established and are under continuing study and review. Guidance in regard to tolerance levels for discharge of contaminated air in different types of localities can best be had from the classified literature which is available through proper clearance procedures.

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### CHAPTER 9

## HEAT TRANSMISSION COEFFICIENTS OF BUILDING MATERIALS

Heat Transfer Symbols; Calculating Overall Coefficients; Conductivity of Homogeneous Materials; Soil Conductivity and Specific Heat; Surface Conductance; Air Space Conductance; Practical Coefficients and Their Use; Insulating Materials; Computed Coefficients of Walls, Roofs, Ceilings and Floors; Combined Ceiling and Roof Coefficients; Glass Coefficients; Calculating Surface Temperatures

THE design of air conditioning or heating systems for buildings requires a knowledge of the thermal properties of the walls enclosing the space. (The term *walls* in this case, includes windows, doors, ceilings, floors, roofs and skylights). The rate of heat flow through the walls under steady-state conditions at design temperatures is usually the basis for calculating the heat required. For a given wall under standard conditions the rate is a specific value designated as *U*, the overall coefficient of heat transmission or thermal transmittance. It may be determined by test in a guarded hot box apparatus, or it may be computed from known values of the thermal conductance of the various components. Because testing of all combinations of building materials is impracticable, the procedure and necessary data for calculation of the value of *U* are given in this chapter, together with tables of computed values for the more common constructions.

### HEAT TRANSFER SYMBOLS

*U* = overall coefficient of heat transmission or thermal transmittance (air to air); the time rate of heat flow expressed in Btu per (hour) (square foot) (Fahrenheit degree temperature difference between air on the inside and air on the outside of a wall, floor, roof or ceiling). The term is applied to the usual combinations of materials, and also to single materials, such as window glass, and includes the surface conductance on both sides.

*k* = thermal conductivity; the time rate of heat flow through a homogeneous material under steady conditions per unit temperature gradient through unit area perpendicular to the temperature gradient. Its value is expressed in Btu per (hour) (square foot) (Fahrenheit degree per inch of thickness). Materials are considered homogeneous when the value of *k* is not affected by variation in thickness or size of sample within the range normally used in construction.

*C* = thermal conductance; the time rate of heat flow through a unit area of a material from one of its surfaces to the other per unit temperature difference between the two surfaces. Its value is expressed in Btu per (hour) (square foot) (Fahrenheit degree). The term is applied to specific materials as used, either homogeneous or heterogeneous, for the thickness stated, not per inch of thickness.

*f* = film or surface conductance; the time rate of heat flow between a unit area of a surface and the surrounding air. Its value is expressed in Btu per (hour) (square foot of surface) (Fahrenheit degree temperature difference). Subscripts *i* and *o* are used to differentiate between inside and outside surface conductances, respectively.

*a* = thermal conductance of an air space; the time rate of heat flow through a unit area of an air space per unit temperature difference between the boundary surfaces. Its value is expressed in Btu per (hour) (square foot of area) (Fahrenheit degree). The conductance of an air space is dependent on the temperature difference, the height, the depth, the position and the character of the boundary surfaces. The relationships are not linear, and accurate values must be obtained by test and not by computation.

$e$  = emissivity; the ratio of the total radiant flux emitted by a surface to that emitted by an ideal black body at the same temperature.

$E$  = effective emissivity; the combined effect of the surface emissivities  $e$  of the boundary surfaces of an air space; the boundaries assumed to be parallel and of large dimensions as compared to the distance between them.

$r$  = surface reflectivity; the ratio of the radiant flux reflected by an opaque surface to that falling upon it.

$R$  = thermal resistance. Its value is obtained from the reciprocal of heat transfer as expressed by  $U$ ,  $k$ ,  $C$ ,  $f$  or  $a$ . It is expressed in (hours) (square feet) (Fahrenheit degrees) per (Btu). For example, a wall with a  $U$  value of 0.25 would have a resistance value of  $R = 1/0.25 = 4.0$ . Therefore, 4 hours would be required for the transfer of one Btu for each square foot of area and each degree of temperature differential.

### CALCULATING OVERALL COEFFICIENTS

From Chapter 5, Equation 7, the total resistance to heat flow through a wall is equal numerically to the sum of the resistances in series.

$$R_T = R_1 + R_2 + R_3 + R_4 + \dots + R_n \quad (1)$$

where  $R_1$ ,  $R_2$ , etc., are the individual resistances of the wall components.

$R_T$  = total resistance.

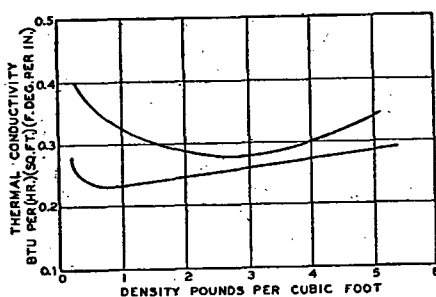


FIG. 1. TYPICAL VARIATION OF THERMAL CONDUCTIVITY WITH DENSITY—FOR FIBROUS MATERIAL

For a wall of a single homogeneous material of conductivity  $k$  and thickness  $x$ , with surface coefficients  $f_i$  and  $f_o$ ,

$$R_T = \frac{1}{f_i} + \frac{x}{k} + \frac{1}{f_o} \quad (2)$$

Then by definition,

$$U = 1/R_T$$

For a wall with air space construction and consisting of two homogeneous materials of conductivities  $k_1$  and  $k_2$ , thicknesses  $x_1$  and  $x_2$ , respectively, and separated by an air space of conductance  $a$ ,

$$R_T = \frac{1}{f_i} + \frac{x_1}{k_1} + \frac{1}{a} + \frac{x_2}{k_2} + \frac{1}{f_o} \quad (3)$$

and

$$U = 1/R_T$$

In the case of types of building materials having non-uniform or irregular sections such as hollow clay tile or concrete blocks, it is necessary to use the conductance  $C$  of the section unit as manufactured instead of a conductivity  $k$ . The resistance of the section  $1/C$  is therefore substituted for  $x/k$  in Equations 2 and 3.

### CONDUCTIVITIES AND CONDUCTANCES

The method of calculating the overall coefficient of heat transmission for a given construction is comparatively simple, but accurate values of conductivities and conductances must be used to obtain satisfactory results. In addition, there are sometimes parallel heat flow paths of different resistances in the same wall, and these may necessitate modification of the formula. In such cases calculated results should be checked by test.

The determination of the fundamental conductivities and conductances requires considerable skill and experience to obtain accurate results. It is recommended that thermal conductivities of homogeneous materials be determined by means of the Guarded Hot Plate.<sup>1</sup> For determination of conductances, a Guarded Hot Box method<sup>2</sup> is generally used.

Tables 1 and 2 give conductivities and conductances selected by the ASHAE Technical Advisory Committee on Insulation from available information. The values selected were those which in the judgment of the committee were good design values for surfaces, spaces, etc., and for the types of products marketed today.

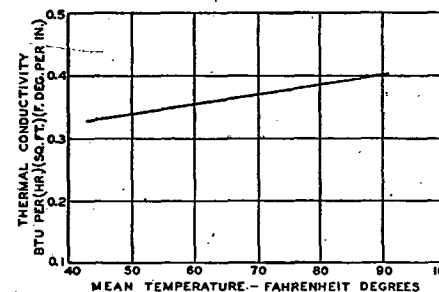


FIG. 2. TYPICAL VARIATION OF THERMAL CONDUCTIVITY WITH MEAN TEMPERATURE

### Conductivity of Homogeneous Materials

*Thermal conductivity* is a property of a homogeneous material and of types of building materials such as lumber, brick, and stone, which may be considered homogeneous. Most insulating materials, except reflective types, are of a porous nature and consist of combinations of solid matter with small voids. The thermal conductivity of these materials will vary with density, mean temperature, size of voids, fibers, or particles, degree and extent of bond between particles, moisture present, and the arrangement of fibers or particles within the material.

The effect of density upon conductivity (at constant mean temperature) is illustrated for two fibrous materials in Fig. 1. Typical variation of conductivity with mean temperature is shown in Fig. 2.

### Thermal Conductivity of Soil

The following statements are based largely on results of a study<sup>3</sup> made in the *Engineering Experiment Station, University of Minnesota*, and published in *Bulletin No. 28*. Tests were made on nineteen different soils which represented a wide textural variety, including gravel, sand, sandy loam, silt loam and clay, as well as some crushed rocks and a fibrous peat. Moisture contents in tests varied from air-dried values to those greater than the optimum moisture content; densities varied from a loosely-poured

TABLE 1. CONDUCTANCES (C) FOR SURFACES AND AIR SPACES  
All conductance values expressed in Btu per (hr) (sq ft) (F deg temp diff)  
Section A. Surface Conductances for Still Air\*

| POSITION OF SURFACE | DIRECTION OF HEAT FLOW | SURFACE EMISSIVITY |      |                   |      |                   |      |
|---------------------|------------------------|--------------------|------|-------------------|------|-------------------|------|
|                     |                        | Non-Reflective     |      | Reflective        |      | Reflective        |      |
|                     |                        | $\epsilon = 0.90$  |      | $\epsilon = 0.20$ |      | $\epsilon = 0.05$ |      |
|                     |                        | C                  | R    | C                 | R    | C                 | R    |
| Horizontal.....     | Upward                 | 1.63               | 0.61 | 0.91              | 1.10 | 0.76              | 1.32 |
| Sloping—45 deg..... | Upward                 | 1.60               | 0.62 | 0.88              | 1.14 | 0.73              | 1.37 |
| Vertical.....       | Horizontal             | 1.46               | 0.68 | 0.74              | 1.35 | 0.59              | 1.70 |
| Sloping—45 deg..... | Downward               | 1.32               | 0.78 | 0.60              | 1.67 | 0.45              | 2.22 |
| Horizontal.....     | Downward               | 1.08               | 0.92 | 0.37              | 2.70 | 0.22              | 4.55 |

\* Conductances are for surfaces of the stated emissivity facing surroundings having an emissivity equal to 0.9 and at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10 F and for surface temperature of 70 F. (See Table 2 for surface conductances for moving air.)

Section B. Thermal Conductances and Resistances of a Plane<sup>a</sup> Air Space\*

| POSITION OF AIR SPACE | HEAT FLOW         | THICKNESS Inches | MEAN TEMP <sup>b</sup> F | TEMP DIFF <sup>c</sup> deg | THERMAL CONDUCTANCE-C   |      |      |      | THERMAL RESISTANCE-R    |      |      |      |
|-----------------------|-------------------|------------------|--------------------------|----------------------------|-------------------------|------|------|------|-------------------------|------|------|------|
|                       |                   |                  |                          |                            | Value of E <sup>d</sup> |      |      |      | Value of E <sup>d</sup> |      |      |      |
|                       |                   |                  |                          |                            | 0.05                    | 0.2  | 0.5  | 0.82 | 0.05                    | 0.2  | 0.5  | 0.82 |
| Horiz.                | Up                | 3/4 to 4         | 50                       | 10                         | 0.41                    | 0.55 | 0.82 | 1.11 | 2.44                    | 1.83 | 1.22 | 0.90 |
|                       |                   |                  | 50                       | 30                         | 0.54                    | 0.88 | 0.95 | 1.24 | 1.84                    | 1.47 | 1.05 | 0.80 |
|                       |                   |                  | 90                       | 10                         | 0.41                    | 0.58 | 0.92 | 1.28 | 2.47                    | 1.73 | 1.09 | 0.78 |
| 45° Slope             | Up                | 3/4 to 4         | 50                       | 10                         | 0.35                    | 0.49 | 0.78 | 1.05 | 2.84                    | 2.05 | 1.31 | 0.95 |
|                       |                   |                  | 50                       | 30                         | 0.48                    | 0.62 | 0.89 | 1.18 | 2.08                    | 1.62 | 1.13 | 0.85 |
|                       |                   |                  | 90                       | 10                         | 0.35                    | 0.52 | 0.86 | 1.23 | 2.85                    | 1.92 | 1.16 | 0.81 |
| Vert.                 | Horiz.            | 3/4 to 4         | 50                       | 10                         | 0.28                    | 0.42 | 0.69 | 0.99 | 3.52                    | 2.37 | 1.44 | 1.02 |
|                       |                   |                  | 50                       | 30                         | 0.38                    | 0.52 | 0.79 | 1.08 | 2.64                    | 1.94 | 1.27 | 0.92 |
|                       |                   |                  | 90                       | 10                         | 0.29                    | 0.46 | 0.80 | 1.16 | 3.49                    | 2.19 | 1.25 | 0.86 |
| 45° Slope             | Down              | 3/4 to 4         | 50                       | 10                         | 0.24                    | 0.38 | 0.65 | 0.94 | 4.14                    | 2.65 | 1.54 | 1.06 |
|                       |                   |                  | 50                       | 30                         | 0.30                    | 0.43 | 0.71 | 1.00 | 3.36                    | 2.30 | 1.41 | 1.00 |
|                       |                   |                  | 90                       | 10                         | 0.25                    | 0.42 | 0.76 | 1.12 | 4.07                    | 2.40 | 1.32 | 0.89 |
| Horiz.                | Down <sup>f</sup> | 3/4              | 50                       | 20                         | 0.28                    | 0.42 | 0.69 | 0.98 | 3.57                    | 2.38 | 1.45 | 1.02 |
|                       |                   |                  | 50                       | 20                         | 0.18                    | 0.31 | 0.58 | 0.87 | 5.56                    | 3.23 | 1.73 | 1.15 |
|                       |                   |                  | 90                       | 20                         | 0.11                    | 0.25 | 0.52 | 0.81 | 8.94                    | 4.03 | 1.92 | 1.23 |
|                       |                   | 1 1/4            | 50                       | 20                         | 0.31                    | 0.48 | 0.82 | 1.18 | 3.23                    | 2.08 | 1.22 | 0.85 |
|                       |                   |                  | 50                       | 20                         | 0.20                    | 0.37 | 0.71 | 1.07 | 5.00                    | 2.70 | 1.41 | 0.93 |
|                       |                   |                  | 90                       | 20                         | 0.13                    | 0.30 | 0.64 | 1.01 | 7.82                    | 3.35 | 1.56 | 0.99 |

Notes: <sup>a</sup> Spaces of uniform thickness, bounded by moderately smooth surfaces.

<sup>b</sup> Where a range of thickness is given, the given conductance is the average over the range; extreme values within the range differ therefrom by less than 10 percent.

<sup>c</sup> Interpolation, and moderate extrapolation, of conductance values are permissible for other values of mean temperature, temperature difference and effective emissivity E.

<sup>d</sup> Effective emissivity of space, E, is given by  $\frac{1}{E} = \frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1$  where  $\epsilon_1$  and  $\epsilon_2$  are the emissivities of the surfaces of the air space. (See Section C. below).

<sup>f</sup> The conductances of horizontal spaces with heat flow downward are substantially independent of temperature difference.

\* Based on National Bureau of Standards data presented in Housing Research Paper No. 32, *Housing and Home Finance Agency*, 1954 (U. S. Government Printing Office, Washington, D. C.)

Section C. Reflectivity and Emissivity Values of Various Surfaces<sup>a</sup> and Effective Emissivities of Air Spaces

| SURFACE                                                                   | REFLECTIVITY IN PERCENT | AVERAGE EMISSIVITY $\epsilon$ | EFFECTIVE EMISSIVITY E OF AIR SPACE                          |                                             |
|---------------------------------------------------------------------------|-------------------------|-------------------------------|--------------------------------------------------------------|---------------------------------------------|
|                                                                           |                         |                               | With one surface having emissivity $\epsilon$ and other 0.90 | With both surfaces of emissivity $\epsilon$ |
| Aluminum foil, bright.....                                                | 92 to 97                | 0.05                          | 0.05                                                         | 0.03                                        |
| Aluminum sheet.....                                                       | 80 to 95                | 0.12                          | 0.12                                                         | 0.06                                        |
| Aluminum coated paper, polished.....                                      | 75 to 84                | 0.20                          | 0.20                                                         | 0.11                                        |
| Steel, galvanized, bright.....                                            | 70 to 80                | 0.25                          | 0.24                                                         | 0.15                                        |
| Aluminum paint.....                                                       | 30 to 70                | 0.50                          | 0.47                                                         | 0.35                                        |
| Building materials: wood, paper, glass, masonry, non-metallic paints..... | 5 to 15                 | 0.90                          | 0.82                                                         | 0.82                                        |

\* See also Chapter 5, Table 3.

TABLE 2. CONDUCTIVITIES (k), CONDUCTANCES (C) AND RESISTANCES (R) OF BUILDING AND INSULATING MATERIALS (Design Values)<sup>a</sup>

These constants are expressed in Btu per (hour) (square foot) (Fahrenheit degree temperature difference). Conductivities (k) are per inch thickness and, conductances (C) are for thickness or construction stated, not per inch thickness

| MATERIAL                                                     | DESCRIPTION                                                                        | DENSITY (LB. PER CU FT) | CONDUCTIVITY OR CONDUCTANCE |       | RESISTANCE (R)                          |                                           |
|--------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------|-----------------------------|-------|-----------------------------------------|-------------------------------------------|
|                                                              |                                                                                    |                         | (k)                         | (C)   | Per Inch Thickness<br>( $\frac{1}{k}$ ) | For Thickness Listed<br>( $\frac{1}{C}$ ) |
| AIR SPACES <sup>b</sup>                                      | See Table 1—Section B.                                                             |                         |                             |       |                                         |                                           |
|                                                              | Position: Horizontal.....                                                          | THICKNESS               |                             |       |                                         |                                           |
|                                                              | Up.....                                                                            | 3/4 in.                 | —                           | —     | 1.18                                    | 0.85                                      |
|                                                              | Sloping (45°).....                                                                 | 3/4 in.                 | —                           | —     | 1.11                                    | 0.90                                      |
|                                                              | Up.....                                                                            | 3/4 in.                 | —                           | —     | 1.03                                    | 0.97                                      |
|                                                              | Sloping (45°).....                                                                 | 3/4 in.                 | —                           | —     | 0.97                                    | 1.03                                      |
|                                                              | Down.....                                                                          | 3/4 in.                 | —                           | —     | 0.98                                    | 1.02                                      |
|                                                              | Horizontal.....                                                                    | 1 1/2 in.               | —                           | —     | 0.87                                    | 1.15                                      |
|                                                              | Down.....                                                                          | 4 in.                   | —                           | —     | 0.81                                    | 1.23                                      |
|                                                              | Horizontal.....                                                                    | 8 in.                   | —                           | —     | 0.80                                    | 1.25                                      |
| AIR SURFACES <sup>c</sup> STILL AIR                          | See Table 1—Section A                                                              |                         |                             |       |                                         |                                           |
|                                                              | Position: Horizontal.....                                                          | HEAT FLOW               |                             |       |                                         |                                           |
|                                                              | Up.....                                                                            | Up                      | —                           | —     | 1.63                                    | 0.61                                      |
|                                                              | Sloping (45°).....                                                                 | Up                      | —                           | —     | 1.60                                    | 0.62                                      |
|                                                              | Vertical.....                                                                      | Horizontal              | —                           | —     | 1.46                                    | 0.68                                      |
|                                                              | Sloping (45°).....                                                                 | Down                    | —                           | —     | 1.32                                    | 0.76                                      |
|                                                              | Horizontal.....                                                                    | Down                    | —                           | —     | 1.08                                    | 0.92                                      |
|                                                              | Any Position—Any Direction.....                                                    | —                       | —                           | —     | 6.00                                    | 0.17                                      |
|                                                              | Any Position—Any Direction.....                                                    | —                       | —                           | —     | 4.00                                    | 0.25                                      |
|                                                              | 15 MPH WIND<br>7/8 MPH WIND                                                        | —                       | —                           | —     | —                                       | —                                         |
| BUILDING BOARDS <sup>d</sup> BOARDS, PANELS, SHEATHING, ETC. | Asbestos-cement board.....                                                         | 120                     | 4.0                         | —     | 0.25                                    | —                                         |
|                                                              | Asbestos-cement board.....                                                         | 3/4 in.                 | —                           | 33.   | —                                       | 0.03                                      |
|                                                              | Gypsum or plaster board.....                                                       | 50                      | —                           | 3.10  | —                                       | 0.32                                      |
|                                                              | Gypsum or plaster board.....                                                       | 1/2 in.                 | —                           | 2.25  | —                                       | 0.45                                      |
|                                                              | Plywood.....                                                                       | 34                      | 0.80                        | —     | 1.25                                    | —                                         |
|                                                              | Plywood.....                                                                       | 3/4 in.                 | —                           | 3.20  | —                                       | 0.31                                      |
|                                                              | Plywood.....                                                                       | 3/4 in.                 | —                           | 2.12  | —                                       | 0.47                                      |
|                                                              | Plywood or Wood Panels.....                                                        | 3/4 in.                 | —                           | 1.60  | —                                       | 0.63                                      |
|                                                              | Wood fiber board, laminated or homogeneous.....                                    | 26                      | 0.42                        | —     | 2.38                                    | 0.94                                      |
|                                                              | Wood fiber—hardboard type.....                                                     | 31                      | 0.50                        | —     | 2.00                                    | —                                         |
| BUILDING PAPER                                               | Wood fiber—hardboard type.....                                                     | 65                      | 1.40                        | —     | 0.72                                    | —                                         |
|                                                              | Wood—fir or pine sheathing.....                                                    | 34 in.                  | —                           | 5.60  | —                                       | 0.18                                      |
|                                                              | Vapor—permeable felt.....                                                          | —                       | —                           | 1.02  | —                                       | 0.98                                      |
|                                                              | Vapor—seal, 2 layers of mopped 15 lb felt.....                                     | —                       | —                           | 16.70 | —                                       | 0.06                                      |
|                                                              | Vapor—seal, plastic film.....                                                      | —                       | —                           | 8.35  | —                                       | 0.12                                      |
|                                                              | —                                                                                  | —                       | —                           | —     | —                                       | Negl                                      |
| FLOORING MATERIALS                                           | Asphalt tile.....                                                                  | 120                     | —                           | 24.80 | —                                       | 0.04                                      |
|                                                              | Carpet and fibrous pad.....                                                        | —                       | —                           | 0.48  | —                                       | 2.08                                      |
|                                                              | Carpet and rubber pad.....                                                         | —                       | —                           | 0.81  | —                                       | 1.23                                      |
|                                                              | Ceramic tile.....                                                                  | 1 in.                   | —                           | 12.50 | —                                       | 0.08                                      |
|                                                              | Cork tile.....                                                                     | 25                      | 0.45                        | —     | 2.22                                    | —                                         |
|                                                              | Cork tile.....                                                                     | 3/8 in.                 | —                           | 3.60  | —                                       | 0.28                                      |
|                                                              | Felt, flooring.....                                                                | —                       | —                           | 16.70 | —                                       | 0.06                                      |
|                                                              | Floor tile or linoleum—av. value.....                                              | 1/4 in.                 | —                           | 20.00 | —                                       | 0.05                                      |
|                                                              | Linoleum.....                                                                      | 80                      | —                           | 12.00 | —                                       | 0.08                                      |
|                                                              | Plywood subfloor.....                                                              | 3/4 in.                 | —                           | 1.28  | —                                       | 0.78                                      |
| INSULATING MATERIALS BLANKET AND BATT BOARD                  | Rubber or plastic tile.....                                                        | 110                     | —                           | 42.40 | —                                       | 0.02                                      |
|                                                              | Terrazzo.....                                                                      | 1 in.                   | —                           | 12.60 | —                                       | 0.08                                      |
|                                                              | Wood subfloor.....                                                                 | 3/4 in.                 | —                           | 1.02  | —                                       | 0.98                                      |
|                                                              | Wood, hardwood finish.....                                                         | 3/4 in.                 | —                           | 1.47  | —                                       | 0.68                                      |
|                                                              | Cotton fiber <sup>e</sup> .....                                                    | 0.8-2.0                 | 0.26                        | —     | 3.85                                    | —                                         |
|                                                              | Mineral wool, fibrous form, processed from rock, slag, or glass <sup>e</sup> ..... | 1.5-4.0                 | 0.27                        | —     | 3.70                                    | —                                         |
|                                                              | Wood fiber <sup>e</sup> .....                                                      | 3.2-3.6                 | 0.25                        | —     | 4.00                                    | —                                         |
|                                                              | Wood fiber, multilayer, stitched expanding <sup>e</sup> .....                      | 1.5-2.0                 | 0.27                        | —     | 3.70                                    | —                                         |
|                                                              | Glass fiber.....                                                                   | 9.5                     | 0.25                        | —     | 4.00                                    | —                                         |
|                                                              | Wood or cane fiber.....                                                            | —                       | —                           | —     | —                                       | —                                         |
| BOARD                                                        | Acoustical tile <sup>f</sup> .....                                                 | 3/4 in.                 | —                           | 0.84  | —                                       | 1.19                                      |
|                                                              | Acoustical tile <sup>f</sup> .....                                                 | 3/4 in.                 | —                           | 0.56  | —                                       | 1.78                                      |
|                                                              | Interior finish (plank, tile, lath).....                                           | 15.0                    | 0.35                        | —     | 2.86                                    | —                                         |
|                                                              | Interior finish (plank, tile, lath).....                                           | 15.0                    | —                           | 0.70  | —                                       | 1.43                                      |
|                                                              | Sheathing (impreg. or coated).....                                                 | 20.0                    | 0.38                        | —     | 2.63                                    | —                                         |
|                                                              | Sheathing (impreg. or coated).....                                                 | 1/4 in.                 | —                           | 0.76  | —                                       | 1.32                                      |
|                                                              | Sheathing (impreg. or coated).....                                                 | 20.0                    | —                           | 0.49  | —                                       | 2.06                                      |
|                                                              | —                                                                                  | 20.0                    | —                           | —     | —                                       | —                                         |
|                                                              | —                                                                                  | —                       | —                           | —     | —                                       | —                                         |
|                                                              | —                                                                                  | —                       | —                           | —     | —                                       | —                                         |

TABLE 2. CONDUCTIVITIES ( $k$ ), CONDUCTANCES ( $C$ ) AND RESISTANCES ( $R$ ) OF BUILDING AND INSULATING MATERIALS (Continued)  
(Design Values)<sup>a</sup>

| MATERIAL                                      | DESCRIPTION                                                                                                                                         | DENSITY<br>(LB. PER<br>CU FT) | CONDUCTIVITY<br>OR<br>CONDUCTANCE |         | RESISTANCE<br>( $R$ )                           |                                                   |
|-----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-----------------------------------|---------|-------------------------------------------------|---------------------------------------------------|
|                                               |                                                                                                                                                     |                               | ( $k$ )                           | ( $C$ ) | Per Inch<br>Thick-<br>ness<br>( $\frac{1}{k}$ ) | For Thick-<br>ness<br>Listed<br>( $\frac{1}{C}$ ) |
| INSULATING<br>MATERIALS<br>BOARD AND<br>SLABS | Cellular glass.....                                                                                                                                 | 9.0                           | 0.40                              | —       | 2.50                                            | —                                                 |
|                                               | Corkboard (without added binder).....                                                                                                               | 6.5-9.0                       | 0.27                              | —       | 3.70                                            | —                                                 |
|                                               | Hog hair (with asphalt binder).....                                                                                                                 | 8.5                           | 0.33                              | —       | 3.00                                            | —                                                 |
|                                               | Plastic (foamed).....                                                                                                                               | 1.62                          | 0.29                              | —       | 3.45                                            | —                                                 |
|                                               | Wood shrodded (cemented in preformed slabs).....                                                                                                    | 22.0                          | 0.55                              | —       | 1.82                                            | —                                                 |
| LOOSE FILL                                    | Macerated paper or pulp products.....                                                                                                               | 2.5-3.5                       | 0.28                              | —       | 3.57                                            | —                                                 |
|                                               | Redwood bark shrodded.....                                                                                                                          | 2.5-3.5                       | 0.30                              | —       | 3.33                                            | —                                                 |
|                                               | Mineral wool (glass, slag, or rock).....                                                                                                            | 2.0-5.0                       | 0.30                              | —       | 3.33                                            | —                                                 |
|                                               | Sawdust or shavings.....                                                                                                                            | 8.0-15.0                      | 0.45                              | —       | 2.22                                            | —                                                 |
|                                               | Vermiculite (expanded).....                                                                                                                         | 7.0                           | 0.48                              | —       | 2.08                                            | —                                                 |
| ROOF<br>INSULATION                            | All types <sup>b</sup>                                                                                                                              | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | Preformed, for use above deck.....                                                                                                                  | —                             | —                                 | 0.72    | —                                               | 1.39                                              |
|                                               | Approx.....                                                                                                                                         | —                             | —                                 | 0.36    | —                                               | 2.78                                              |
|                                               | Approx.....                                                                                                                                         | —                             | —                                 | 0.24    | —                                               | 4.17                                              |
|                                               | Approx.....                                                                                                                                         | —                             | —                                 | 0.19    | —                                               | 5.26                                              |
|                                               | Approx.....                                                                                                                                         | —                             | —                                 | 0.15    | —                                               | 6.67                                              |
| MASONRY<br>MATERIALS<br>CONCRETES             | Cement mortar.....                                                                                                                                  | 116                           | 5.0                               | —       | 0.20                                            | —                                                 |
|                                               | Gypsum-fiber concrete 87½% gypsum, 12½% wood chips.....                                                                                             | 51                            | 1.66                              | —       | 0.60                                            | —                                                 |
|                                               | Lightweight aggregates including expanded shale, clay or slate; expanded slags; cinders; pumice; perlite; vermiculite; also cellular concretes..... | 120                           | 5.2                               | —       | 0.19                                            | —                                                 |
|                                               | .....                                                                                                                                               | 100                           | 3.6                               | —       | 0.28                                            | —                                                 |
|                                               | .....                                                                                                                                               | 80                            | 2.5                               | —       | 0.40                                            | —                                                 |
|                                               | .....                                                                                                                                               | 60                            | 1.7                               | —       | 0.59                                            | —                                                 |
|                                               | .....                                                                                                                                               | 40                            | 1.15                              | —       | 0.86                                            | —                                                 |
|                                               | .....                                                                                                                                               | 30                            | 0.90                              | —       | 1.11                                            | —                                                 |
|                                               | .....                                                                                                                                               | 20                            | 0.70                              | —       | 1.43                                            | —                                                 |
|                                               | Sand and gravel or stone aggregate (oven dried).....                                                                                                | 140                           | 9.0                               | —       | 0.11                                            | —                                                 |
|                                               | Sand and gravel or stone aggregate (not dried).....                                                                                                 | 140                           | 12.0                              | —       | 0.08                                            | —                                                 |
|                                               | Stucco.....                                                                                                                                         | 116                           | 5.0                               | —       | 0.20                                            | —                                                 |
| MASONRY<br>UNITS                              | Brick, common.....                                                                                                                                  | 120                           | 5.0                               | —       | 0.20                                            | —                                                 |
|                                               | Brick, face.....                                                                                                                                    | 130                           | 9.0                               | —       | 0.11                                            | —                                                 |
|                                               | Clay tile, hollow:                                                                                                                                  | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | 1 cell deep.....                                                                                                                                    | 3 in.                         | —                                 | 1.25    | —                                               | 0.80                                              |
|                                               | 1 cell deep.....                                                                                                                                    | 4 in.                         | —                                 | 0.90    | —                                               | 1.11                                              |
|                                               | 2 cells deep.....                                                                                                                                   | 4 in.                         | —                                 | 0.66    | —                                               | 1.52                                              |
|                                               | 2 cells deep.....                                                                                                                                   | 6 in.                         | —                                 | 0.54    | —                                               | 1.85                                              |
|                                               | 2 cells deep.....                                                                                                                                   | 8 in.                         | —                                 | 0.45    | —                                               | 2.22                                              |
|                                               | 2 cells deep.....                                                                                                                                   | 10 in.                        | —                                 | 0.40    | —                                               | 2.50                                              |
|                                               | 2 cells deep.....                                                                                                                                   | 12 in.                        | —                                 | —       | —                                               | —                                                 |
|                                               | Concrete blocks, three oval core:                                                                                                                   | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | Sand & gravel aggregate.....                                                                                                                        | 4 in.                         | —                                 | 1.40    | —                                               | 0.71                                              |
|                                               | .....                                                                                                                                               | 8 in.                         | —                                 | 0.90    | —                                               | 1.11                                              |
|                                               | .....                                                                                                                                               | 12 in.                        | —                                 | 0.73    | —                                               | 1.36                                              |
|                                               | Cinder aggregate.....                                                                                                                               | 3 in.                         | —                                 | 1.18    | —                                               | 0.85                                              |
|                                               | .....                                                                                                                                               | 4 in.                         | —                                 | 0.90    | —                                               | 1.11                                              |
|                                               | .....                                                                                                                                               | 8 in.                         | —                                 | 0.58    | —                                               | 1.72                                              |
|                                               | .....                                                                                                                                               | 12 in.                        | —                                 | 0.53    | —                                               | 1.89                                              |
| Gypsum partition tile:                        | 3 x 12 x 30 in. solid.....                                                                                                                          | —                             | —                                 | 0.79    | —                                               | 1.26                                              |
|                                               | 3 x 12 x 30 in. 4-cell.....                                                                                                                         | —                             | —                                 | 0.74    | —                                               | 1.35                                              |
|                                               | 4 x 12 x 30 in. 3-cell.....                                                                                                                         | —                             | —                                 | 0.67    | —                                               | 1.49                                              |
|                                               | Lightweight aggregate (expanded shale, clay, slate or slag; pumice).....                                                                            | 3 in.                         | —                                 | 0.79    | —                                               | 1.27                                              |
|                                               | .....                                                                                                                                               | 4 in.                         | —                                 | 0.67    | —                                               | 1.50                                              |
|                                               | .....                                                                                                                                               | 8 in.                         | —                                 | 0.50    | —                                               | 2.00                                              |
|                                               | .....                                                                                                                                               | 12 in.                        | —                                 | 0.44    | —                                               | 2.27                                              |
|                                               | Stone, lime or sand.....                                                                                                                            | —                             | —                                 | 12.50   | —                                               | 0.08                                              |
|                                               | (See Chapter 5, Table 1)                                                                                                                            | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | (See Chapter 5, Table 1)                                                                                                                            | —                             | —                                 | —       | —                                               | —                                                 |
| METALS                                        | (See Chapter 5, Table 1)                                                                                                                            | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | (See Chapter 5, Table 1)                                                                                                                            | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | (See Chapter 5, Table 1)                                                                                                                            | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | (See Chapter 5, Table 1)                                                                                                                            | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | (See Chapter 5, Table 1)                                                                                                                            | —                             | —                                 | —       | —                                               | —                                                 |
| PLASTERING<br>MATERIALS                       | Cement plaster, sand aggregate.....                                                                                                                 | 116                           | 5.0                               | —       | 0.20                                            | —                                                 |
|                                               | Sand aggregate.....                                                                                                                                 | —                             | —                                 | 10.00   | —                                               | 0.10                                              |
|                                               | Sand aggregate.....                                                                                                                                 | —                             | —                                 | 6.66    | —                                               | 0.15                                              |
|                                               | Gypsum plaster:                                                                                                                                     | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | Lightweight aggregate.....                                                                                                                          | 45                            | —                                 | 3.12    | —                                               | 0.32                                              |
| Lightweight aggregate.....                    | .....                                                                                                                                               | 45                            | —                                 | 2.67    | —                                               | 0.39                                              |
|                                               | .....                                                                                                                                               | —                             | —                                 | 2.13    | —                                               | 0.47                                              |

TABLE 2. CONDUCTIVITIES ( $k$ ), CONDUCTANCES ( $C$ ) AND RESISTANCES ( $R$ ) OF BUILDING AND INSULATING MATERIALS (Concluded)  
(Design Values)<sup>a</sup>

| MATERIAL                                      | DESCRIPTION                                | DENSITY<br>(LB. PER<br>CU FT) | CONDUCTIVITY<br>OR<br>CONDUCTANCE |         | RESISTANCE<br>( $R$ )                           |                                                   |
|-----------------------------------------------|--------------------------------------------|-------------------------------|-----------------------------------|---------|-------------------------------------------------|---------------------------------------------------|
|                                               |                                            |                               | ( $k$ )                           | ( $C$ ) | Per Inch<br>Thick-<br>ness<br>( $\frac{1}{k}$ ) | For Thick-<br>ness<br>Listed<br>( $\frac{1}{C}$ ) |
| PLASTERING<br>MATERIALS                       | Perlite aggregate.....                     | 45                            | 1.5                               | —       | 0.67                                            | —                                                 |
|                                               | Sand aggregate.....                        | 105                           | 5.6                               | —       | 0.18                                            | —                                                 |
|                                               | Sand aggregate.....                        | 105                           | —                                 | 11.10   | —                                               | 0.09                                              |
|                                               | Sand aggregate on metal lath.....          | 105                           | —                                 | 9.10    | —                                               | 0.11                                              |
|                                               | Sand aggregate on wood lath.....           | —                             | —                                 | 7.70    | —                                               | 0.13                                              |
| ROOFING                                       | Vermiculite aggregate.....                 | 45                            | 1.7                               | —       | 0.59                                            | —                                                 |
|                                               | Asbestos-cement shingles.....              | 120                           | —                                 | 4.76    | —                                               | 0.21                                              |
|                                               | Asphalt roll roofing.....                  | 70                            | —                                 | 6.50    | —                                               | 0.15                                              |
|                                               | Asphalt shingles.....                      | 70                            | —                                 | 2.27    | —                                               | 0.44                                              |
|                                               | Built-up roofing.....                      | 70                            | —                                 | 3.00    | —                                               | 0.33                                              |
| SIDING<br>MATERIALS<br>(ON FLAT SUR-<br>FACE) | Sheet metal.....                           | —                             | —                                 | 20.00   | —                                               | 0.05                                              |
|                                               | Wood shingles.....                         | —                             | 400+                              | 1.06    | —                                               | 0.94                                              |
|                                               | Shingles                                   | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | Wood, 16-in. 7½-in. exposure.....          | —                             | —                                 | 1.15    | —                                               | 0.87                                              |
|                                               | Wood, double, 16-in., 12-in. exposure..... | —                             | —                                 | 0.84    | —                                               | 1.19                                              |
| WOODS                                         | Wood, plus insul. backer board.....        | —                             | —                                 | 0.71    | —                                               | 1.40                                              |
|                                               | Siding                                     | —                             | —                                 | —       | —                                               | —                                                 |
|                                               | Asbestos-cement, ¼ in., lapped.....        | —                             | —                                 | 4.76    | —                                               | 0.21                                              |
|                                               | Asphalt Roll Siding.....                   | —                             | —                                 | 6.50    | —                                               | 0.15                                              |
|                                               | Asphalt Insulating Siding (¾ in. bd.)..... | —                             | —                                 | 0.69    | —                                               | 1.45                                              |
| WOODS                                         | Wood, Drop, 1 x 8 in., lapped.....         | —                             | —                                 | 1.27    | —                                               | 0.79                                              |
|                                               | Wood, Bevel, ½ x 8 in., lapped.....        | —                             | —                                 | 1.23    | —                                               | 0.81                                              |
|                                               | Wood, Bevel, ¾ x 10 in., lapped.....       | —                             | —                                 | 0.95    | —                                               | 1.05                                              |
|                                               | Wood, Plywood, ¾ in., lapped.....          | —                             | —                                 | 1.59    | —                                               | 0.59                                              |
|                                               | Structural glass.....                      | —                             | —                                 | 10.00   | —                                               | 0.10                                              |
| WOODS                                         | Maple, oak, and similar hardwoods.....     | 45                            | 1.10                              | —       | 0.91                                            | —                                                 |
|                                               | Fir, pine, and similar softwoods.....      | 32                            | 0.80                              | —       | 1.25                                            | —                                                 |

<sup>a</sup> Representative values for dry materials at 75 F mean temperature, selected by the A.S.H.A.E. Technical Advisory Committee on Insulation. They are intended as design (not specification) values for materials of building construction in normal use. For conductivity of a particular product, the user may obtain the value supplied by the manufacturer or secure the results of unbiased tests.

<sup>b</sup> Air space resistance values shown here are based on a temperature difference of 20 F deg and a mean temperature of 50 F for spaces faced both sides with ordinary non-reflective materials ( $e = 0.90$  and  $E = 0.82$ ).

<sup>c</sup> Surface resistance values shown here are for ordinary non-reflective materials ( $e = 0.90$ ).

<sup>d</sup> See also Insulating Materials, Board.

<sup>e</sup> Includes paper backing and facing if any. In cases where the insulation forms a boundary (highly reflective or otherwise) of an air space, refer to Table 1, Sections B and C, to obtain the insulating value of the air space for the appropriate effective emissivity and temperature conditions of the space.

<sup>f</sup> Insulating values of acoustical tile vary depending on density of the board and on the type, size and depth of the perforations. An average conductivity  $k$  value is 0.42.

<sup>g</sup> The U. S. Department of Commerce, Simplified Practice Recommendation for Thermal Conductance Factors for Preformed Above-Deck Roof Insulation, No. R 257-55, recognizes the specification of roof insulation on the basis of the  $C$  values shown. Roof insulation is made in thicknesses to meet these values. Therefore, thickness supplied by different manufacturers may vary depending on the conductivity  $k$  value of the particular material.

<sup>h</sup> Not oven dried—conductivity  $k$  prior to drying, approximately 1 to 3 years.

condition to the maximum density obtainable by heavy ramming. The general findings of the investigation are as follows:

**Effect of Temperature.** Soils were tested at several mean temperatures. The degree of influence of temperature depends upon whether it is above or below freezing. For increases of moisture content exceeding about 6 to 12 percent, the conductivity of frozen soil becomes progressively greater than that of the unfrozen soil.

**Effect of Density.** Density affects the thermal conductivity of a soil in about the same manner for all soils, at any moisture content, and for either the frozen or unfrozen condition. On the average, each one pound per cubic foot increase in dry density increases the thermal conductivity by about 3 percent.

**Effect of Moisture.** An increase in moisture content, up to the point of saturation,

causes an increase in thermal conductivity. The rate of increase in typical soils was as follows: average conductivities, in Btu per (square foot) (hour) (Fahrenheit degree per inch), of four sands at a density of 110 lb per cu ft were: 6.8 at 2.5 percent moisture, 8.9 at 5 percent moisture, 11.2 at 10 percent moisture. Five soils of a fine texture at a density of 100 lb per cu ft, gave average conductivities of 6.7 at 10 percent moisture, and 9.5 at 20 percent. Thus, the doubling of moisture content within the ranges cited increases the conductivity by approximately 30 or 40 percent. At higher moisture contents the percentage increase would be less.

**Effect of Soil Characteristics.** The thermal conductivity of the soil, at a given density and moisture content, varies in general with the texture of a soil, being relatively high for coarse-textured soils and relatively low for fine-textured soils. The mineral composition of the soils also affects the conductivity. Quartz tends to give high values, whereas minerals such as plagioclase-feldspar and pyroxene, which are constituents of basic rocks tend to give low values of thermal conductivity. These points are illustrated by the values in Table 3 which lists seventeen soils in approximate order of their magnitude of thermal conductivity from greatest to least for

TABLE 3. THERMAL CONDUCTIVITY ( $k$ ) VALUES OF SOILS IN APPROXIMATE ORDER OF DECREASING VALUES<sup>a</sup>  
Mean Temperature—40 F

TABLE 7. —  
MECHANICAL ANALYSIS

Mean Temperature—40 F

| SOIL DESIGNATION          | MECHANICAL ANALYSIS<br>% BY WEIGHT |                         |                           |                      | MOISTURE CONTENT—%       |      |      |      |      |      |      |  |
|---------------------------|------------------------------------|-------------------------|---------------------------|----------------------|--------------------------|------|------|------|------|------|------|--|
|                           | Gravel                             | Sand                    | Silt                      | Clay                 | 4                        | 4    | 4    | 10   | 10   | 20   | 20   |  |
|                           | Over<br>2.0<br>mm                  | 0.5<br>to<br>2.00<br>mm | 0.005<br>to<br>0.05<br>mm | Under<br>0.005<br>mm | DRY DENSITY—LB PER CU FT |      |      |      |      |      |      |  |
|                           |                                    |                         |                           |                      | 100                      | 110  | 120  | 90   | 110  | 90   | 100  |  |
| Fine Crushed Quartz       | 0.0                                | 100.0                   | 0.0                       | 0.0                  | 12.0                     | 16.0 | 22.0 |      |      |      |      |  |
| Crushed Quartz            | 15.5                               | 79.0                    | 5.5                       | 0.1                  | 11.5                     | 16.0 | 14.0 |      |      |      |      |  |
| Graded Ottawa Sand        | 0.0                                | 99.9                    | 0.1                       | 0.0                  | 10.0                     | 10.5 | 13.5 |      | 15.0 |      |      |  |
| Fairbanks Sand            | 27.5                               | 70.0                    | 2.5                       | 0.0                  | 8.5±                     | 11.0 |      |      | 13.5 |      |      |  |
| Lowell Sand               | 0.0                                | 100.0                   | 0.0                       | 0.0                  | 8.5                      |      |      |      |      |      |      |  |
| Chena River Gravel        | 80.0                               | 19.4                    | 0.6                       | 0.0                  | 9.0±                     | 13.0 |      |      |      |      |      |  |
| Crushed Feldspar          | 25.5                               | 70.3                    | 4.2                       | 0.0                  | 6.0                      | 7.5  | 9.5  |      |      |      |      |  |
| Crushed Granite           | 16.2                               | 77.0                    | 6.8                       | 0.0                  | 5.5                      | 7.5  | 10.0 |      | 13±  |      |      |  |
| Dakota Sandy Loam         | 10.9                               | 57.9                    | 21.2                      | 10.0                 | 5.0                      | 6.5  | 9.5  |      |      |      |      |  |
| Crushed Trap Rock         | 27.0                               | 63.0                    | 10.0                      | 0.0                  |                          | 6.0  | 7.0  |      |      |      |      |  |
| Ramsey Sandy Loam         | 0.4                                | 53.6                    | 27.5                      | 18.5                 | 4.5                      | 6.5  |      |      | 10.0 |      |      |  |
| Northway Fine Sand        | 0.0                                | 97.0                    | 3.0                       | 0.0                  | 4.5                      | 5.5  |      |      | 7.5± |      |      |  |
| Northway Sand             | 3.0                                | 97.0                    | 0.0                       | 0.0                  | 4.5                      | 6.0  |      |      | 9.0± | 8.0  | 10.0 |  |
| Healy Clay                | 0.0                                | 1.9                     | 20.1                      | 78.0                 | 4.0±                     |      |      | 5.5  | 9.0± | 7.5  | 10.0 |  |
| Fairbanks Silt Loam       | 0.0                                | 7.6                     | 80.9                      | 11.5                 |                          |      |      | 5.0  | 9.0± | 7.5  | 9.5  |  |
| Fairbanks Silty Clay Loam | 0.0                                | 9.2                     | 63.8                      | 27.0                 |                          |      |      | 4.0± | 7.0± | 6.0± | 7.0± |  |
| Northway Silt Loam        | 1.0                                | 21.0                    | 64.4                      | 13.6                 |                          |      |      |      |      |      |      |  |

— (inches per inch).

<sup>a</sup>  $k$  = Btu per (square foot) (hour) (Fahrenheit degree per inch).

seven different density-moisture content conditions. Some of the values in this table have been determined by extrapolation and are consequently approximate. Blank spaces in the table indicate that the density or moisture content, or both, are such that no tests were possible for that condition or that no tests were sufficiently close to permit a reasonable extrapolation of the data. Granular soils, particularly those with high quartz contents, head the tabulation or have the greatest conductivity at a given condition. Sandy loam soils are midway in the table and fine grained soils such as clay and silt loam are last.

**Estimating Thermal Conductivity.** The four diagrams of Fig. 3 are presented to aid in the estimate of the thermal conductivity of any soil. Two of the charts are for sands or sandy soils, and two for silt and clay soils. One of the diagrams for each type of soils is for the frozen, and the other for the unfrozen condition. It is expected that these charts will give conductivity values with a precision of 25 percent. The effect of such factors as density, moisture content, freezing, or texture may be easily approximated by use of these graphs.

### Specific Heat of Soils

Tests to determine specific heat were run on twelve soils. On five of the soils, tests were made at three or four mean temperatures varying

from about 10 to 140 F. The specific heat values of all twelve soils varied by only a small amount (about 0.01), and averaged 0.19 at 140 F. The specific heat values of the soils decreased with a decrease in temperature. The average value at zero F would be about 0.16. Values at temperatures between zero and 140 F can be estimated by considering a straight-line relationship between the two values given.

### Surface Conductance

The surface conductance of a wall is the combined heat transfer to or from the wall by radiation, convection and conduction. Each of the three portions making up the total may vary, independently of the others, thus

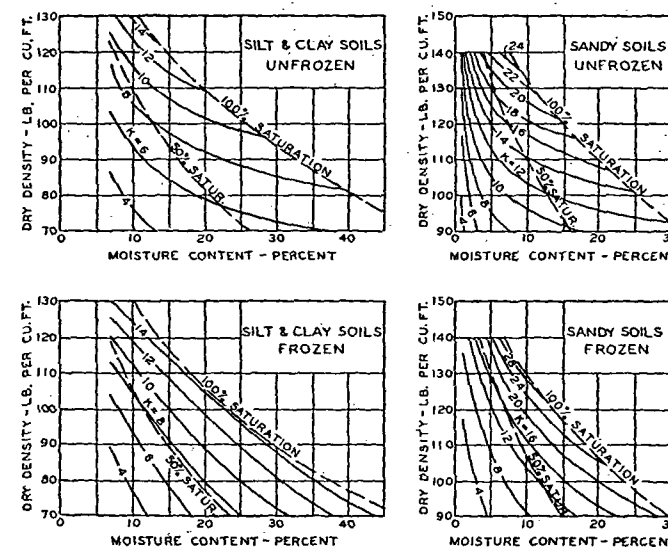


FIG. 3. DETERMINING THERMAL CONDUCTIVITY OF SOILS FROM DENSITY AND MOISTURE CONTENT

affecting the total conductance. The heat transfer by radiation between two surfaces is controlled by the character of the surfaces (emissivity), the temperature difference between them, and the solid angle through which they see each other. The heat transfer by convection and conduction is controlled by the roughness of the surface, by air movement, and temperature difference between the air and the surface.

The importance of the effect of temperature of surrounding surfaces on the surface conductance, due to the effect on radiation, is illustrated in Table 4, which applies to a vertical surface at 80 F, with ambient air at 70 F and with radiation exchange corresponding to an effective emissivity of 0.83.

In many cases, because the heat resistance of the internal parts of the wall is high compared with the surface resistance, the surface factors are of minor importance. In other cases, e.g., single glass windows, the surface resistances constitute almost the entire resistance and are therefore very important. An analysis of various factors affecting surface conductance

and the difference between surface and air temperatures will be found in Reference 5. (See also Chapter 24.)

The convection part of the surface conductance is affected markedly by air movement. This is illustrated by Fig. 4, which shows the results of tests<sup>6</sup> made on 12 in. square samples of different materials at a mean temperature of 20 F, and for wind velocities up to 40 mph. These conductances include the radiation portion of the coefficient which, for the conditions of the tests, was about 0.7 Btu per (hr) (sq ft) (F deg). More recent tests<sup>7</sup> on smooth surfaces show that surface length also affects significantly the convection part of conductance; the average value decreases as the surface length increases. Moreover, observations<sup>8</sup> of the magnitude of low temperature radiant energy received from outdoor surroundings show that only under certain conditions may the out-of-doors be treated as a black body radiating at air temperature.

Because of these factors, the selection of surface conductance coefficients for a practical building becomes a matter of judgment. In calculating the overall heat transmission coefficients for the walls, etc., of Tables 7, 8, 9, 15, 16, 17, 18, 19, and 21, 1.65 has been selected as an average inside surface conductance, and 6.0 as an average outside surface conductance for a 15 mph

TABLE 4. VARIATION IN SURFACE CONDUCTANCE COEFFICIENT FOR VERTICAL SURFACES WITH DIFFERENT TEMPERATURES OF SURROUNDING SURFACE

| SURROUNDING SURFACE TEMPERATURE    | 75 F | 70 F | 60 F | 60 F | 50 F |
|------------------------------------|------|------|------|------|------|
| Convection—Btu per (hr) (sq ft)... | 6.6  | 6.6  | 6.6  | 6.6  | 6.6  |
| Radiation—Btu per (hr) (sq ft).... | 4.4  | 8.6  | 9.6  | 17.0 | 24.9 |
| Total—Btu per (hr) (sq ft).....    | 11.0 | 15.2 | 16.2 | 23.6 | 31.5 |

wind. Both values combine the effects of convection and radiation, and are applicable to ordinary building materials. They should not be used for low emissivity surfaces such as bright metal. Values of  $U$  for windows in Table 20 have been computed from somewhat different data, as described in a later section, in order to give proper weight to actual surface conductance.

In special cases, where surface conductances become important factors in the overall rates of heat transfer, more selective coefficients may be required. Principles and data given in Chapter 5, Heat Transfer, may be applied in such cases.

#### Air Space Conductance

The transfer of heat across an air space involves the boundary surfaces as well as the intervening air, and depends markedly on the orientation of the air space and the direction of heat flow. The coefficients given for air space conductance represent the total conductance from one surface bounding the air space to the other. The total conductance is the sum of a component due to radiation and a component due to convection and conduction combined. These components may vary independently of each other.

The radiation portion of the coefficient is affected by the temperature of the two boundary surfaces, and by their respective surface emissivities<sup>9</sup>, the combined effect of which is expressed by means of the effective emissivity  $E$  of the air space. The radiation component is not affected by the thickness of the space or by its orientation or direction of heat flow. The

#### Heat Transmission Coefficients of Building Materials

heat transfer by convection and conduction combined, however, is markedly affected by the orientation of the air space and the direction of heat flow, is significantly affected by the temperature difference across the space and in some cases by the thickness of the space, and is affected to only a small extent by the mean temperature of its surfaces. For air spaces usually employed in building construction, the radiation and convection-conduction components may vary independently of each other.

Table 1, Section B, gives the thermal conductances and resistances of air spaces of uniform thickness and moderately smooth surfaces, based on

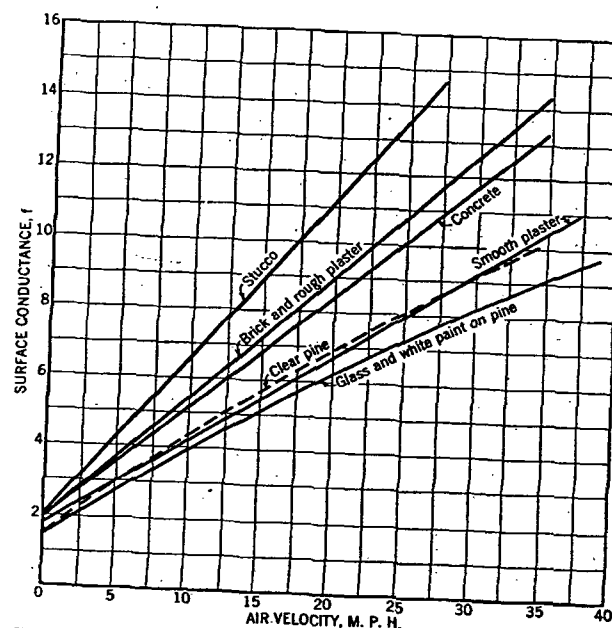


FIG. 4. CURVES SHOWING RELATION BETWEEN SURFACE CONDUCTANCES FOR DIFFERENT SURFACES AT 20 F MEAN TEMPERATURE

experimental measurements conducted at the National Bureau of Standards.<sup>9</sup> Although the conductances of air spaces vary to some extent with thickness in the range over  $\frac{3}{4}$  in., average values are tabulated for the range from  $\frac{3}{4}$  in. to 4 in., for all except horizontal spaces with heat flow downward. The error involved by averaging is less than 10 percent in the extreme case and less than 5 percent in most. For more exact values Reference 9 may be consulted.

For narrow air spaces, which may be defined as those for which the product of the cube of the thickness of the space in inches times the temperature difference (Fahrenheit degrees) across the space is less than 3 for heat flow horizontally or downward, or less than 1 for heat flow upward, the conductance is the sum of the radiative heat transfer coefficient and that for conduction alone through air, since convection is practically suppressed. The radiation component can be computed by means of Equation 4 and Table 4 of Chapter 5; the conduction component can be



TABLE 5. CONDUCTIVITIES ( $k$ ), CONDUCTANCES ( $C$ ), AND RESISTANCES ( $R$ ) USED IN CALCULATING HEAT TRANSMISSION COEFFICIENTS ( $U$ ) IN TABLES 7 TO 19\*

These constants are expressed in Btu per (hour) (square foot) (Fahrenheit degree temperature difference). Conductivities ( $k$ ) are per inch thickness and conductances ( $C$ ) are for thickness or construction stated, not per inch thickness

Conductivities (k) are for construction stated, not per inch thickness

| MATERIAL                                  | DESCRIPTION                                                           | CONDUCTIVITY OR CONDUCTANCE |      | RESISTANCE                              |                                           |
|-------------------------------------------|-----------------------------------------------------------------------|-----------------------------|------|-----------------------------------------|-------------------------------------------|
|                                           |                                                                       | (k)                         | (C)  | Per Inch Thickness<br>( $\frac{1}{k}$ ) | For Thickness Listed<br>( $\frac{1}{C}$ ) |
| AIR SPACES                                |                                                                       |                             |      |                                         |                                           |
| BOUNDED BY ORDINARY MATERIALS             | Vertical, $\frac{1}{2}$ in. or more in width                          | —                           | 1.10 | —                                       | 0.91                                      |
| BOUNDED BY ALUMINUM FOIL                  | Vertical, $\frac{1}{2}$ in. or more in width                          | —                           | 0.46 | —                                       | 2.17                                      |
| EXTERIOR FINISHES                         |                                                                       |                             |      |                                         |                                           |
| (FRAME WALLS)                             | 4 in. thick (nominal)                                                 | —                           | 2.27 | —                                       | 0.44                                      |
| BRICK VENEER                              |                                                                       | 12.50                       | —    | 0.08                                    | —                                         |
| STUCCO (1 in.)                            |                                                                       | —                           | 1.28 | —                                       | 0.78                                      |
| WOOD SHINGLES                             |                                                                       | —                           | 1.28 | —                                       | 0.78                                      |
| YELLOW PINE LAP SIDING                    |                                                                       | —                           | —    | —                                       | —                                         |
| INSULATING MATERIALS                      |                                                                       |                             |      |                                         |                                           |
| ALUMINUM FOIL                             | See Air Spaces                                                        | —                           | —    | —                                       | —                                         |
| BATS AND BLANKETS                         | Made from mineral or vegetable fiber or animal hair, enclosed or open | 0.27                        | —    | 3.70                                    | —                                         |
|                                           | Pure, no added binder                                                 | 0.30                        | —    | 3.33                                    | —                                         |
|                                           | Vegetable fiber                                                       | 0.33                        | —    | 3.03                                    | —                                         |
|                                           | Fiber made from rock, slag or glass                                   | 0.27                        | —    | 3.70                                    | —                                         |
|                                           | Expanded                                                              | 0.48                        | —    | 2.08                                    | —                                         |
| INTERIOR FINISHES                         |                                                                       |                             |      |                                         |                                           |
| COMPOSITION WALLBOARD                     | $\frac{1}{2}$ in. to $\frac{1}{2}$ in. thick                          | 0.50                        | —    | 2.00                                    | —                                         |
| GYPSON PLASTER                            |                                                                       | 3.30                        | —    | 0.30                                    | —                                         |
| GYPSON BOARD (1 in.)                      | Plain or decorated                                                    | —                           | 3.70 | —                                       | 0.27                                      |
| GYPSON LATH (1 in.) AND PLASTER           | Plaster thickness assumed $\frac{1}{2}$ in.                           | —                           | 2.4  | —                                       | 0.42                                      |
| INSULATING BOARD LATH (1 in.) AND PLASTER | Plaster thickness assumed $\frac{1}{2}$ in.                           | —                           | 0.66 | —                                       | 1.52                                      |
| INSULATING BOARD LATH (1 in.) AND PLASTER | Plaster thickness assumed $\frac{1}{2}$ in.                           | —                           | 0.60 | —                                       | 1.67                                      |
| INSULATING BOARD LATH (1 in.) AND PLASTER | Plaster thickness assumed $\frac{1}{2}$ in.                           | —                           | 0.31 | —                                       | 3.18                                      |
| METAL LATH AND PLASTER                    | Plaster thickness assumed $\frac{1}{2}$ in.                           | —                           | 4.40 | —                                       | 0.23                                      |
| PLYWOOD (1 in.)                           | Plaster thickness assumed $\frac{1}{2}$ in.                           | —                           | 2.12 | —                                       | 0.47                                      |
| WOOD LATH AND PLASTER                     | Plain or decorated                                                    | —                           | 2.50 | —                                       | 0.40                                      |
| MASONRY MATERIALS                         |                                                                       |                             |      |                                         |                                           |
| ADOBE                                     | Adobe, assumed 4 in. thick                                            | —                           | 0.89 | —                                       | 1.12                                      |
| BRICK                                     | Common, assumed 4 in. thick                                           | —                           | 1.25 | —                                       | 0.80                                      |
| BRICK                                     | Face, assumed 4 in. thick                                             | —                           | 2.30 | —                                       | 0.43                                      |
| CEMENT MORTAR                             |                                                                       | 12.00                       | —    | 0.08                                    | —                                         |
| 3 IN. CLAY TILE (HOLLOW)                  |                                                                       | —                           | 1.28 | —                                       | 0.78                                      |
| 4 IN. CLAY TILE (HOLLOW)                  |                                                                       | —                           | 1.00 | —                                       | 1.00                                      |
| 6 IN. CLAY TILE (HOLLOW)                  |                                                                       | —                           | 0.64 | —                                       | 1.57                                      |
| 8 IN. CLAY TILE (HOLLOW)                  |                                                                       | —                           | 0.60 | —                                       | 1.67                                      |
| 10 IN. CLAY TILE (HOLLOW)                 |                                                                       | —                           | 0.58 | —                                       | 1.72                                      |
| 12 IN. CLAY TILE (HOLLOW)                 |                                                                       | —                           | 0.40 | —                                       | 2.50                                      |
| 16 IN. CLAY TILE (HOLLOW)                 |                                                                       | —                           | 0.31 | —                                       | 3.23                                      |
| CONCRETE                                  | Light weight aggregate                                                | 2.50                        | —    | 0.40                                    | —                                         |
| CONCRETE                                  | Sand and gravel aggregate                                             | 12.00                       | —    | 0.08                                    | —                                         |
| CONCRETE                                  | Hollow, cinder aggregate                                              | —                           | 1.28 | —                                       | 0.78                                      |
| 3 IN. CONCRETE BLOCKS                     | Hollow, cinder aggregate                                              | —                           | 1.00 | —                                       | 1.00                                      |
| 4 IN. CONCRETE BLOCKS                     | Hollow, gravel aggregate                                              | —                           | 1.00 | —                                       | 1.00                                      |
| 8 IN. CONCRETE BLOCKS                     | Hollow, gravel aggregate                                              | —                           | 0.80 | —                                       | 1.25                                      |
| 12 IN. CONCRETE BLOCKS                    | Hollow, gravel aggregate                                              | —                           | 0.60 | —                                       | 1.68                                      |
| 8 IN. CONCRETE BLOCKS                     | Hollow, cinder aggregate                                              | —                           | 0.53 | —                                       | 1.88                                      |
| 12 IN. CONCRETE BLOCKS                    | Hollow, cinder aggregate                                              | —                           | 0.50 | —                                       | 2.00                                      |
| 8 IN. CONCRETE BLOCKS                     | Hollow, light weight aggregate                                        | —                           | 0.47 | —                                       | 2.13                                      |
| 12 IN. CONCRETE BLOCKS                    | Hollow, light weight aggregate                                        | —                           | —    | —                                       | —                                         |
| GYPSUM FIBER CONCRETE                     | 87 percent gypsum and 12 percent wood chips                           | 1.66                        | —    | 0.60                                    | —                                         |
|                                           | Hollow                                                                | —                           | 0.61 | —                                       | 1.64                                      |
|                                           | Hollow                                                                | —                           | 0.46 | —                                       | 2.18                                      |
| 3 IN. GYPSUM TILE                         | Hollow                                                                | 12.50                       | —    | 0.08                                    | —                                         |
| 4 IN. GYPSUM TILE                         | Hollow                                                                | 12.00                       | —    | 0.08                                    | —                                         |
| STUCCO                                    | For flooring                                                          | 12.50                       | —    | 0.08                                    | —                                         |
| TILE AND TERRAZZO                         |                                                                       | —                           | —    | —                                       | —                                         |
| STONE                                     |                                                                       | —                           | —    | —                                       | —                                         |

TABLE 5. CONDUCTIVITIES ( $k$ ), CONDUCTANCES ( $C$ ), AND RESISTANCES ( $R$ ) USED IN CALCULATING HEAT TRANSMISSION COEFFICIENTS ( $U$ ) IN TABLES 7 TO 19 (Concluded)

These constants are expressed in Btu per (hour) (square foot) (Fahrenheit degree temperature difference). Conductivities ( $k$ ) are per inch thickness and conductances ( $C$ ) are for thickness or construction stated, not per inch thickness

| MATERIAL                                                                     | DESCRIPTION                                         | CONDUCTIVITY<br>OR<br>CONDUCTANCE |       | RESISTANCE                                      |                                                      |
|------------------------------------------------------------------------------|-----------------------------------------------------|-----------------------------------|-------|-------------------------------------------------|------------------------------------------------------|
|                                                                              |                                                     | (k)                               | (C)   | Per Inch<br>Thick-<br>ness<br>( $\frac{1}{k}$ ) | For<br>Thick-<br>ness<br>Listed<br>( $\frac{1}{C}$ ) |
| ROOFING MATERIALS                                                            |                                                     |                                   |       |                                                 |                                                      |
| ASBESTOS SHINGLES.....                                                       | .....                                               | —                                 | 6.00  | —                                               | 0.17                                                 |
| ASPHALT SHINGLES.....                                                        | .....                                               | —                                 | 6.50  | —                                               | 0.15                                                 |
| BUILT-UP ROOFING.....                                                        | Assumed thickness $\frac{1}{2}$ in.....             | —                                 | 3.53  | —                                               | 0.28                                                 |
| HEAVY ROLL ROOFING.....                                                      | .....                                               | —                                 | 6.50  | —                                               | 0.15                                                 |
| SLATE.....                                                                   | Assumed $\frac{1}{2}$ in.....                       | 10.00                             | 20.00 | 0.10                                            | 0.05                                                 |
| WOOD SHINGLES.....                                                           | .....                                               | —                                 | 1.28  | —                                               | 0.78                                                 |
| SHEATHING                                                                    |                                                     |                                   |       |                                                 |                                                      |
| GYPSUM ( $\frac{1}{2}$ IN.).....                                             | .....                                               | —                                 | 2.82  | —                                               | 0.35                                                 |
| INSULATING BOARD ( $\frac{1}{2}$ IN.).....                                   | .....                                               | —                                 | 0.42  | —                                               | 2.37                                                 |
| PLYWOOD ( $\frac{1}{2}$ IN.).....                                            | .....                                               | —                                 | 2.56  | —                                               | 0.39                                                 |
| FIR OR YELLOW PINE (1 IN.).....                                              | Actual thickness $\frac{1}{2}$ in.....              | —                                 | 1.02  | —                                               | 0.98                                                 |
| FIR, PLUS BUILDING PAPER.....                                                | Actual thickness $\frac{1}{2}$ in.....              | —                                 | 0.86  | —                                               | 1.16                                                 |
| SURFACES                                                                     |                                                     |                                   |       |                                                 |                                                      |
| STILL AIR.....                                                               | Ordinary non-reflective materials,<br>vertical..... | —                                 | 1.65  | —                                               | 0.61                                                 |
| 15 MPH WIND VELOCITY.....                                                    | Ordinary non-reflective materials,<br>vertical..... | —                                 | 6.00  | —                                               | 0.17                                                 |
| WOODS                                                                        |                                                     |                                   |       |                                                 |                                                      |
| FIR SHEATHING (1 IN.) BUILD-<br>ING PAPER AND YELLOW<br>PINE LAP SIDING..... | .....                                               | —                                 | 0.50  | —                                               | 2.00                                                 |
| MAPLE OR OAK.....                                                            | .....                                               | 1.15                              | —     | 0.87                                            | —                                                    |
| YELLOW PINE OR FIR.....                                                      | .....                                               | 0.80                              | —     | 1.25                                            | —                                                    |

\* The values in this table do not agree exactly with those given in Table 2 which was revised in this issue, but the differences are not significant for design use. Tables 5 and 7 through 19 are in the process of revision so that they will correspond to Table 2.

† For practical accuracy these values can be used as an average for vertical and horizontal surfaces. Where accuracy is desired refer to Table 2. These values for Tables 5 and 7 through 19 are in the process of revision.

computed using the conductivity of air at the appropriate mean temperature (see Table 1, Chapter 5).

The effects of different mean temperatures, temperature differences, and effective emissivities are indicated in Table 1, Section B. As indicated, use may be made of interpolation and moderate extrapolation of conductance values in the table to obtain conductances for conditions moderately different from those given. Interpolation of resistance values is not recommended, especially in relation to emissivity values.

Table 1, Section C gives values for the surface reflectivities and emissivities of materials used as boundaries of air spaces in building construction, for total radiation at ordinary building temperatures. Effective emissivities for various combinations of these materials, for use in conjunction with Section B of Table 1, are given in the last two columns of Section C.

When considering heat transfer across air spaces in building construction, the emissivities of the boundary surfaces should be known. The possibility of change in emissivity of highly reflective surfaces due to exposure to conditions promoting chemical action, deposition of dust, soiling of the surface

or the application of coatings, even though transparent to the eye, must be considered in selecting a material for use.<sup>10</sup> Surface emissivity values should be obtained by tests.

### PRACTICAL COEFFICIENTS AND THEIR USE

For practical purposes it is necessary to compute average coefficients that may be applied to various materials and types of construction. Table 2, as revised in this issue, gives representative values for dry materials at 70 F mean temperature, as selected by the ASHAE Technical Advisory Committee on Insulation. Since there may be some variation in the materials and in test conditions, these selected values may not be in exact agreement with published data of all manufacturers. The exact value for the conductivity or conductance of a certain manufacturer's material can only be secured from unbiased tests or guaranteed by the manufacturer.

#### Caution

The conductivity or conductance values given in Tables 1 and 2 are taken from values obtained in most cases by the guarded hot plate method ASTM Standard C-177-45 which states,

"Because of the requirements prescribed in this method as to conditions under which conductivity tests shall be made, it should be recognized that the conductivity coefficients obtained will not necessarily be the values pertaining under all service conditions. As an example, the method provides that the conductivity coefficient shall be obtained by test on dry specimens, while in service such a condition will seldom be realized."

The user should realize that the average conductivity and conductance values given in Tables 2 or 5 do not necessarily apply to all products of the same general description. In using these values, judgment should be exercised with regard to the extent to which the product (either as received or as applied) will comply with the tabulated values. Exact conductivities or conductances for specific materials should be obtained from the manufacturer. Table 5 has been retained in this edition because it is the basis for computation of the  $U$ -values shown in Tables 7 to 18.

Because  $U$  values for heat flow upward, such as for ceilings in winter, may differ greatly from  $U$  values for heat flow downward, such as for ceilings in summer, a serious error may be made in calculating heat losses or gains if the appropriate  $U$  value is not used. (See Chapter 13 for recommended temperature gradients for cooling loads.)

Due to the inconsistency of actual building construction, because of the human element, many designers do not use overall coefficients of transmission lower than 0.10 for walls and particularly roofs, except where the construction is installed under continuous supervision. It should also be noted that these coefficients do not include any factor of safety and that when no supervision is used, some designers incorporate a 10 percent factor of safety.

Attention is called to the necessity of applying the insulating material in accordance with the manufacturer's specification. The engineer must evaluate carefully the economic considerations involved in the selection of an insulating material as adapted to various building constructions. Lack of proper evaluation, or improper installation may lead to unsatisfactory results. Special attention must be given to vapor barriers as outlined in Chapter 10. Moisture from condensation or other sources materially reduces the heat-flow resistance of insulation.

### Insulating Materials

In order to determine the benefit derived from the addition of insulating materials to a given construction, the overall coefficient of heat transmission,  $U_i$  of the insulated construction may be compared with the corresponding coefficient  $U$  without insulation. Table 6 (Part A to Part D) may be used for determining the coefficients of transmission of constructions with any combination of fibrous, bulk, or mass insulation and air spaces of various effective emissivities.

### INSULATED CONSTRUCTIONS—HOW TO USE TABLE 6

In Tables 7 to 17,  $U$  values are given for many common types of building wall, floor, and ceiling constructions. For such of these constructions as contain an air space, the tabulated  $U$  value is based on the assumption that the air space is empty, and that its surfaces are of ordinary building materials of low thermal reflectivity, such as wood, masonry, plaster or paper. Considerable benefit in reducing the heat transmission coefficient of a construction can be effected by the application of thermal insulating materials in the air space.

Table 6 provides a means of determining, without calculations, the  $U$  value of the between-framing area of such constructions with the added insulation installed in the air space. Column 1 of Table 6 refers to the  $U$  values of uninsulated constructions as taken from Tables 7 to 17. Columns 2 to 14 of the table give corresponding coefficients  $U_i$  for the constructions with various insulating applications in the between-framing air space, as indicated by the column headings. Table 6 is in four parts, corresponding to the type of building element and the direction of heat flow. Each part is based on temperature conditions considered generally appropriate for the case.

Any and all  $U$  values are based on a series of assumptions as to nominal characteristics. Common variations in conditions, materials, workmanship, etc. can introduce much greater variations in  $U$  values than the variations resulting from the assumed mean temperatures and temperature differences described. From this it is also clear that the use of more than two significant figures in stating a  $U$  value is assuming more precision than can possibly exist. Three significant figures are used in Table 6 merely as a means of reducing cumulative errors when the table is used several times to obtain a single result. It should not be assumed that the figures are accurate, over-all, to three significant figures. Also a result taken from Table 6 should always be rounded off to two significant figures.

#### To use Table 6:

1. Find in Column 1 of the appropriate table the value for  $U$  obtained from Tables 7 to 17.
2. If there is a column which exactly corresponds to the condition for which you desire the  $U$  value, read the answer in this column, opposite the Column 1 value. Interpolate if necessary.
3. If there is no column which fully corresponds to the condition for which you desire the  $U$  value, then obtain the answer by means of two or more steps—each time using the value obtained in one step to reenter the same table through Column 1. In this way  $U$  values may be obtained for combinations of insulation in the framing space.

#### Special Uses of Table 6

Values of  $U_i$  for insulating applications or combinations other than those indicated by the headings of Columns 2 to 14 of Table 6 can be ascertained



TABLE 6. DETERMINATION OF  $U$  VALUE RESULTING FROM ADDITION OF INSULATION OR AIR SPACES TO UNINSULATED BUILDING SECTIONS\*  
PART A. WALLS\*

| U VALUE <sup>b</sup><br>WITHOUT ADDED<br>INSULATION | FIBROUS INSULATION <sup>c</sup> THICKNESS—INCHES |   |       |       |       | ONE AIR SPACE <sup>d</sup> OF EFFECTIVE<br>EMISSIVITY <sup>e</sup> $E$ |       |       | TWO AIR SPACES <sup>d</sup> OF EFFECTIVE<br>EMISSIVITY <sup>e</sup> $E$ |       |       | THREE AIR SPACES <sup>d</sup> OF EFFECTIVE<br>EMISSIVITY <sup>e</sup> $E$ |       |       |
|-----------------------------------------------------|--------------------------------------------------|---|-------|-------|-------|------------------------------------------------------------------------|-------|-------|-------------------------------------------------------------------------|-------|-------|---------------------------------------------------------------------------|-------|-------|
|                                                     | 1                                                |   | 2     |       | 3     | 0.82 <sup>f</sup>                                                      | 0.20  | 0.05  | 0.82                                                                    | 0.20  | 0.05  | 0.82                                                                      | 0.20  | 0.05  |
|                                                     | 1/4                                              | 2 | 1     | 2     | 3     | 6                                                                      | 7     | 8     | 9                                                                       | 10    | 11    | 12                                                                        | 13    | 14    |
| Col. 1                                              |                                                  |   |       |       |       |                                                                        |       |       |                                                                         |       |       |                                                                           |       |       |
| 0.70                                                | 0.304                                            |   | 0.194 | 0.113 | 0.080 | 0.752                                                                  | 0.463 | 0.380 | 0.437                                                                   | 0.240 | 0.189 | 0.298                                                                     | 0.150 | 0.112 |
| 0.60                                                | 0.284                                            |   | 0.186 | 0.110 | 0.078 | 0.630                                                                  | 0.412 | 0.341 | 0.392                                                                   | 0.225 | 0.177 | 0.276                                                                     | 0.144 | 0.108 |
| 0.50                                                | 0.266                                            |   | 0.168 | 0.104 | 0.075 | 0.480                                                                  | 0.331 | 0.280 | 0.318                                                                   | 0.195 | 0.158 | 0.237                                                                     | 0.130 | 0.098 |
| 0.45                                                | 0.230                                            |   | 0.161 | 0.101 | 0.074 | 0.409                                                                  | 0.299 | 0.258 | 0.291                                                                   | 0.185 | 0.149 | 0.222                                                                     | 0.125 | 0.095 |
| 0.35                                                | 0.212                                            |   | 0.152 | 0.097 | 0.072 | 0.354                                                                  | 0.267 | 0.234 | 0.262                                                                   | 0.172 | 0.140 | 0.205                                                                     | 0.119 | 0.092 |
| 0.30                                                | 0.192                                            |   | 0.142 | 0.093 | 0.069 | 0.307                                                                  | 0.234 | 0.207 | 0.232                                                                   | 0.158 | 0.130 | 0.186                                                                     | 0.112 | 0.087 |
| 0.28                                                | 0.184                                            |   | 0.138 | 0.091 | 0.068 | 0.287                                                                  | 0.221 | 0.196 | 0.220                                                                   | 0.151 | 0.125 | 0.178                                                                     | 0.108 | 0.084 |
| 0.26                                                | 0.175                                            |   | 0.133 | 0.089 | 0.066 | 0.267                                                                  | 0.208 | 0.185 | 0.207                                                                   | 0.144 | 0.120 | 0.169                                                                     | 0.104 | 0.082 |
| 0.24                                                | 0.166                                            |   | 0.127 | 0.087 | 0.065 | 0.247                                                                  | 0.194 | 0.173 | 0.194                                                                   | 0.137 | 0.115 | 0.160                                                                     | 0.100 | 0.079 |
| 0.22                                                | 0.156                                            |   | 0.121 | 0.084 | 0.064 | 0.227                                                                  | 0.180 | 0.161 | 0.180                                                                   | 0.129 | 0.110 | 0.150                                                                     | 0.096 | 0.076 |
| 0.20                                                | 0.145                                            |   | 0.115 | 0.081 | 0.062 | 0.207                                                                  | 0.165 | 0.149 | 0.166                                                                   | 0.120 | 0.104 | 0.140                                                                     | 0.091 | 0.073 |
| 0.18                                                | 0.134                                            |   | 0.108 | 0.078 | 0.060 | 0.187                                                                  | 0.150 | 0.137 | 0.152                                                                   | 0.112 | 0.098 | 0.129                                                                     | 0.086 | 0.069 |
| 0.16                                                | 0.123                                            |   | 0.100 | 0.074 | 0.057 | 0.167                                                                  | 0.136 | 0.124 | 0.137                                                                   | 0.103 | 0.090 | 0.118                                                                     | 0.080 | 0.065 |
| 0.14                                                | 0.111                                            |   | 0.092 | 0.069 | 0.054 | 0.147                                                                  | 0.120 | 0.111 | 0.122                                                                   | 0.094 | 0.083 | 0.106                                                                     | 0.075 | 0.061 |
| 0.12                                                | 0.098                                            |   | 0.083 | 0.064 | 0.051 | 0.127                                                                  | 0.105 | 0.098 | 0.107                                                                   | 0.084 | 0.075 | 0.094                                                                     | 0.068 | 0.056 |
| 0.10                                                | 0.085                                            |   | 0.073 | 0.058 | 0.047 | 0.107                                                                  | 0.089 | 0.084 | 0.091                                                                   | 0.074 | 0.068 | 0.082                                                                     | 0.061 | 0.051 |
| 0.08                                                | 0.070                                            |   | 0.062 | 0.050 | 0.042 | 0.087                                                                  | 0.073 | 0.068 | 0.074                                                                   | 0.062 | 0.056 | 0.068                                                                     | 0.053 | 0.045 |

\* For constructions with air spaces as insulation, coefficients are based on National Bureau of Standards data in Housing Research Paper No. 32 (U. S. Government Printing Office, Washington, D. C.).

<sup>a</sup> Based on an indoor-outdoor temperature difference of 70 F deg, and a mean temperature of 50 F. Values are applicable conservatively to winter and summer conditions.

<sup>b</sup>  $U$  value taken from Tables 7 to 17, based on one non-reflective air space between framing members.

<sup>c</sup> Thermal conductivity of fibrous or bulk insulation taken as 0.27 Btu per (hr) (sq ft) (F deg per in.).

<sup>d</sup> Spaces of uniform thickness not less than 3/4 in.

<sup>e</sup> For values of effective emissivity  $E$  of air space, see Table 1, Section C.

<sup>f</sup> Certain  $U$  values in Column 6 differ from Column 1 because they are adjusted to the specific temperature drop across the air space in question as affected by the  $U$  value of the construction.

TABLE 6. DETERMINATION OF  $U$  VALUE RESULTING FROM ADDITION OF INSULATION OR AIR SPACES TO UNINSULATED BUILDING SECTIONS\* (Continued)  
PART B. FLOORS—HEAT FLOW DOWN

| U VALUE <sup>b</sup> WITHOUT<br>ADDED INSULATION | FIBROUS INSULATION <sup>c</sup> THICKNESS—INCHES |   |       |       |       | ONE AIR SPACE <sup>d</sup> OF EFFECTIVE<br>EMISSIVITY <sup>e</sup> $E$ |       |       | TWO AIR SPACES <sup>d</sup> OF EFFECTIVE<br>EMISSIVITY <sup>e</sup> $E$ |       |       | THREE AIR SPACES <sup>d</sup> OF EFFECTIVE<br>EMISSIVITY <sup>e</sup> $E$ |       |       |
|--------------------------------------------------|--------------------------------------------------|---|-------|-------|-------|------------------------------------------------------------------------|-------|-------|-------------------------------------------------------------------------|-------|-------|---------------------------------------------------------------------------|-------|-------|
|                                                  | 1                                                |   | 2     |       | 3     | 0.82 <sup>f</sup>                                                      | 0.20  | 0.05  | 0.82                                                                    | 0.20  | 0.05  | 0.82                                                                      | 0.20  | 0.05  |
|                                                  | 1/4                                              | 2 | 1     | 2     | 3     | 6                                                                      | 7     | 8     | 9                                                                       | 10    | 11    | 12                                                                        | 13    | 14    |
| Col. 1                                           |                                                  |   |       |       |       |                                                                        |       |       |                                                                         |       |       |                                                                           |       |       |
| 0.70                                             | 0.305                                            |   | 0.195 | 0.113 | 0.080 | 0.70                                                                   | 0.240 | 0.114 | 0.377                                                                   | 0.122 | 0.087 | 0.262                                                                     | 0.086 | 0.042 |
| 0.60                                             | 0.284                                            |   | 0.186 | 0.110 | 0.078 | 0.60                                                                   | 0.236 | 0.111 | 0.346                                                                   | 0.118 | 0.086 | 0.246                                                                     | 0.084 | 0.041 |
| 0.50                                             | 0.260                                            |   | 0.175 | 0.106 | 0.076 | 0.50                                                                   | 0.210 | 0.106 | 0.310                                                                   | 0.114 | 0.085 | 0.228                                                                     | 0.082 | 0.041 |
| 0.45                                             | 0.246                                            |   | 0.168 | 0.104 | 0.075 | 0.45                                                                   | 0.200 | 0.103 | 0.290                                                                   | 0.111 | 0.085 | 0.217                                                                     | 0.081 | 0.040 |
| 0.40                                             | 0.230                                            |   | 0.161 | 0.101 | 0.074 | 0.40                                                                   | 0.189 | 0.100 | 0.268                                                                   | 0.107 | 0.084 | 0.205                                                                     | 0.079 | 0.040 |
| 0.35                                             | 0.212                                            |   | 0.152 | 0.097 | 0.072 | 0.35                                                                   | 0.176 | 0.096 | 0.244                                                                   | 0.103 | 0.082 | 0.192                                                                     | 0.077 | 0.040 |
| 0.30                                             | 0.192                                            |   | 0.142 | 0.093 | 0.069 | 0.30                                                                   | 0.162 | 0.091 | 0.219                                                                   | 0.098 | 0.081 | 0.175                                                                     | 0.074 | 0.039 |
| 0.28                                             | 0.184                                            |   | 0.138 | 0.091 | 0.068 | 0.28                                                                   | 0.156 | 0.089 | 0.208                                                                   | 0.096 | 0.080 | 0.168                                                                     | 0.073 | 0.039 |
| 0.26                                             | 0.175                                            |   | 0.133 | 0.089 | 0.066 | 0.26                                                                   | 0.150 | 0.087 | 0.197                                                                   | 0.094 | 0.079 | 0.161                                                                     | 0.072 | 0.038 |
| 0.24                                             | 0.166                                            |   | 0.127 | 0.087 | 0.065 | 0.24                                                                   | 0.143 | 0.084 | 0.185                                                                   | 0.091 | 0.078 | 0.153                                                                     | 0.070 | 0.038 |
| 0.22                                             | 0.156                                            |   | 0.121 | 0.084 | 0.064 | 0.22                                                                   | 0.136 | 0.081 | 0.173                                                                   | 0.088 | 0.075 | 0.145                                                                     | 0.068 | 0.037 |
| 0.20                                             | 0.145                                            |   | 0.115 | 0.081 | 0.062 | 0.20                                                                   | 0.128 | 0.078 | 0.160                                                                   | 0.084 | 0.072 | 0.136                                                                     | 0.066 | 0.036 |
| 0.18                                             | 0.134                                            |   | 0.108 | 0.078 | 0.060 | 0.18                                                                   | 0.119 | 0.074 | 0.148                                                                   | 0.080 | 0.065 | 0.126                                                                     | 0.064 | 0.036 |
| 0.16                                             | 0.123                                            |   | 0.100 | 0.074 | 0.057 | 0.16                                                                   | 0.110 | 0.070 | 0.133                                                                   | 0.076 | 0.064 | 0.116                                                                     | 0.061 | 0.035 |
| 0.14                                             | 0.111                                            |   | 0.092 | 0.069 | 0.054 | 0.14                                                                   | 0.099 | 0.065 | 0.118                                                                   | 0.071 | 0.058 | 0.105                                                                     | 0.058 | 0.034 |
| 0.12                                             | 0.098                                            |   | 0.083 | 0.064 | 0.051 | 0.12                                                                   | 0.088 | 0.060 | 0.103                                                                   | 0.066 | 0.054 | 0.094                                                                     | 0.054 | 0.033 |
| 0.10                                             | 0.085                                            |   | 0.073 | 0.058 | 0.047 | 0.10                                                                   | 0.076 | 0.054 | 0.089                                                                   | 0.058 | 0.047 | 0.081                                                                     | 0.049 | 0.031 |
| 0.08                                             | 0.070                                            |   | 0.062 | 0.050 | 0.042 | 0.08                                                                   | 0.063 | 0.047 | 0.072                                                                   | 0.050 | 0.033 | 0.068                                                                     | 0.044 | 0.028 |

\* For constructions with air spaces as insulation, coefficients are based on National Bureau of Standards data in Housing Research Paper No. 32 (U. S. Government Printing Office, Washington, D. C.).

<sup>a</sup> Based on a temperature difference of 50 F deg from air to air, and a mean temperature of 50 F.

<sup>b</sup>  $U$  value taken from Tables 12 and 13, in which it is assumed that the air space between joists or above the suspended ceiling is non-reflective ( $E = 0.92$ ).

<sup>c</sup> Thermal conductivity of fibrous or bulk insulation taken as 0.27 Btu per (hr) (sq ft) (F deg per in.).

<sup>d</sup> Spaces of uniform thickness not less than 3/4 in.

<sup>e</sup> For values of effective emissivity  $E$  of air space, see Table 1, Section C.

TABLE 6. DETERMINATION OF U VALUE RESULTING FROM ADDITION OF INSULATION OR AIR SPACES TO UNINSULATED BUILDING SECTIONS\* (Continued)

PART C. CEILINGS—HEAT FLOW UP† (WINTER CONDITION)

| U VALUE <sup>u</sup><br>WITHOUT ADDED<br>INSULATION | FIBROUS INSULATION <sup>a</sup> THICKNESS—INCHES |       |       |       |       | ONE AIR SPACE <sup>c</sup> OF EFFECTIVE<br>EMISSIVITY <sup>p</sup> E |       |       |       | TWO AIR SPACES <sup>c</sup> OF EFFECTIVE<br>EMISSIVITY <sup>p</sup> E |       |       |       | THREE AIR SPACES <sup>c</sup> OF EFFECTIVE<br>EMISSIVITY <sup>p</sup> E |    |  |  |
|-----------------------------------------------------|--------------------------------------------------|-------|-------|-------|-------|----------------------------------------------------------------------|-------|-------|-------|-----------------------------------------------------------------------|-------|-------|-------|-------------------------------------------------------------------------|----|--|--|
|                                                     | 1/2                                              |       | 1     | 2     | 3     | 3                                                                    | 6     | 7     | 8     | 9                                                                     | 10    | 11    | 12    | 13                                                                      | 14 |  |  |
|                                                     | 1/2                                              | 2     | 3     | 4     | 5     | 6                                                                    | 7     | 8     | 9     | 10                                                                    | 11    | 12    | 13    | 14                                                                      |    |  |  |
| Col. 1                                              |                                                  |       |       |       |       |                                                                      |       |       |       |                                                                       |       |       |       |                                                                         |    |  |  |
| 0.70                                                | 0.305                                            | 0.195 | 0.113 | 0.080 | 0.080 | 0.690                                                                | 0.472 | 0.403 | 0.427 | 0.282                                                                 | 0.216 | 0.307 | 0.180 | 0.146                                                                   |    |  |  |
| 0.60                                                | 0.284                                            | 0.186 | 0.110 | 0.078 | 0.078 | 0.588                                                                | 0.417 | 0.362 | 0.385 | 0.244                                                                 | 0.204 | 0.284 | 0.171 | 0.139                                                                   |    |  |  |
| 0.50                                                | 0.260                                            | 0.175 | 0.106 | 0.076 | 0.076 | 0.488                                                                | 0.361 | 0.318 | 0.339 | 0.224                                                                 | 0.189 | 0.258 | 0.160 | 0.131                                                                   |    |  |  |
| 0.45                                                | 0.246                                            | 0.168 | 0.104 | 0.075 | 0.075 | 0.438                                                                | 0.331 | 0.295 | 0.316 | 0.212                                                                 | 0.180 | 0.243 | 0.154 | 0.126                                                                   |    |  |  |
| 0.40                                                | 0.230                                            | 0.161 | 0.101 | 0.074 | 0.074 | 0.389                                                                | 0.300 | 0.270 | 0.288 | 0.199                                                                 | 0.170 | 0.227 | 0.146 | 0.121                                                                   |    |  |  |
| 0.35                                                | 0.212                                            | 0.152 | 0.097 | 0.072 | 0.072 | 0.340                                                                | 0.269 | 0.244 | 0.260 | 0.185                                                                 | 0.158 | 0.209 | 0.138 | 0.115                                                                   |    |  |  |
| 0.30                                                | 0.192                                            | 0.142 | 0.093 | 0.069 | 0.069 | 0.292                                                                | 0.237 | 0.215 | 0.230 | 0.168                                                                 | 0.145 | 0.189 | 0.129 | 0.108                                                                   |    |  |  |
| 0.28                                                | 0.184                                            | 0.138 | 0.091 | 0.068 | 0.068 | 0.272                                                                | 0.224 | 0.203 | 0.217 | 0.161                                                                 | 0.140 | 0.181 | 0.125 | 0.104                                                                   |    |  |  |
| 0.26                                                | 0.175                                            | 0.133 | 0.089 | 0.066 | 0.066 | 0.253                                                                | 0.211 | 0.191 | 0.204 | 0.154                                                                 | 0.134 | 0.172 | 0.120 | 0.101                                                                   |    |  |  |
| 0.24                                                | 0.166                                            | 0.127 | 0.087 | 0.065 | 0.065 | 0.234                                                                | 0.199 | 0.179 | 0.191 | 0.146                                                                 | 0.128 | 0.163 | 0.115 | 0.097                                                                   |    |  |  |
| 0.22                                                | 0.156                                            | 0.121 | 0.084 | 0.064 | 0.064 | 0.214                                                                | 0.186 | 0.166 | 0.178 | 0.137                                                                 | 0.120 | 0.153 | 0.109 | 0.093                                                                   |    |  |  |
| 0.20                                                | 0.145                                            | 0.115 | 0.081 | 0.062 | 0.062 | 0.195                                                                | 0.173 | 0.154 | 0.164 | 0.128                                                                 | 0.114 | 0.143 | 0.104 | 0.088                                                                   |    |  |  |
| 0.18                                                | 0.134                                            | 0.108 | 0.078 | 0.060 | 0.060 | 0.176                                                                | 0.159 | 0.141 | 0.150 | 0.119                                                                 | 0.106 | 0.132 | 0.097 | 0.084                                                                   |    |  |  |
| 0.16                                                | 0.123                                            | 0.100 | 0.074 | 0.057 | 0.057 | 0.156                                                                | 0.146 | 0.128 | 0.136 | 0.109                                                                 | 0.098 | 0.121 | 0.090 | 0.079                                                                   |    |  |  |
| 0.14                                                | 0.111                                            | 0.092 | 0.069 | 0.054 | 0.054 | 0.137                                                                | 0.132 | 0.115 | 0.120 | 0.099                                                                 | 0.090 | 0.109 | 0.083 | 0.073                                                                   |    |  |  |
| 0.12                                                | 0.098                                            | 0.083 | 0.064 | 0.051 | 0.051 | 0.118                                                                | 0.118 | 0.101 | 0.105 | 0.088                                                                 | 0.080 | 0.096 | 0.075 | 0.068                                                                   |    |  |  |
| 0.10                                                | 0.085                                            | 0.073 | 0.058 | 0.047 | 0.047 | 0.099                                                                | 0.105 | 0.088 | 0.090 | 0.076                                                                 | 0.071 | 0.082 | 0.067 | 0.062                                                                   |    |  |  |
| 0.08                                                | 0.070                                            | 0.062 | 0.050 | 0.042 | 0.042 | 0.079                                                                | 0.091 | 0.074 | 0.073 | 0.064                                                                 | 0.061 | 0.067 | 0.058 | 0.056                                                                   |    |  |  |

\* For construction with air spaces as insulation, coefficients are based on National Bureau of Standards data in Housing Research Paper No. 32 (U. S. Government Printing Office, Wash., D. C.).

<sup>1</sup> Based on a temperature difference of 75 deg F from air to air, and a mean temperature of 40 F.

<sup>2</sup> U value taken from Tables 12, 13 and 15-16, in which it is assumed that the air space between joists or above the suspended ceiling is non-reflective (E = 0.82).

<sup>3</sup> Thermal conductivity of fibrous or bulk insulation taken as 0.27 Btu per (hr) (sq ft) (F deg per in.).

<sup>4</sup> Spaces of uniform thickness not less than 1/4 in.

<sup>5</sup> For values of effective emissivity E of air space, see Table 1, Section C.

<sup>6</sup> Certain U values in Column 6 differ from Column 1 because they are adjusted to the specific temperature drop across the air space in question as affected by the U value of the insulation.

TABLE 6. DETERMINATION OF U VALUE RESULTING FROM ADDITION OF INSULATION OR AIR SPACES TO UNINSULATED BUILDING SECTIONS\* (Continued)

PART D. CEILINGS—HEAT FLOW DOWN† (SUMMER CONDITION)

| U VALUE <sup>a</sup><br>WITHOUT ADDED<br>INSULATION | FIBROUS INSULATION <sup>u</sup> THICKNESS—INCHES |       |       |       |       | ONE AIR SPACE <sup>u</sup> OF EFFECTIVE<br>EMISSIVITY <sup>u</sup> E |       |       |       | TWO AIR SPACES <sup>u</sup> OF EFFECTIVE<br>EMISSIVITY <sup>u</sup> E |       |       |       | THREE AIR SPACES <sup>u</sup> OF EFFECTIVE<br>EMISSIVITY <sup>u</sup> E |    |  |  |
|-----------------------------------------------------|--------------------------------------------------|-------|-------|-------|-------|----------------------------------------------------------------------|-------|-------|-------|-----------------------------------------------------------------------|-------|-------|-------|-------------------------------------------------------------------------|----|--|--|
|                                                     | 1/2                                              |       | 2     |       | 3     | 3                                                                    | 6     | 7     | 8     | 9                                                                     | 10    | 11    | 12    | 13                                                                      | 14 |  |  |
|                                                     | 1                                                | 2     | 3     | 4     | 5     | 6                                                                    | 7     | 8     | 9     | 10                                                                    | 11    | 12    | 13    | 14                                                                      |    |  |  |
| Col. 1                                              |                                                  |       |       |       |       |                                                                      |       |       |       |                                                                       |       |       |       |                                                                         |    |  |  |
| 0.70                                                | 0.305                                            | 0.195 | 0.113 | 0.080 | 0.080 | 0.704                                                                | 0.269 | 0.119 | 0.423 | 0.144                                                                 | 0.081 | 0.306 | 0.103 | 0.046                                                                   |    |  |  |
| 0.60                                                | 0.284                                            | 0.186 | 0.110 | 0.078 | 0.078 | 0.602                                                                | 0.252 | 0.116 | 0.384 | 0.139                                                                 | 0.080 | 0.284 | 0.100 | 0.046                                                                   |    |  |  |
| 0.50                                                | 0.260                                            | 0.175 | 0.106 | 0.076 | 0.076 | 0.501                                                                | 0.231 | 0.112 | 0.340 | 0.133                                                                 | 0.089 | 0.260 | 0.097 | 0.045                                                                   |    |  |  |
| 0.45                                                | 0.246                                            | 0.168 | 0.104 | 0.075 | 0.075 | 0.450                                                                | 0.220 | 0.108 | 0.316 | 0.128                                                                 | 0.088 | 0.246 | 0.095 | 0.044                                                                   |    |  |  |
| 0.40                                                | 0.230                                            | 0.161 | 0.101 | 0.074 | 0.074 | 0.400                                                                | 0.206 | 0.105 | 0.291 | 0.123                                                                 | 0.087 | 0.230 | 0.092 | 0.044                                                                   |    |  |  |
| 0.35                                                | 0.212                                            | 0.152 | 0.097 | 0.072 | 0.072 | 0.350                                                                | 0.192 | 0.100 | 0.264 | 0.118                                                                 | 0.086 | 0.213 | 0.090 | 0.044                                                                   |    |  |  |
| 0.30                                                | 0.192                                            | 0.142 | 0.093 | 0.069 | 0.069 | 0.300                                                                | 0.175 | 0.095 | 0.234 | 0.112                                                                 | 0.086 | 0.193 | 0.086 | 0.042                                                                   |    |  |  |
| 0.28                                                | 0.184                                            | 0.138 | 0.091 | 0.068 | 0.068 | 0.280                                                                | 0.168 | 0.093 | 0.222 | 0.109                                                                 | 0.086 | 0.185 | 0.085 | 0.042                                                                   |    |  |  |
| 0.26                                                | 0.175                                            | 0.133 | 0.089 | 0.066 | 0.066 | 0.260                                                                | 0.160 | 0.090 | 0.209 | 0.105                                                                 | 0.086 | 0.176 | 0.083 | 0.041                                                                   |    |  |  |
| 0.24                                                | 0.166                                            | 0.127 | 0.087 | 0.065 | 0.065 | 0.240                                                                | 0.152 | 0.087 | 0.195 | 0.102                                                                 | 0.083 | 0.167 | 0.080 | 0.040                                                                   |    |  |  |
| 0.22                                                | 0.156                                            | 0.121 | 0.084 | 0.064 | 0.064 | 0.220                                                                | 0.144 | 0.084 | 0.182 | 0.098                                                                 | 0.086 | 0.157 | 0.078 | 0.040                                                                   |    |  |  |
| 0.20                                                | 0.145                                            | 0.115 | 0.081 | 0.062 | 0.062 | 0.200                                                                | 0.135 | 0.081 | 0.168 | 0.094                                                                 | 0.086 | 0.146 | 0.075 | 0.039                                                                   |    |  |  |
| 0.18                                                | 0.134                                            | 0.108 | 0.078 | 0.060 | 0.060 | 0.180                                                                | 0.125 | 0.077 | 0.154 | 0.089                                                                 | 0.086 | 0.135 | 0.072 | 0.038                                                                   |    |  |  |
| 0.16                                                | 0.123                                            | 0.100 | 0.074 | 0.057 | 0.057 | 0.160                                                                | 0.115 | 0.073 | 0.139 | 0.084                                                                 | 0.086 | 0.124 | 0.068 | 0.038                                                                   |    |  |  |
| 0.14                                                | 0.111                                            | 0.092 | 0.069 | 0.054 | 0.054 | 0.140                                                                | 0.104 | 0.069 | 0.124 | 0.078                                                                 | 0.086 | 0.111 | 0.064 | 0.037                                                                   |    |  |  |
| 0.12                                                | 0.098                                            | 0.083 | 0.064 | 0.051 | 0.051 | 0.120                                                                | 0.093 | 0.063 | 0.108 | 0.072                                                                 | 0.086 | 0.098 | 0.059 | 0.036                                                                   |    |  |  |
| 0.10                                                | 0.085                                            | 0.073 | 0.058 | 0.047 | 0.047 | 0.099                                                                | 0.080 | 0.056 | 0.091 | 0.064                                                                 | 0.086 | 0.084 | 0.054 | 0.033                                                                   |    |  |  |
| 0.08                                                | 0.070                                            | 0.062 | 0.050 | 0.042 | 0.042 | 0.079                                                                | 0.068 | 0.048 | 0.074 | 0.054                                                                 | 0.084 | 0.070 | 0.046 | 0.030                                                                   |    |  |  |

For construction with air spaces as insulation, see Fig. 1.

\* For construction with air spaces as insulation, coefficients are based on National Bureau of Standards data in Housing Research Paper No. 32 (U. S. Government Printing Office, Wash., D. C.).

<sup>1</sup> Based on a temperature difference of 35 F deg from air to air, and a mean temperature of 100 F.

<sup>2</sup> U value taken from Tables 7 to 17, in which it is assumed that the air space between joists or above the suspended ceiling is non-reflective (E = 0.82).

<sup>3</sup> Thermal conductivity of fibrous or bulk insulation taken as 0.27 Btu per (hr) (sq ft) (F deg per in.).

<sup>4</sup> Spaces of uniform thickness not less than 1/4 in.

<sup>5</sup> For values of effective emissivity E of air space, see Table 1, Section C.

if the table is used appropriately. For instance, going horizontally in the table from Column 2 to Column 3 is equivalent to adding  $\frac{1}{2}$  in. of fibrous insulation to the construction; similarly, going from Column 2 to Column 4 adds  $1\frac{1}{2}$  in. of fibrous insulation to the construction. In the same way, going horizontally from Column 8 to Column 11 is equivalent to adding to a construction the insulating value of one additional highly reflective ( $E = 0.05$ ) air space, and going from Column 6 to Column 12 in effect adds two non-reflective ( $E = 0.82$ ) air spaces to the construction, etc.

### CORRECTION FOR FRAMING

Correction for parallel heat flow through framing and insulated areas may be made by use of Fig. 5. Correction for the effect of framing should

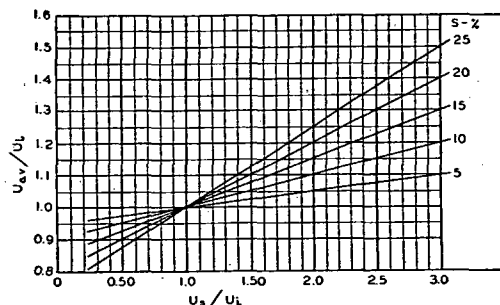


FIG. 5. CORRECTION FOR EFFECT OF FRAMING IN INSULATED BUILDING SECTIONS

$U_{av}$  = average  $U$  value for building section.  
 $U_i$  =  $U$  value for area between framing members.  
 $U_s$  =  $U$  value for area backed by framing members.  
 $S$  = Percentage of area backed by framing members.

be applied after final  $U_i$  and  $U_s$  values have been obtained for a given construction. In many cases this correction may be omitted.

**Example 1:** Consider a frame wall with 2-in. blanket insulation which has a  $U_i$  value of 0.08. By calculation it is found that heat loss from the area backed by framing members ( $U_s$ ) is 0.13.  $U_s/U_i$  is 1.63. From Fig. 5 if 15 per cent of wall area is backed by framing, the value  $U_{av}/U_i = 1.1$ .  $U_{av}$  is therefore  $1.1 \times 0.08 = 0.088$ .

### Computed Heat Transmission Coefficients

Computed overall heat transmission coefficients of many common types of building construction are given in Tables 7 to 21. In the analysis of any wall construction for the purpose of calculating the overall coefficient of heat transmission  $U$ , it is first necessary to determine the paths of heat flow, that is, whether they are parallel or series, or a combination of both. This is in accordance with the basic laws of heat transfer which state that in parallel flow the conductances are additive, while in series flow the resistances are additive. Likewise, in order to determine the total resistance for the wall, the conductance must be known.

The importance of this analysis cannot be over-emphasized. This is especially true in wall constructions in which there are parallel paths of heat flow, and one path has a high heat transfer, while others have a low heat transfer. The method of making this calculation can best be shown by *Example 2* and Fig. 6. As this wall was tested by the hot box method

at the University of Minnesota, a direct comparison can be made between calculated and tested values.

**Example 2:** Calculate the coefficient of heat transmission  $U$  for a wall shown in Fig. 6. Wall construction consists of two 4-in. concrete walls separated by a  $2\frac{1}{2}$ -in. space filled with insulation;  $\frac{1}{4}$ -in. diameter metal tie rods are imbedded a distance of 1 in. in each 4-in. concrete wall, and spaced 9 in. vertically and 12 in. horizontally. Values of  $k$  are: insulation 0.30, concrete 12.00, tie rods 400.00.

**Solution:** In Fig. 6 the following paths of heat flow from plane A to plane F will be noted:

1. From A to B: One path through 3 in. of concrete.
2. From B to C: Two paths, (a) through 1 in. of tie rod, and (b) through 1 in. of concrete.

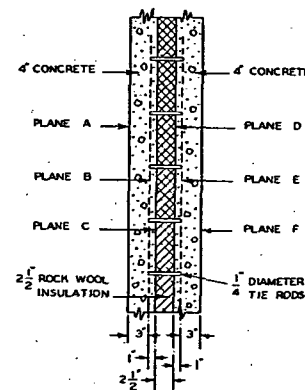


FIG. 6. SECTION OF CONCRETE WALL HAVING STEEL TIE RODS AND INSULATION

3. From C to D: Two paths, (a) through  $2\frac{1}{2}$  in. of tie rod, and (b) through  $2\frac{1}{2}$  in. of insulation.
4. From D to E: Two paths, (a) through 1 in. of tie rod, and (b) through 1 in. of concrete.
5. From E to F: One path through 3 in. of concrete.

It will be noted that items 2 and 4 are paths of similar flow, and could be treated as one. If equilibrium or steady state heat transfer is assumed, there will exist a temperature difference between the metal tie rod and the concrete, and also between the metal tie rod and the insulating material. The rate of heat transfer between these materials is dependent upon their conductivity values and the temperature difference. As the conductivity of the metal tie rods is considerably higher than that of the concrete or insulating material, it cannot be assumed that the same rate of heat transfer takes place for all parallel paths. Likewise, an appreciable error would be made by assuming that no heat transfer takes place between the metal tie rod and the surrounding materials. Although the pattern of the isotherms is unknown, the following method of calculation does partially take into account the heat flow between the metal tie rods and its bounding materials.

**Parallel Flow.** The conductances through the areas of parallel heat flow may be determined as follows:

1. The area of each  $\frac{1}{4}$ -in. diameter tie rod is 0.00034 sq ft, and as the tie rods are spaced 9 in. vertically, and 12 in. horizontally, there will be  $0.00034 \times \frac{4}{3} = 0.00045$  sq ft of tie rod to each square foot of wall area. Then from plane B to plane C, the conductance  $C_1$  is

$$C_1 = \frac{0.00045}{1.0} \times \frac{400}{1.0} + \frac{0.99955}{1.0} \times \frac{12}{1.0} = 0.180 + 11.994 = 12.174$$

2. For tie rod and insulation from plane C to plane D the conductance  $C_2$  is

$$C_2 = \frac{0.00045}{1.0} \times \frac{400}{2.5} + \frac{0.99952}{1.0} \times \frac{0.30}{2.5} = 0.072 + 0.120 = 0.192$$

3. For tie rod and concrete from plane D to plane E the conductance  $C_3$  is

$$C_3 = \frac{0.00045}{1.0} \times \frac{400}{1.0} + \frac{0.99952}{1.0} \times \frac{12}{1.0} = 0.180 + 11.994 = 12.174$$

*Series Flow.* After the conductance values have been determined, the total resistance and  $U$  value can be determined as follows:

$$R_T = \frac{1}{f_i} + \frac{x_1}{k_1} + \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{x_2}{k_2} + \frac{1}{f_o}$$

$$R_T = \frac{1}{1.65} + \frac{3.0}{12.0} + \frac{1}{12.174} + \frac{1}{0.192} + \frac{1}{12.174} + \frac{3.0}{12.0} + \frac{1}{6.0}$$

$$R_T = 0.606 + 0.250 + 0.0822 + 5.208 + 0.0822 + 0.250 + 0.167 = 6.727$$

$$U = \frac{1}{R_T} = \frac{1}{6.727} = 0.149 \text{ Btu per (hr) (sq ft) (F deg).}$$

The Hot Box test value, from *University of Minnesota*, for this wall, corrected for a 15 mph wind velocity, was  $U = 0.150$  Btu per (hr) (sq ft) (F deg). The error between the calculated and test values would be

$$\frac{0.150 - 0.149}{0.150} \times 100 = 1 \text{ percent.}$$

If the effect of the tie rods were omitted from the calculations, the overall  $U$  value would be 0.103. Although the percentage of area occupied by

the tie rods per square foot of wall area is  $\frac{0.00045}{1.0} \times 100 = 0.045$  percent, the error between the calculated and test values would be

$$\frac{0.150 - 0.103}{0.150} \times 100 = 31 \text{ percent.}$$

### Values Used in Calculation of $U$ Value Tables

In making the calculations for values of  $U$  shown in Tables 7 to 19, the following conditions have been assumed:

- Equilibrium or steady-state heat transfer, eliminating effects of heat capacity.
- Surrounding surfaces at ambient air temperatures.
- Exterior wind velocity of 15 mph for winter and 7.5 mph for summer.
- Surface emissivity of ordinary building materials = 0.83.
- Spaces between framing or furring not insulated. (See Table 6 for method of correcting for added insulation.)
- Air spaces are  $\frac{3}{4}$  in. or more in width.
- Variations of conductivity with mean temperature neglected.
- Corrections for framing to be made on basis of parallel heat flow through  $2 \times 4$  in. (nominal) studs, 16 in. on centers, the framing covering 15 per cent of wall area, as indicated in Fig. 5.
- Thermal resistance for gypsum board and insulating board apply equally to plain material and to those which may be decorated at the factory or on the job.

Actual thicknesses of lumber assumed to be as follows:

| Nominal                    | Actual             | Nominal                         | Actual             |
|----------------------------|--------------------|---------------------------------|--------------------|
| 1 in. (S-2-S)              | $\frac{3}{4}$ in.  | 3 in. (S-2-S)                   | $2\frac{3}{4}$ in. |
| $1\frac{1}{2}$ in. (S-2-S) | $1\frac{1}{8}$ in. | 4 in. (S-2-S)                   | $3\frac{3}{4}$ in. |
| 2 in. (S-2-S)              | $1\frac{1}{2}$ in. | Finish flooring, (maple or oak) | $\frac{1}{4}$ in.  |
| $2\frac{1}{2}$ in. (S-2-S) | $2\frac{1}{4}$ in. |                                 |                    |

Coefficients for frame construction are corrected for the effect of framing where such correction would increase the coefficients, but not where the correction would decrease the coefficients.<sup>11</sup>

It should be noted that the effects of poor workmanship in construction and installation have an increasingly greater percentage effect on heat transmission as the coefficient becomes numerically smaller. Failure to meet design estimates may be caused by lack of proper attention to exact compliance with specifications. A factor of safety may be employed as a precaution when it is judged desirable.

### Roof Coefficients

Computations for wood shingle roofs applied over wood stripping are based on 1 by 4 in. wood strips, spaced 2 in. apart. Values for roofs containing Spanish and French clay roofing tile are assumed the same as for slate roofs. Values for pitched roofs in Table 17 apply where the roof is over a heated attic or top floor, so that the heat passes directly through the roof structure, including any interior finish material.

### Combined Ceiling and Roof Coefficients

If the attic space between the ceiling and roof is unheated and not ventilated, the combined coefficient from room air below the ceiling to exterior air can be calculated from the following formula:

$$R_T = \frac{1}{U_{ce}} + \frac{1}{nU_r} \quad (4)$$

and

$$U = 1/R_T \quad (5)$$

where  $U$  = combined coefficient to be used with ceiling area.

$R_T$  = total resistance of ceiling and roof.

$U_{ce}$  = coefficient of transmission of ceiling.

$U_r$  = coefficient of transmission of roof.

$n$  = ratio of roof area to ceiling area.

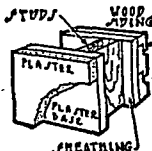
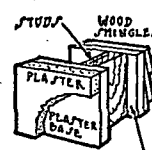
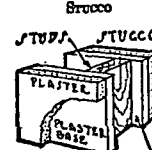
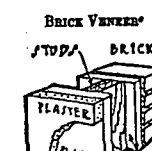
It should be noted that the overall coefficient  $U$  should be multiplied by the ceiling area to determine heat loss, and not by the roof area. Values of  $U_r$  and  $U_{ce}$  should be calculated using a value of 2.2 (the reciprocal of one-half the air space resistance) rather than 1.65 for the conductances of surfaces facing the attic, since the attic is equivalent to an air space.

If the attic contains windows, dormers and vertical wall spaces, and if their area is small compared to that of the roof, they may be considered part of the roof area. For accuracy, the sum of the coefficients of each individual section, multiplied by its percentage of the total area, should be used as  $U_r$ . Where attic wall areas are large, it is preferable to estimate the attic temperature as illustrated in Chapter 12, and calculate the heat loss through the ceiling by multiplying the value of  $U_{ce}$  for the ceiling by the difference in temperature above and below the ceiling.

TABLE 7. COEFFICIENTS OF TRANSMISSION (*U*) OF FRAME WALLS\*

These coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph.

NO INSULATION BETWEEN STUDS\* (SEE TABLE 6)

| EXTERIOR FINISH                                                                                                  | INTERIOR FINISH                                        | TYPE OF SHEATHING      |                         |                                  |                                  | WALL NUMBER |
|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|------------------------|-------------------------|----------------------------------|----------------------------------|-------------|
|                                                                                                                  |                                                        | Gypsum (1/2 in. thick) | Plywood (3/4 in. thick) | Wood (3/4 in. thick) Bldg. Paper | Insulating Board (1/2 in. thick) |             |
|                                                                                                                  |                                                        | A                      | B                       | C                                | D                                |             |
| <br>Wood Siding (Clapboard)     | Metal Lath and Plaster <sup>a</sup>                    | 0.33                   | 0.32                    | 0.26                             | 0.20                             | 1           |
|                                                                                                                  | Gypsum Board (1/2 in.) Decorated                       | 0.32                   | 0.32                    | 0.26                             | 0.20                             | 2           |
|                                                                                                                  | Wood Lath and Plaster                                  | 0.31                   | 0.31                    | 0.25                             | 0.19                             | 3           |
|                                                                                                                  | Gypsum Lath (1/2 in.) Plastered <sup>b</sup>           | 0.31                   | 0.30                    | 0.25                             | 0.19                             | 4           |
|                                                                                                                  | Plywood (3/4 in.) Plain or Decorated                   | 0.30                   | 0.30                    | 0.24                             | 0.19                             | 5           |
|                                                                                                                  | Insulating Board (1/2 in.) Plain or Decorated          | 0.29                   | 0.29                    | 0.19                             | 0.16                             | 6           |
|                                                                                                                  | Insulating Board Lath (1/2 in.) Plastered <sup>c</sup> | 0.23                   | 0.23                    | 0.19                             | 0.15                             | 7           |
|                                                                                                                  | Insulating Board Lath (1 in.) Plastered <sup>d</sup>   | 0.17                   | 0.17                    | 0.15                             | 0.12                             | 8           |
| <br>Wood Shingles               | Metal Lath and Plaster <sup>a</sup>                    | 0.25                   | 0.25                    | 0.26                             | 0.17                             | 9           |
|                                                                                                                  | Gypsum Board (1/2 in.) Decorated                       | 0.25                   | 0.25                    | 0.26                             | 0.17                             | 10          |
|                                                                                                                  | Wood Lath and Plaster                                  | 0.24                   | 0.24                    | 0.25                             | 0.16                             | 11          |
|                                                                                                                  | Gypsum Lath (1/2 in.) Plastered <sup>b</sup>           | 0.24                   | 0.24                    | 0.25                             | 0.16                             | 12          |
|                                                                                                                  | Plywood (3/4 in.) Plain or Decorated                   | 0.24                   | 0.24                    | 0.24                             | 0.16                             | 13          |
|                                                                                                                  | Insulating Board (1/2 in.) Plain or Decorated          | 0.19                   | 0.19                    | 0.19                             | 0.13                             | 14          |
|                                                                                                                  | Insulating Board Lath (1/2 in.) Plastered <sup>c</sup> | 0.19                   | 0.18                    | 0.19                             | 0.13                             | 15          |
|                                                                                                                  | Insulating Board Lath (1 in.) Plastered <sup>d</sup>   | 0.14                   | 0.14                    | 0.15                             | 0.11                             | 16          |
| <br>Stucco                    | Metal Lath and Plaster <sup>a</sup>                    | 0.43                   | 0.42                    | 0.32                             | 0.23                             | 17          |
|                                                                                                                  | Gypsum Board (1/2 in.) Decorated                       | 0.42                   | 0.41                    | 0.31                             | 0.22                             | 18          |
|                                                                                                                  | Wood Lath and Plaster                                  | 0.40                   | 0.39                    | 0.30                             | 0.22                             | 19          |
|                                                                                                                  | Gypsum Lath (1/2 in.) Plastered <sup>b</sup>           | 0.39                   | 0.39                    | 0.30                             | 0.22                             | 20          |
|                                                                                                                  | Plywood (3/4 in.) Plain or Decorated                   | 0.39                   | 0.38                    | 0.29                             | 0.22                             | 21          |
|                                                                                                                  | Insulating Board (1/2 in.) Plain or Decorated          | 0.27                   | 0.27                    | 0.22                             | 0.18                             | 22          |
|                                                                                                                  | Insulating Board Lath (1/2 in.) Plastered <sup>c</sup> | 0.26                   | 0.26                    | 0.22                             | 0.17                             | 23          |
|                                                                                                                  | Insulating Board Lath (1 in.) Plastered <sup>d</sup>   | 0.19                   | 0.19                    | 0.16                             | 0.14                             | 24          |
| <br>Brick Veneer <sup>e</sup> | Metal Lath and Plaster <sup>a</sup>                    | 0.37                   | 0.36                    | 0.28                             | 0.21                             | 25          |
|                                                                                                                  | Gypsum Board (1/2 in.) Decorated                       | 0.36                   | 0.36                    | 0.28                             | 0.21                             | 26          |
|                                                                                                                  | Wood Lath and Plaster                                  | 0.35                   | 0.34                    | 0.27                             | 0.20                             | 27          |
|                                                                                                                  | Gypsum Lath (1/2 in.) Plastered <sup>b</sup>           | 0.34                   | 0.34                    | 0.27                             | 0.20                             | 28          |
|                                                                                                                  | Plywood (3/4 in.) Plain or Decorated                   | 0.34                   | 0.33                    | 0.27                             | 0.20                             | 29          |
|                                                                                                                  | Insulating Board (1/2 in.) Plain or Decorated          | 0.25                   | 0.25                    | 0.21                             | 0.17                             | 30          |
|                                                                                                                  | Insulating Board Lath (1/2 in.) Plastered <sup>c</sup> | 0.24                   | 0.24                    | 0.20                             | 0.16                             | 31          |
|                                                                                                                  | Insulating Board Lath (1 in.) Plastered <sup>d</sup>   | 0.18                   | 0.18                    | 0.15                             | 0.13                             | 32          |

(See text p. 186.) \* See Table 5, Note a.

<sup>a</sup> Coefficients not weighted; effect of studding neglected.

<sup>b</sup> Plaster assumed 3/4 in. thick.

<sup>c</sup> Plaster assumed 1/2 in. thick.

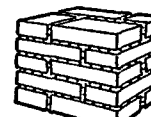
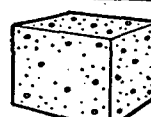
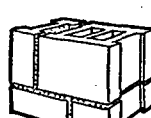
<sup>d</sup> Furring strips (1 in. nominal thickness) between wood shingles and all sheathings except wood.

<sup>e</sup> Small air space and mortar between building paper and brick veneer neglected.

<sup>f</sup> Nominal thickness, 1 in.

TABLE 8. COEFFICIENTS OF TRANSMISSION (*U*) OF MASONRY WALLS\*

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph.

| TYPE OF MASONRY                                                                                                                | THICKNESS OF MASONRY INCHES         | INTERIOR FINISH<br>(PLUS INSULATION WHERE INDICATED) |                            |                                     |                                                      |                                                     |                                                                   |                                                               |                                                             |                                                                         | WALL NUMBER |
|--------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|------------------------------------------------------|----------------------------|-------------------------------------|------------------------------------------------------|-----------------------------------------------------|-------------------------------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------------|-------------|
|                                                                                                                                |                                     | Plain Walls—No Interior Finish                       | Plaster (1/2 in.) on Walls | Metal Lath and Plaster <sup>a</sup> | Gypsum Board (1/2 in.) Decorated—Furred <sup>b</sup> | Gypsum Lath (1/2 in.) Plastered—Furred <sup>c</sup> | Insulating Board (1/2 in.) Plain or Decorated—Furred <sup>d</sup> | Insulating Board Lath (1/2 in.) Plastered—Furred <sup>e</sup> | Insulating Board Lath (1 in.) Plastered—Furred <sup>f</sup> | Gypsum Lath Plastered Plus 1 in. Blanket Insulation—Furred <sup>g</sup> |             |
|                                                                                                                                |                                     | A                                                    | B                          | C                                   | D                                                    | E                                                   | F                                                                 | G                                                             | H                                                           | I                                                                       |             |
| <br>Solid Brick                             | 8                                   | 0.50                                                 | 0.46 <sup>h</sup>          | 0.32                                | 0.31                                                 | 0.30                                                | 0.22                                                              | 0.22                                                          | 0.16                                                        | 0.14                                                                    | 67          |
|                                                                                                                                | 12                                  | 0.36                                                 | 0.34                       | 0.25                                | 0.25                                                 | 0.24                                                | 0.19                                                              | 0.19                                                          | 0.14                                                        | 0.13                                                                    | 68          |
|                                                                                                                                | 16                                  | 0.28                                                 | 0.27                       | 0.21                                | 0.21                                                 | 0.20                                                | 0.17                                                              | 0.16                                                          | 0.13                                                        | 0.12                                                                    | 69          |
| <br>Hollow Tile<br>(Stucco Exterior Finish) | 8                                   | 0.40                                                 | 0.37                       | 0.27                                | 0.27                                                 | 0.26                                                | 0.20                                                              | 0.20                                                          | 0.15                                                        | 0.13                                                                    | 70          |
|                                                                                                                                | 10                                  | 0.39                                                 | 0.37                       | 0.27                                | 0.27                                                 | 0.26                                                | 0.20                                                              | 0.19                                                          | 0.15                                                        | 0.13                                                                    | 71          |
|                                                                                                                                | 12                                  | 0.30                                                 | 0.28                       | 0.22                                | 0.22                                                 | 0.21                                                | 0.17                                                              | 0.17                                                          | 0.13                                                        | 0.12                                                                    | 72          |
| <br>Stone                                   | 8                                   | 0.70                                                 | 0.64                       | 0.39                                | 0.38                                                 | 0.36                                                | 0.26                                                              | 0.25                                                          | 0.18                                                        | 0.16                                                                    | 74          |
|                                                                                                                                | 12                                  | 0.57                                                 | 0.53                       | 0.35                                | 0.34                                                 | 0.33                                                | 0.24                                                              | 0.23                                                          | 0.17                                                        | 0.15                                                                    | 75          |
|                                                                                                                                | 16                                  | 0.49                                                 | 0.45                       | 0.31                                | 0.31                                                 | 0.29                                                | 0.22                                                              | 0.22                                                          | 0.16                                                        | 0.14                                                                    | 76          |
| <br>Poured Concrete                        | 8                                   | 0.79                                                 | 0.71                       | 0.42                                | 0.41                                                 | 0.39                                                | 0.27                                                              | 0.26                                                          | 0.19                                                        | 0.16                                                                    | 78          |
|                                                                                                                                | 10                                  | 0.70                                                 | 0.64                       | 0.39                                | 0.38                                                 | 0.36                                                | 0.26                                                              | 0.25                                                          | 0.18                                                        | 0.16                                                                    | 79          |
|                                                                                                                                | 12                                  | 0.63                                                 | 0.58                       | 0.37                                | 0.36                                                 | 0.34                                                | 0.25                                                              | 0.24                                                          | 0.18                                                        | 0.15                                                                    | 80          |
| <br>Hollow Concrete Blocks                | 8                                   | 0.56                                                 | 0.52                       | 0.34                                | 0.34                                                 | 0.32                                                | 0.24                                                              | 0.23                                                          | 0.17                                                        | 0.15                                                                    | 82          |
|                                                                                                                                | 12                                  | 0.49                                                 | 0.46                       | 0.32                                | 0.31                                                 | 0.30                                                | 0.22                                                              | 0.22                                                          | 0.16                                                        | 0.14                                                                    | 83          |
|                                                                                                                                | Gravel Aggregate                    |                                                      |                            |                                     |                                                      |                                                     |                                                                   |                                                               |                                                             |                                                                         |             |
|                                                                                                                                | 8                                   | 0.41                                                 | 0.39                       | 0.28                                | 0.28                                                 | 0.27                                                | 0.21                                                              | 0.20                                                          | 0.15                                                        | 0.13                                                                    | 84          |
|                                                                                                                                | 12                                  | 0.38                                                 | 0.36                       | 0.26                                | 0.26                                                 | 0.25                                                | 0.20                                                              | 0.19                                                          | 0.15                                                        | 0.13                                                                    | 85          |
|                                                                                                                                | Cinder Aggregate                    |                                                      |                            |                                     |                                                      |                                                     |                                                                   |                                                               |                                                             |                                                                         |             |
|                                                                                                                                | 8                                   | 0.36                                                 | 0.34                       | 0.26                                | 0.25                                                 | 0.24                                                | 0.19                                                              | 0.19                                                          | 0.15                                                        | 0.13                                                                    | 86          |
|                                                                                                                                | 12                                  | 0.34                                                 | 0.33                       | 0.25                                | 0.24                                                 | 0.24                                                | 0.19                                                              | 0.18                                                          | 0.14                                                        | 0.13                                                                    | 87          |
|                                                                                                                                | Light Weight Aggregate <sup>g</sup> |                                                      |                            |                                     |                                                      |                                                     |                                                                   |                                                               |                                                             |                                                                         |             |
|                                                                                                                                | 8                                   | 0.36                                                 | 0.34                       | 0.26                                | 0.25                                                 | 0.24                                                | 0.19                                                              | 0.19                                                          | 0.15                                                        | 0.13                                                                    | 88          |
|                                                                                                                                | 12                                  | 0.34                                                 | 0.33                       | 0.25                                | 0.24                                                 | 0.24                                                | 0.19                                                              | 0.18                                                          | 0.14                                                        | 0.13                                                                    | 89          |

(See text p. 186.) \* See Table 5 Note a.

<sup>a</sup> Based on 4 in. hard brick and remainder common brick.

<sup>b</sup> The 8 in. and 10 in. tile figures are based on two cells in the direction of heat flow. The 12 in. tile is based on three cells in the direction of heat flow. The 16 in. tile consists of one 10 in. and one 6 in. tile, each having two cells in the direction of heat flow.

<sup>c</sup> Limestone or sandstone.

<sup>d</sup> These figures may be used with sufficient accuracy for concrete walls with stucco exterior finish.

<sup>e</sup> Expanded slag, burned clay or pumice.

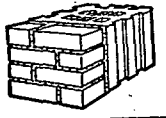
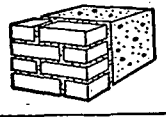
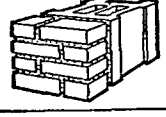
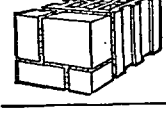
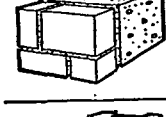
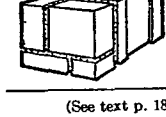
<sup>f</sup> Thickness of plaster assumed 1/2 in.

<sup>g</sup> Thickness of plaster assumed 1/2 in.

<sup>h</sup> Based on 2 in. furring strips; one air space.

TABLE 9. COEFFICIENTS OF TRANSMISSION (*U*) OF BRICK AND STONE VENEER MASONRY WALLS\*

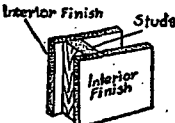
Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph.

| TYPICAL CONSTRUCTION                                                                | FACING                              | BACKING                                                                  | INTERIOR FINISH<br>(PLUS INSULATION WHERE INDICATED) |                          |                                            |                                                    |                                                   |                                                                 |                                                             |                                                             |                                                                         |
|-------------------------------------------------------------------------------------|-------------------------------------|--------------------------------------------------------------------------|------------------------------------------------------|--------------------------|--------------------------------------------|----------------------------------------------------|---------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------------|
|                                                                                     |                                     |                                                                          | Plain Walls—no Interior Finish                       | Plaster (½ in.) on Walls | Metal Lath and Plaster—Furred <sup>d</sup> | Gypsum Board (½ in.) Decorated—Furred <sup>d</sup> | Gypsum Lath (¾ in.) Plastered—Furred <sup>d</sup> | Insulating Board (¾ in.) Plain or Decorated—Furred <sup>d</sup> | Insulating Board Lath (¾ in.) Plastered—Furred <sup>d</sup> | Insulating Board Lath (1 in.) Plastered—Furred <sup>d</sup> | Gypsum Lath Plastered Plus 1 in. Blanket Insulation—Furred <sup>d</sup> |
|                                                                                     |                                     |                                                                          |                                                      |                          |                                            |                                                    |                                                   |                                                                 |                                                             |                                                             |                                                                         |
|                                                                                     |                                     |                                                                          | A                                                    | B                        | C                                          | D                                                  | E                                                 | F                                                               | G                                                           | H                                                           | I                                                                       |
|    |                                     | 8 in. Hollow Tile <sup>a</sup>                                           | 0.35                                                 | 0.34                     | 0.25                                       | 0.25                                               | 0.24                                              | 0.19                                                            | 0.18                                                        | 0.14                                                        | 0.13                                                                    |
|                                                                                     |                                     | 8 in. Hollow Tile <sup>b</sup>                                           | 0.34                                                 | 0.33                     | 0.25                                       | 0.24                                               | 0.23                                              | 0.19                                                            | 0.18                                                        | 0.14                                                        | 0.13                                                                    |
|    | 4 in. Brick Veneer <sup>a</sup>     | 6 in. Concrete                                                           | 0.59                                                 | 0.54                     | 0.35                                       | 0.35                                               | 0.33                                              | 0.24                                                            | 0.23                                                        | 0.17                                                        | 0.15                                                                    |
|                                                                                     |                                     | 8 in. Concrete                                                           | 0.54                                                 | 0.50                     | 0.33                                       | 0.33                                               | 0.31                                              | 0.23                                                            | 0.23                                                        | 0.17                                                        | 0.15                                                                    |
|   |                                     | 8 in. Concrete Blocks <sup>a</sup> (Gravel Aggregate)                    | 0.44                                                 | 0.41                     | 0.29                                       | 0.29                                               | 0.28                                              | 0.21                                                            | 0.21                                                        | 0.16                                                        | 0.14                                                                    |
|                                                                                     |                                     | 8 in. Concrete Blocks <sup>a</sup> (Cinder Aggregate)                    | 0.34                                                 | 0.33                     | 0.25                                       | 0.24                                               | 0.24                                              | 0.19                                                            | 0.18                                                        | 0.14                                                        | 0.13                                                                    |
|                                                                                     |                                     | 8 in. Concrete Blocks <sup>a</sup> (Light Weight Aggregate) <sup>c</sup> | 0.31                                                 | 0.29                     | 0.23                                       | 0.23                                               | 0.22                                              | 0.18                                                            | 0.17                                                        | 0.14                                                        | 0.12                                                                    |
|                                                                                     |                                     |                                                                          |                                                      |                          |                                            |                                                    |                                                   |                                                                 |                                                             |                                                             |                                                                         |
|  |                                     | 8 in. Hollow Tile <sup>a</sup>                                           | 0.37                                                 | 0.35                     | 0.26                                       | 0.26                                               | 0.25                                              | 0.19                                                            | 0.19                                                        | 0.15                                                        | 0.13                                                                    |
|                                                                                     |                                     | 8 in. Hollow Tile <sup>b</sup>                                           | 0.36                                                 | 0.34                     | 0.25                                       | 0.25                                               | 0.24                                              | 0.19                                                            | 0.19                                                        | 0.14                                                        | 0.13                                                                    |
|  | 4 in. Cut Stone Veneer <sup>a</sup> | 6 in. Concrete                                                           | 0.63                                                 | 0.58                     | 0.37                                       | 0.36                                               | 0.24                                              | 0.25                                                            | 0.24                                                        | 0.18                                                        | 0.15                                                                    |
|                                                                                     |                                     | 8 in. Concrete                                                           | 0.57                                                 | 0.53                     | 0.35                                       | 0.34                                               | 0.33                                              | 0.24                                                            | 0.23                                                        | 0.17                                                        | 0.15                                                                    |
|  |                                     | 8 in. Concrete Blocks <sup>a</sup> (Gravel Aggregate)                    | 0.47                                                 | 0.44                     | 0.30                                       | 0.30                                               | 0.29                                              | 0.22                                                            | 0.21                                                        | 0.16                                                        | 0.14                                                                    |
|                                                                                     |                                     | 8 in. Concrete Blocks <sup>a</sup> (Cinder Aggregate)                    | 0.36                                                 | 0.34                     | 0.25                                       | 0.25                                               | 0.24                                              | 0.19                                                            | 0.19                                                        | 0.15                                                        | 0.13                                                                    |
|                                                                                     |                                     | 8 in. Concrete Blocks <sup>a</sup> (Light Weight Aggregate) <sup>c</sup> | 0.32                                                 | 0.30                     | 0.23                                       | 0.23                                               | 0.22                                              | 0.18                                                            | 0.17                                                        | 0.14                                                        | 0.12                                                                    |
|                                                                                     |                                     |                                                                          |                                                      |                          |                                            |                                                    |                                                   |                                                                 |                                                             |                                                             |                                                                         |

(See text p. 186). \* See Table 5, Note a.

<sup>a</sup> Calculation based on ½ in. cement mortar between backing and facing, except in the case of the concrete backing which is assumed to be poured in place.<sup>b</sup> The hollow tile figures are based on two air cells in the direction of heat flow.<sup>c</sup> Hollow concrete blocks.<sup>d</sup> Expanded slag, burned clay or pumice.<sup>e</sup> Thickness of plaster assumed ½ in.<sup>f</sup> Thickness of plaster assumed ¾ in.<sup>g</sup> Based on 2 in. furring strips; one air space.TABLE 10. COEFFICIENTS OF TRANSMISSION (*U*) OF FRAME PARTITIONS OR INTERIOR WALLS\*

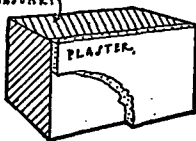
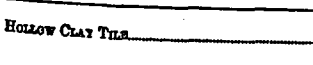
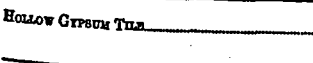
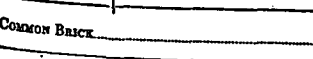
Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on still air (no wind) conditions on both sides.

| INTERIOR<br>FINISH                                   |  | SINGLE<br>PARTITION<br>(Finish on one<br>side only of studs) | DOUBLE PARTITION<br>(Finish on both sides of studs) |                                                                |   | PARTITION NUMBER |
|------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------|-----------------------------------------------------|----------------------------------------------------------------|---|------------------|
|                                                      |                                                                                     |                                                              | No INSULATION<br>BETWEEN STUDS                      | 1 IN. BLANKET <sup>d</sup><br>BETWEEN STUDS.<br>ONE AIR SPACE. | C |                  |
|                                                      |                                                                                     |                                                              |                                                     |                                                                |   |                  |
|                                                      |                                                                                     | A                                                            | B                                                   | C                                                              |   |                  |
| Metal Lath and Plaster <sup>a</sup>                  |                                                                                     | 0.69                                                         | 0.39                                                | 0.16                                                           | 1 |                  |
| Gypsum Board (½ in.) Decorated                       |                                                                                     | 0.67                                                         | 0.37                                                | 0.16                                                           | 2 |                  |
| Wood Lath and Plaster                                |                                                                                     | 0.62                                                         | 0.34                                                | 0.15                                                           | 3 |                  |
| Gypsum Lath (¾ in.) Plastered <sup>a</sup>           |                                                                                     | 0.61                                                         | 0.34                                                | 0.15                                                           | 4 |                  |
| Plywood (¾ in.) Plain or Decorated                   |                                                                                     | 0.59                                                         | 0.33                                                | 0.15                                                           | 5 |                  |
| Insulating Board (¾ in.) Plain or Decorated          |                                                                                     | 0.36                                                         | 0.19                                                | 0.11                                                           | 6 |                  |
| Insulating Board Lath (¾ in.) Plastered <sup>a</sup> |                                                                                     | 0.35                                                         | 0.18                                                | 0.11                                                           | 7 |                  |
| Insulating Board Lath (1 in.) Plastered <sup>a</sup> |                                                                                     | 0.23                                                         | 0.12                                                | 0.082                                                          | 8 |                  |

(See text p. 186). \* See Table 5, Note a.

<sup>a</sup> Coefficients not weighted; effect of studding neglected.<sup>b</sup> Plaster assumed ½ in. thick.<sup>c</sup> Plaster assumed ¾ in. thick.<sup>d</sup> For partitions with other insulations between studs refer to Table 6, using values in Column B of above table, in left-hand column of Table 6. Example: What is the coefficient of transmission (*U*) of a partition consisting of gypsum lath and plaster on both sides of studs with 2 in. blanket between studs? Solution: According to above table, this partition with no insulation between studs (No. 4B) has a coefficient of 0.34. Referring to Table 6, it will be found that a wall having a coefficient of 0.34 with no insulation between studs, will have a coefficient of 0.10 (approx.) with 2 in. of blanket insulation between studs (No. 56B).TABLE 11. COEFFICIENTS OF TRANSMISSION (*U*) OF MASONRY PARTITIONS\*

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on still air (no wind) conditions on both sides.

| TYPE OF PARTITION                       |   | THICKNESS OF MASONRY<br>(INCHES) | TYPE OF FINISH                |                        |                                       | PARTITION NUMBER |
|-----------------------------------------|---------------------------------------------------------------------------------------|----------------------------------|-------------------------------|------------------------|---------------------------------------|------------------|
|                                         |                                                                                       |                                  | No<br>FINISH<br>(Plain walls) | PLASTER<br>ONE<br>SIDE | PLASTER<br>BOTH<br>SIDES <sup>a</sup> |                  |
|                                         |                                                                                       |                                  | A                             | B                      | C                                     |                  |
| HOLLOW CLAY TILE                        |  | 3                                | 0.50                          | 0.47                   | 0.43                                  | 9                |
|                                         |                                                                                       | 4                                | 0.45                          | 0.42                   | 0.40                                  |                  |
| HOLLOW GYPSUM TILE                      |  | 3                                | 0.35                          | 0.33                   | 0.32                                  | 11               |
|                                         |                                                                                       | 4                                | 0.29                          | 0.28                   | 0.27                                  |                  |
| HOLLOW<br>CONCRETE<br>TILE OR<br>BLOCKS | Cinder Aggregate                                                                      | 3                                | 0.50                          | 0.47                   | 0.43                                  | 13               |
|                                         |                                                                                       | 4                                | 0.45                          | 0.42                   | 0.40                                  |                  |
|                                         | Light Weight Aggregate <sup>b</sup>                                                   | 3                                | 0.41                          | 0.39                   | 0.37                                  | 15               |
|                                         |                                                                                       | 4                                | 0.35                          | 0.34                   | 0.32                                  |                  |
| COMMON BRICK                            |  | 4                                | 0.50                          | 0.46                   | 0.43                                  | 17               |

(See text p. 186). \* See Table 5, Note a.

<sup>a</sup> 2 in. solid plaster partition, *U* = 0.53.<sup>b</sup> Expanded slag, burned clay or pumice.

TABLE 12. COEFFICIENTS OF TRANSMISSION ( $U$ ) OF FRAME CONSTRUCTION CEILINGS AND FLOORS\*

TABLE 12. COEFFICIENTS OF TRANSMISSION (U) OF FRAME CONSTRUCTION CEILINGS AND FLOORS  
Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference between the air on the two sides) and are based on still air (no wind) conditions on both sides.

TYPE OF CEILING

| TYPE OF CEILING                               | INSULATION BETWEEN, OR ON TOP OF, JOISTS<br>(No Flooring Above) | WITH FLOORING*<br>(On Top of Ceiling Joists) | NUMBER |                                           |       |                                       |       |                                        |       |       |       |  |
|-----------------------------------------------|-----------------------------------------------------------------|----------------------------------------------|--------|-------------------------------------------|-------|---------------------------------------|-------|----------------------------------------|-------|-------|-------|--|
|                                               | Insulating Board on Top of Joists                               |                                              |        | Blanket or Bat Insulation/ Between Joists |       | Vermiculite Insulation Between Joists |       | Mineral Wool Insulation Between Joists |       |       |       |  |
|                                               | 1 in.                                                           | 2 in.                                        |        | 1 in.                                     | 2 in. | 1 in.                                 | 2 in. | 1 in.                                  | 2 in. | 3 in. | 4 in. |  |
| No Ceiling                                    | 0.99                                                            | 0.69                                         | 0.24   | 0.19                                      | 0.12  | 0.093                                 | 0.11  | 0.12                                   | 0.093 | 0.077 |       |  |
| Metal Lath and Plaster                        | 0.67                                                            | 0.38                                         | 0.18   | 0.19                                      | 0.12  | 0.082                                 | 0.13  | 0.10                                   | 0.092 | 0.077 |       |  |
| Gypsum Board (1/2 in.) Plain or Decorated     | 0.52                                                            | 0.28                                         | 0.13   | 0.19                                      | 0.12  | 0.081                                 | 0.17  | 0.13                                   | 0.10  | 0.091 | 0.076 |  |
| Wood Lath and Plaster                         | 0.51                                                            | 0.28                                         | 0.13   | 0.19                                      | 0.12  | 0.081                                 | 0.17  | 0.13                                   | 0.10  | 0.091 | 0.076 |  |
| Gypsum Lath (1/4 in.) Plastered               | 0.49                                                            | 0.24                                         | 0.18   | 0.19                                      | 0.12  | 0.081                                 | 0.17  | 0.13                                   | 0.10  | 0.091 | 0.076 |  |
| Plywood (1/2 in.) Plain or Decorated          | 0.39                                                            | 0.19                                         | 0.15   | 0.19                                      | 0.10  | 0.083                                 | 0.14  | 0.12                                   | 0.097 | 0.10  | 0.082 |  |
| Insulating Board (1/2 in.) Plain or Decorated | 0.35                                                            | 0.19                                         | 0.15   | 0.19                                      | 0.10  | 0.081                                 | 0.14  | 0.11                                   | 0.096 | 0.10  | 0.082 |  |
| Insulating Board Lath (1/4 in.) Plastered     | 0.23                                                            | 0.16                                         | 0.12   | 0.12                                      | 0.089 | 0.072                                 | 0.13  | 0.097                                  | 0.094 | 0.073 | 0.061 |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
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|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
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|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
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|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |
|                                               |                                                                 |                                              |        |                                           |       |                                       |       |                                        |       |       |       |  |

(See text p. 189). \* See Table 5, Note a.

a Coefficient corrected for framing on basis of 15 percent area, 2 in. x 4 in. (nominal) framing, 16 in. on centers.

b 1/2 in. yellow pine or fir.

c 1/2 in. pine or fir sub-flooring plus 1/2 in. hardwood finish flooring.

d Plaster assumed 1/2 in. thick.

e Plaster assumed 1/2 in. thick.

f Based on insulation in contact with ceiling, and consequently no air space between.

g For coefficients for constructions in Columns M and N (except No. 1) with insulation between joists, refer to Table 6. Example: The coefficient for No. 3-N of Table 12 is 0.24. With 2 in. blanket insulation between joists, the coefficient will be 0.083. (See Table 6). Column D of Table 6 applicable only for 3/4 in. joists.

h For 1/2 in. insulating board sheathing applied to the under side of the joists, the coefficient for single wood floor (Column M) is 0.18 and for double wood floor (Column N) is 0.10.

i For coefficients with insulation between joists, see Table 6.

TABLE 13. COEFFICIENTS OF TRANSMISSION ( $U$ ) OF CONCRETE CONSTRUCTION FLOORS AND CEILINGS\*

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on still air (no wind) conditions on both sides.

| TYPE OF CEILING                                                 | THICKNESS OF CONCRETE (INCHES) | TYPE OF FLOORING            |                                       |                                           |                                        |                               | NUMBER |
|-----------------------------------------------------------------|--------------------------------|-----------------------------|---------------------------------------|-------------------------------------------|----------------------------------------|-------------------------------|--------|
|                                                                 |                                | No Flooring (Concrete Bare) | Tile or Terrazzo Flooring on Concrete | 1/2 in. Asphalt Tile Directly on Concrete | Parquet Flooring in Mastic on Concrete | Double Wood Floor on Sleepers |        |
|                                                                 |                                | A                           | B                                     | C                                         | D                                      | E                             |        |
| No Ceiling                                                      | 3                              | 0.68                        | 0.65                                  | 0.66                                      | 0.45                                   | 0.25                          | 1      |
|                                                                 | 6                              | 0.59                        | 0.56                                  | 0.58                                      | 0.41                                   | 0.23                          | 2      |
|                                                                 | 10                             | 0.50                        | 0.48                                  | 0.49                                      | 0.36                                   | 0.22                          | 3      |
| 1/2 in. Plaster Applied to Underside of Concrete                | 3                              | 0.62                        | 0.59                                  | 0.60                                      | 0.43                                   | 0.24                          | 4      |
|                                                                 | 6                              | 0.54                        | 0.52                                  | 0.53                                      | 0.39                                   | 0.22                          | 5      |
|                                                                 | 10                             | 0.46                        | 0.44                                  | 0.45                                      | 0.34                                   | 0.21                          | 6      |
| Metal Lath and Plaster—Suspended or Furred                      | 3                              | 0.38                        | 0.37                                  | 0.37                                      | 0.30                                   | 0.19                          | 7      |
|                                                                 | 6                              | 0.35                        | 0.34                                  | 0.35                                      | 0.28                                   | 0.18                          | 8      |
|                                                                 | 10                             | 0.32                        | 0.31                                  | 0.32                                      | 0.26                                   | 0.17                          | 9      |
| Gypsum Board (1/2 in.) and Plaster—Suspended or Furred          | 3                              | 0.36                        | 0.35                                  | 0.35                                      | 0.28                                   | 0.19                          | 10     |
|                                                                 | 6                              | 0.32                        | 0.32                                  | 0.33                                      | 0.27                                   | 0.18                          | 11     |
|                                                                 | 10                             | 0.30                        | 0.29                                  | 0.30                                      | 0.24                                   | 0.17                          | 12     |
| Insulating Board Lath (1/2 in.) and Plaster—Suspended or Furred | 3                              | 0.25                        | 0.24                                  | 0.25                                      | 0.21                                   | 0.15                          | 13     |
|                                                                 | 6                              | 0.23                        | 0.23                                  | 0.23                                      | 0.20                                   | 0.15                          | 14     |
|                                                                 | 10                             | 0.22                        | 0.21                                  | 0.22                                      | 0.19                                   | 0.14                          | 15     |

\* Thickness of tile assumed to be 1 in. \* See Table 5, Note a.

b Conductivity of asphalt tile assumed to be 3.1.

c Thickness of wood assumed to be 1/2 in.; thickness of mastic, 1/2 in. (k = 4.5). Col. D may also be used for concrete covered with carpet.

d Based on 1/2 in. yellow pine or fir sub-flooring and 1/2 in. hardwood finish flooring with an air space between sub-floor and concrete.

e Thickness of plaster assumed to be 1/2 in.

f Thickness of plaster assumed to be 1/2 in.

g For other thickness of concrete, interpolate.

TABLE 14. COEFFICIENTS OF TRANSMISSION ( $U$ ) OF CONCRETE BASEMENT FLOORS ON GROUND WITH VARIOUS TYPES OF FINISH FLOORING

$U = 0.10$  Btu per (hr) (sq ft) (Fahrenheit degree temperature difference between the ground and the air over the floor).

\* Since authentic data are not available, this coefficient is sometimes used for concrete floors on ground. For more recent procedures refer to National Bureau of Standards Report BMS-103, 11, 12.

### Basement Floor, Basement Wall and Concrete Slab Floor Coefficients

The heat transfer through basement walls and floors to the ground is dependent on the temperature difference between the air within and that of the ground, on the material constituting the wall or floor, and on the conductivity of the surrounding earth. The conductivity of the earth will vary with local conditions, and is usually unknown. Tests<sup>12</sup> at the A.S.H.A.E. Research Laboratory indicate a heat flow of approximately 2.0 Btu per (hr) (sq ft) through an uninsulated concrete basement floor, with a temperature difference of 20 deg between ground temperature and the air temperature 6 in. above the floor. Based on this result a coefficient of 0.10 Btu per (hr) (sq ft) (Fahrenheit degree difference) is recommended for calculation where it is desirable to allow for the small basement floor heat loss, e.g., for heated basements.

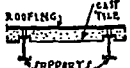
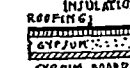
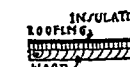
For basement walls the same coefficient may be used, but due to closer proximity to the surface of the ground, the temperature difference for win-



TABLE 15. COEFFICIENTS OF TRANSMISSION (*U*) OF FLAT ROOFS COVERED WITH BUILT-UP ROOFING. NO CEILING—UNDER SIDE OF ROOF EXPOSED\*

(See Table 16 for Flat Roofs with Ceilings)

These coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph.

| TYPE OF ROOF DECK                                                                   | THICK-<br>NESS OF<br>ROOF<br>DECK<br>(INCHES) | NO IN-<br>SULA-<br>TION | INSULATION ON TOP OF DECK<br>(COVERED WITH BUILT-UP ROOFING) |       |           |       |       |                                |       |       | NUM-<br>BER |
|-------------------------------------------------------------------------------------|-----------------------------------------------|-------------------------|--------------------------------------------------------------|-------|-----------|-------|-------|--------------------------------|-------|-------|-------------|
|                                                                                     |                                               |                         | INSULATING BOARD<br>(Thickness Below)                        |       |           |       |       | CORKBOARD<br>(Thickness Below) |       |       |             |
|                                                                                     |                                               |                         | 1/2 In.                                                      | 1 In. | 1 1/2 In. | 2 In. | 1 In. | 1 1/2 In.                      | 2 In. |       |             |
|                                                                                     |                                               |                         | A                                                            | B     | C         | D     | E     | F                              | G     | H     |             |
| Flat Metal Roof Deck <sup>a</sup>                                                   |                                               |                         |                                                              |       |           |       |       |                                |       |       |             |
|    |                                               |                         | 0.94                                                         | 0.39  | 0.24      | 0.18  | 0.14  | 0.23                           | 0.17  | 0.13  |             |
| Precast Cement Tile                                                                 |                                               |                         |                                                              |       |           |       |       |                                |       |       |             |
|    | 1 1/2 in.                                     |                         | 0.84                                                         | 0.3   | 0.24      | 0.17  | 0.14  | 0.22                           | 0.16  | 0.13  | 2           |
| Concrete                                                                            |                                               |                         |                                                              |       |           |       |       |                                |       |       |             |
|   | 2 in.                                         |                         | 0.82                                                         | 0.36  | 0.24      | 0.17  | 0.14  | 0.22                           | 0.16  | 0.13  | 3           |
|                                                                                     | 4 in.                                         |                         | 0.72                                                         | 0.34  | 0.23      | 0.17  | 0.13  | 0.21                           | 0.16  | 0.12  | 4           |
|                                                                                     | 6 in.                                         |                         | 0.65                                                         | 0.33  | 0.22      | 0.16  | 0.13  | 0.21                           | 0.15  | 0.12  | 5           |
| Gypsum Fiber Concrete <sup>b</sup><br>on 1/2 in. Gypsum Board                       |                                               |                         |                                                              |       |           |       |       |                                |       |       |             |
|  | 2 1/2 in.                                     |                         | 0.38                                                         | 0.24  | 0.18      | 0.14  | 0.12  | 0.17                           | 0.13  | 0.11  | 6           |
|                                                                                     | 3 1/2 in.                                     |                         | 0.31                                                         | 0.21  | 0.16      | 0.13  | 0.11  | 0.15                           | 0.12  | 0.10  | 7           |
| Wood <sup>c</sup>                                                                   |                                               |                         |                                                              |       |           |       |       |                                |       |       |             |
|  | 1 in.                                         |                         | 0.49                                                         | 0.28  | 0.20      | 0.15  | 0.12  | 0.19                           | 0.14  | 0.12  | 8           |
|                                                                                     | 1 1/2 in.                                     |                         | 0.37                                                         | 0.24  | 0.17      | 0.14  | 0.11  | 0.17                           | 0.13  | 0.11  | 9           |
|                                                                                     | 2 in.                                         |                         | 0.32                                                         | 0.22  | 0.16      | 0.13  | 0.11  | 0.16                           | 0.12  | 0.10  | 10          |
|                                                                                     | 3 in.                                         |                         | 0.23                                                         | 0.17  | 0.14      | 0.11  | 0.096 | 0.13                           | 0.11  | 0.091 | 11          |

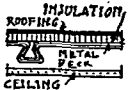
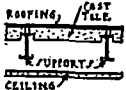
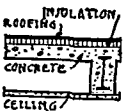
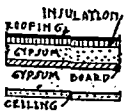
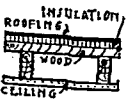
\* See Table 5, Note a.

\* Coefficient of transmission of bare corrugated iron (no roofing) is 1.50 Btu per (hr) (sq ft of projected area) (F deg difference in temperature) based on an outside wind velocity of 15 mph.

<sup>b</sup> 67 1/2 percent gypsum, 12 1/2 percent wood fiber. Thickness indicated includes 1/2 in. gypsum board.<sup>c</sup> Nominal thicknesses specified—actual thicknesses used in calculations.TABLE 16. COEFFICIENTS OF TRANSMISSION (*U*) OF FLAT ROOFS COVERED WITH BUILT-UP ROOFING. WITH LATH AND PLASTER CEILINGS\*

(See Table 15 for Flat Roofs with No Ceilings)

These coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph.

| TYPE OF ROOF DECK                                                                     | THICK-<br>NESS OF<br>ROOF<br>DECK<br>(INCHES) | NO IN-<br>SULA-<br>TION      | INSULATION ON TOP OF DECK<br>(COVERED WITH BUILT-UP ROOFING) |                              |                              |                                |                                |                               |                                 |                      | NUM-<br>BER |
|---------------------------------------------------------------------------------------|-----------------------------------------------|------------------------------|--------------------------------------------------------------|------------------------------|------------------------------|--------------------------------|--------------------------------|-------------------------------|---------------------------------|----------------------|-------------|
|                                                                                       |                                               |                              | INSULATING BOARD<br>(Thickness Below)                        |                              |                              |                                | CORKBOARD<br>(Thickness Below) |                               |                                 |                      |             |
|                                                                                       |                                               |                              | 1 In.                                                        | 1 In.                        | 1½ In.                       | 2 In.                          | 1 In.                          | 1½ In.                        | 2 In.                           |                      |             |
|                                                                                       |                                               |                              | A                                                            | B                            | C                            | D                              | E                              | F                             | G                               | H                    |             |
| Flat Metal Roof Deck                                                                  |                                               |                              |                                                              |                              |                              |                                |                                |                               |                                 |                      |             |
|    |                                               | 0.46                         | 0.27                                                         | 0.19                         | 0.15                         | 0.12                           | 0.18                           | 0.14                          | 0.11                            | 12                   |             |
| Precast Cement Tile                                                                   |                                               |                              |                                                              |                              |                              |                                |                                |                               |                                 |                      |             |
|    | 1½ in.                                        | 0.43                         | 0.26                                                         | 0.19                         | 0.15                         | 0.12                           | 0.18                           | 0.14                          | 0.11                            | 13                   |             |
| Concrete                                                                              |                                               |                              |                                                              |                              |                              |                                |                                |                               |                                 |                      |             |
|   | 2 in.<br>4 in.<br>6 in.                       | 0.42<br>0.40<br>0.37         | 0.26<br>0.25<br>0.24                                         | 0.19<br>0.18<br>0.18         | 0.14<br>0.14<br>0.14         | 0.12<br>0.12<br>0.11           | 0.18<br>0.17<br>0.17           | 0.14<br>0.13<br>0.13          | 0.11<br>0.11<br>0.11            | 14<br>15<br>16       |             |
| Gypsum Fiber Concrete <sup>b</sup><br>on ½ in. Gypsum Board                           |                                               |                              |                                                              |                              |                              |                                |                                |                               |                                 |                      |             |
|  | 2½ in.<br>3½ in.                              | 0.27<br>0.23                 | 0.19<br>0.17                                                 | 0.15<br>0.14                 | 0.12<br>0.11                 | 0.10<br>0.097                  | 0.14<br>0.13                   | 0.12<br>0.11                  | 0.097<br>0.091                  | 17<br>18             |             |
| Wood <sup>c</sup>                                                                     |                                               |                              |                                                              |                              |                              |                                |                                |                               |                                 |                      |             |
|  | 1 in.<br>1½ in.<br>2 in.<br>3 in.             | 0.31<br>0.26<br>0.24<br>0.18 | 0.21<br>0.19<br>0.17<br>0.14                                 | 0.16<br>0.15<br>0.14<br>0.12 | 0.13<br>0.12<br>0.11<br>0.10 | 0.11<br>0.10<br>0.097<br>0.087 | 0.15<br>0.14<br>0.13<br>0.11   | 0.12<br>0.11<br>0.11<br>0.095 | 0.10<br>0.095<br>0.092<br>0.083 | 19<br>20<br>21<br>22 |             |

\* See Table 5, Note a.

\* Calculations based on metal lath and plaster ceilings, but coefficients may be used with sufficient accuracy for gypsum lath or wood lath and plaster ceilings. It is assumed that there is an air space between the under side of the roof deck and the upper side of the ceiling.

<sup>b</sup> 67 1/2 percent gypsum, 12 1/2 percent wood fiber. Thickness indicated includes 1/2 in. gypsum board.<sup>c</sup> Nominal thicknesses specified—actual thicknesses used in calculations.

TABLE 17. COEFFICIENTS OF TRANSMISSION ( $U$ ) OF PITCHED ROOFS\*  
Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph.

Coefficients are expressed in *Btu per (hour) (square foot)*, and are based on an outside wind velocity of 15 mph.  
the air on the two sides), and are based on an outside wind velocity of 15 mph.

TYPE OF CEILING  
(APPLIED DIRECTLY TO ROOF RAFTERS)

No Ceiling Applied to Rafters.

| TYPE OF CEILING<br>(APPLIED DIRECTLY TO ROOF RAFTERS)  | WOOD SHINGLES OR<br>ROLL ROOFING<br>(ON 1 X 4 WOOD STRIPS <sup>c</sup><br>SPACED 2 IN. APART) |       |                |                | ASPHALT SHINGLES OR<br>ROLL ROOFING<br>(ON SOLID WOOD SHEATHING) <sup>e</sup> |       |                |                | SLATE OR TILE<br>(ON SOLID WOOD SHEATHING) <sup>e</sup> |                |                |                | NUM-<br>BER |  |
|--------------------------------------------------------|-----------------------------------------------------------------------------------------------|-------|----------------|----------------|-------------------------------------------------------------------------------|-------|----------------|----------------|---------------------------------------------------------|----------------|----------------|----------------|-------------|--|
|                                                        | INSULATION BETWEEN RAFTERS                                                                    |       |                |                | INSULATION BETWEEN RAFTERS                                                    |       |                |                | INSULATION BETWEEN RAFTERS                              |                |                |                |             |  |
|                                                        | Blanket or Bat<br>(Thickness Below)                                                           |       |                |                | Blanket or Bat<br>(Thickness Below)                                           |       |                |                | Blanket or Bat<br>(Thickness Below)                     |                |                |                |             |  |
|                                                        | None                                                                                          | 1 In. | 2 In.          | 3 In.          | None                                                                          | 1 In. | 2 In.          | 3 In.          | None                                                    | 1 In.          | 2 In.          | 3 In.          |             |  |
| No Ceiling Applied to Rafters.                         | A                                                                                             | B     | C <sup>d</sup> | D <sup>e</sup> | E                                                                             | F     | G <sup>e</sup> | H <sup>e</sup> | I                                                       | J <sup>f</sup> | K <sup>g</sup> | L <sup>a</sup> | 1           |  |
| Metal Lath and Plaster <sup>d</sup>                    | 0.48 <sup>f</sup>                                                                             | 0.15  | 0.10           | 0.081          | 0.32 <sup>f</sup>                                                             | 0.15  | 0.11           | 0.084          | 0.55 <sup>f</sup>                                       | 0.16           | 0.11           | 0.085          | 1           |  |
| Gypsum Board (3/8 in.) Decorated                       | 0.31                                                                                          | 0.14  | 0.10           | 0.081          | 0.33                                                                          | 0.15  | 0.10           | 0.083          | 0.34                                                    | 0.15           | 0.10           | 0.083          | 2           |  |
| Insulating Board Lath (1/4 in.) Plastered              | 0.30                                                                                          | 0.14  | 0.10           | 0.080          | 0.32                                                                          | 0.15  | 0.10           | 0.082          | 0.33                                                    | 0.15           | 0.10           | 0.083          | 3           |  |
| Wood Lath and Plaster                                  | 0.29                                                                                          | 0.14  | 0.10           | 0.080          | 0.31                                                                          | 0.14  | 0.10           | 0.081          | 0.32                                                    | 0.15           | 0.10           | 0.082          | 4           |  |
| Gypsum Lath (3/8 in.) Plastered <sup>d</sup>           | 0.29                                                                                          | 0.14  | 0.10           | 0.079          | 0.31                                                                          | 0.14  | 0.10           | 0.081          | 0.32                                                    | 0.15           | 0.10           | 0.082          | 5           |  |
| Plywood (3/8 in.) Plain or Decorated                   | 0.29                                                                                          | 0.14  | 0.099          | 0.079          | 0.30                                                                          | 0.14  | 0.10           | 0.081          | 0.31                                                    | 0.15           | 0.10           | 0.081          | 6           |  |
| Insulating Board Lath (1/4 in.) Plain or Decorated     | 0.23                                                                                          | 0.12  | 0.080          | 0.072          | 0.23                                                                          | 0.12  | 0.091          | 0.074          | 0.24                                                    | 0.13           | 0.092          | 0.074          | 7           |  |
| Insulating Board Lath (1/4 in.) Plastered              | 0.22                                                                                          | 0.12  | 0.080          | 0.072          | 0.22                                                                          | 0.12  | 0.090          | 0.073          | 0.23                                                    | 0.12           | 0.091          | 0.074          | 8           |  |
| Insulating Board Lath (1/4 in.) Plastered <sup>d</sup> | 0.16                                                                                          | 0.10  | 0.078          | 0.064          | 0.17                                                                          | 0.10  | 0.079          | 0.060          | 0.17                                                    | 0.10           | 0.080          | 0.066          | 9           |  |

(See text on p. 189) \* See Table 5, Note a.  
<sup>a</sup> Coefficients corrected for framing on basis of 15 percent area, 2 in. x 4 in. (nominal), 16 in. on centers.  
<sup>b</sup> Figures in Columns I, J, K and L may be used with sufficient accuracy for rigid asbestos shingles on wood sheathing. Layer of slater's felt neglected.

<sup>c</sup> Sheathing and wood strips assumed 2 1/2 in. thick.

<sup>d</sup> Plaster assumed 3/4 in. thick.

<sup>e</sup> Plaster assumed 1/2 in. thick.

<sup>f</sup> No air space included in I-A, I-E or I-I; all other coefficients based on one air space.

TABLE 18. COMBINED COEFFICIENTS OF TRANSMISSION ( $U$ ) OF UNVENTED PITCHED ROOFS\* AND HORIZONTAL CEILINGS—BASED ON CEILING AREA\*\*

Coefficients are expressed in Btu per (hour) (square foot of ceiling area) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph.

| CEILING<br>COEFFICIENTS<br>(FROM<br>TABLE 12) | TYPE OF ROOFING AND ROOF SHEATHING                                |                                                                                |                                                                                |                                                                                 |                                                                                |                                                                                | NUMBER |
|-----------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------|
|                                               | WOOD SHINGLES ON WOOD STRIPS <sup>d</sup>                         |                                                                                |                                                                                | ASPHALT SHINGLES <sup>e</sup> OR ROLL ROOFING<br>ON WOOD SHEATHING <sup>f</sup> |                                                                                |                                                                                |        |
|                                               | No Roof<br>Insulation<br>(Rafters<br>Exposed)<br>( $U_r = 0.48$ ) | ½ In. Insu-<br>lating Board<br>on Under Side<br>of Rafters<br>( $U_r = 0.22$ ) | 1 In. Insu-<br>lating Board<br>on Under Side<br>of Rafters<br>( $U_r = 0.16$ ) | No Roof<br>Insulation<br>(Rafters<br>Exposed)<br>( $U_r = 0.53$ )               | ½ In. Insu-<br>lating Board<br>on Under Side<br>of Rafters<br>( $U_r = 0.23$ ) | 1 In. Insu-<br>lating Board<br>on Under Side<br>of Rafters<br>( $U_r = 0.17$ ) |        |
|                                               | A                                                                 | B                                                                              | C                                                                              | D                                                                               | E                                                                              | F                                                                              |        |
| 0.10                                          | 0.085                                                             | 0.073                                                                          | 0.066                                                                          | 0.087                                                                           | 0.074                                                                          | 0.067                                                                          | 19     |
| 0.11                                          | 0.092                                                             | 0.078                                                                          | 0.07                                                                           | 0.094                                                                           | 0.079                                                                          | 0.071                                                                          | 20     |
| 0.12                                          | 0.099                                                             | 0.082                                                                          | 0.074                                                                          | 0.10                                                                            | 0.083                                                                          | 0.075                                                                          | 21     |
| 0.13                                          | 0.11                                                              | 0.087                                                                          | 0.078                                                                          | 0.11                                                                            | 0.088                                                                          | 0.079                                                                          | 22     |
| 0.14                                          | 0.11                                                              | 0.091                                                                          | 0.081                                                                          | 0.11                                                                            | 0.093                                                                          | 0.083                                                                          | 23     |
| 0.15                                          | 0.12                                                              | 0.096                                                                          | 0.084                                                                          | 0.12                                                                            | 0.097                                                                          | 0.086                                                                          | 24     |
| 0.16                                          | 0.13                                                              | 0.10                                                                           | 0.087                                                                          | 0.13                                                                            | 0.10                                                                           | 0.089                                                                          | 25     |
| 0.17                                          | 0.13                                                              | 0.10                                                                           | 0.090                                                                          | 0.13                                                                            | 0.10                                                                           | 0.092                                                                          | 26     |
| 0.18                                          | 0.14                                                              | 0.11                                                                           | 0.093                                                                          | 0.14                                                                            | 0.11                                                                           | 0.095                                                                          | 27     |
| 0.19                                          | 0.14                                                              | 0.11                                                                           | 0.095                                                                          | 0.15                                                                            | 0.11                                                                           | 0.098                                                                          | 28     |
| 0.20                                          | 0.15                                                              | 0.11                                                                           | 0.098                                                                          | 0.15                                                                            | 0.12                                                                           | 0.10                                                                           | 29     |
| 0.21                                          | 0.15                                                              | 0.12                                                                           | 0.10                                                                           | 0.16                                                                            | 0.12                                                                           | 0.10                                                                           | 30     |
| 0.22                                          | 0.16                                                              | 0.12                                                                           | 0.10                                                                           | 0.17                                                                            | 0.12                                                                           | 0.11                                                                           | 31     |
| 0.23                                          | 0.16                                                              | 0.12                                                                           | 0.10                                                                           | 0.17                                                                            | 0.12                                                                           | 0.11                                                                           | 32     |
| 0.24                                          | 0.17                                                              | 0.13                                                                           | 0.11                                                                           | 0.18                                                                            | 0.12                                                                           | 0.11                                                                           | 33     |
| 0.25                                          | 0.17                                                              | 0.13                                                                           | 0.11                                                                           | 0.18                                                                            | 0.13                                                                           | 0.11                                                                           | 34     |
| 0.26                                          | 0.18                                                              | 0.13                                                                           | 0.11                                                                           | 0.19                                                                            | 0.13                                                                           | 0.11                                                                           | 35     |
| 0.27                                          | 0.18                                                              | 0.13                                                                           | 0.11                                                                           | 0.19                                                                            | 0.13                                                                           | 0.12                                                                           | 36     |
| 0.28                                          | 0.19                                                              | 0.14                                                                           | 0.12                                                                           | 0.19                                                                            | 0.14                                                                           | 0.12                                                                           | 37     |
| 0.29                                          | 0.19                                                              | 0.14                                                                           | 0.12                                                                           | 0.20                                                                            | 0.14                                                                           | 0.12                                                                           | 38     |
| 0.30                                          | 0.20                                                              | 0.14                                                                           | 0.12                                                                           | 0.20                                                                            | 0.14                                                                           | 0.12                                                                           | 39     |
| 0.34                                          | 0.21                                                              | 0.15                                                                           | 0.12                                                                           | 0.22                                                                            | 0.15                                                                           | 0.13                                                                           | 40     |
| 0.35                                          | 0.22                                                              | 0.15                                                                           | 0.13                                                                           | 0.22                                                                            | 0.15                                                                           | 0.13                                                                           | 41     |
| 0.36                                          | 0.22                                                              | 0.15                                                                           | 0.13                                                                           | 0.23                                                                            | 0.15                                                                           | 0.13                                                                           | 42     |
| 0.37                                          | 0.23                                                              | 0.15                                                                           | 0.13                                                                           | 0.23                                                                            | 0.16                                                                           | 0.13                                                                           | 43     |
| 0.45                                          | 0.25                                                              | 0.17                                                                           | 0.13                                                                           | 0.26                                                                            | 0.17                                                                           | 0.14                                                                           | 44     |
| 0.59                                          | 0.29                                                              | 0.18                                                                           | 0.14                                                                           | 0.30                                                                            | 0.19                                                                           | 0.15                                                                           | 45     |
| 0.61                                          | 0.29                                                              | 0.18                                                                           | 0.15                                                                           | 0.31                                                                            | 0.19                                                                           | 0.15                                                                           | 46     |
| 0.62                                          | 0.30                                                              | 0.19                                                                           | 0.15                                                                           | 0.31                                                                            | 0.19                                                                           | 0.15                                                                           | 47     |
| 0.67                                          | 0.31                                                              | 0.19                                                                           | 0.15                                                                           | 0.33                                                                            | 0.20                                                                           | 0.16                                                                           | 48     |
| 0.69                                          | 0.31                                                              | 0.19                                                                           | 0.15                                                                           | 0.33                                                                            | 0.20                                                                           | 0.16                                                                           | 49     |

(See text on p. 189.) \* See Table 5, Note a.

<sup>a</sup> Calculations based on 1/2 pitch roof ( $n = 1.2$ ) using the following formula:

$$U = \frac{U_r \times U_{ce}}{U_r + \frac{U_{ce}}{n}}$$

$U$  = combined coefficient to be used with ceiling area.

$U_r$  = coefficient of transmission of the roof.

$U_{ce}$  = coefficient of transmission of the ceiling.

$n$  = the ratio of the area of the roof to the area of the ceiling.

<sup>b</sup> Use ceiling area (not roof area) with these coefficients.

<sup>c</sup> Coefficients in Columns D, E and F may be used with sufficient accuracy for tile, slate and rigid asbestos shingles on wood sheathing.

<sup>d</sup> Based on 1 x 4 in. strips spaced 2 in. apart.

<sup>e</sup> Sheathing assumed 2 1/2 in. thick.

<sup>f</sup> Values of  $U_{ce}$  to be used in this column may be selected from Table 12.

ter design conditions will be greater than for the floor. The test results indicate a unit area heat loss, at mid-height of the basement wall approximately twice that of the same floor area.

For concrete slab floors laid in contact with the ground at grade level, recent tests<sup>13</sup> indicate that for small floor areas (equal to that of a house 25 feet square) the heat loss may be calculated as proportional to the length of exposed edge rather than total area. This amounts to 0.81 Btu per (hr) (linear foot of exposed edge) (Fahrenheit degree difference between

TABLE 19. COEFFICIENTS OF TRANSMISSION ( $U$ ) OF SOLID WOOD DOORS\*  
Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based upon an outside wind velocity of 15 mph.

| NOMINAL THICKNESS<br>INCHES | ACTUAL THICKNESS<br>INCHES | $U_{a, b}$<br>EXPOSED DOOR | $U_{a, b}$<br>WITH GLASS STORM DOOR <sup>c</sup> |
|-----------------------------|----------------------------|----------------------------|--------------------------------------------------|
| 1                           | $\frac{3}{4}$              | 0.69                       | 0.35                                             |
| $1\frac{1}{4}$              | $1\frac{1}{4}$             | 0.59                       | 0.32                                             |
| $1\frac{1}{2}$              | $1\frac{1}{2}$             | 0.52                       | 0.30                                             |
| $1\frac{3}{4}$              | $1\frac{3}{4}$             | 0.51                       | 0.30                                             |
| 2                           | $1\frac{5}{8}$             | 0.46                       | 0.28                                             |
| $2\frac{1}{2}$              | $2\frac{1}{8}$             | 0.38                       | 0.25                                             |
| 3                           | $2\frac{3}{8}$             | 0.33                       | 0.23                                             |

\* See Table 5, Note a.

<sup>b</sup> Computed using  $k = 1.15$  for wood,  $f_i = 1.65$ ,  $f_o = 6.0$ , and 1.10 for air space.

<sup>c</sup> A  $U$  value of 0.85 may be used for single exposed doors containing thin wood panels or single panes of glass, and 0.39 for the same with glass storm doors.

<sup>d</sup> 50 percent glass and thin wood panels.

TABLE 20. COEFFICIENTS OF TRANSMISSION ( $U$ ) OF WINDOWS, SKYLIGHTS  
AND GLASS BLOCK WALLS

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based upon the following outdoor conditions: 0 F air temperature, clear skies, no solar radiation

| SECTION A—VERTICAL GLASS SHEETS |      |               |               |                |               |               |                |
|---------------------------------|------|---------------|---------------|----------------|---------------|---------------|----------------|
| NUMBER OF SHEETS                | ONE  | TWO           |               |                | THREE         |               |                |
| Air Space, inches               | None | $\frac{3}{4}$ | $\frac{1}{2}$ | 1 <sup>a</sup> | $\frac{3}{4}$ | $\frac{1}{2}$ | 1 <sup>a</sup> |
| $U$                             | 1.13 | 0.61          | 0.55          | 0.53           | 0.41          | 0.36          | 0.34           |

| SECTION B—HORIZONTAL GLASS SHEETS (HEAT FLOW UP) |      |               |               |                |
|--------------------------------------------------|------|---------------|---------------|----------------|
| NUMBER OF SHEETS                                 | ONE  | TWO           |               |                |
| Air Space, inches                                | None | $\frac{3}{4}$ | $\frac{1}{2}$ | 1 <sup>a</sup> |
| $U$                                              | 1.40 | 0.70          | 0.66          | 0.63           |

| SECTION C—WALLS OF HOLLOW GLASS BLOCK                                                                        |  | $U$  |
|--------------------------------------------------------------------------------------------------------------|--|------|
| DESCRIPTION                                                                                                  |  |      |
| $5\frac{1}{2} \times 5\frac{1}{2} \times 3\frac{1}{2}$ in. thick                                             |  | 0.60 |
| $7\frac{1}{2} \times 7\frac{1}{2} \times 3\frac{1}{2}$ in. thick                                             |  | 0.56 |
| $11\frac{1}{2} \times 11\frac{1}{2} \times 3\frac{1}{2}$ in. thick                                           |  | 0.52 |
| $7\frac{1}{2} \times 7\frac{1}{2} \times 3\frac{1}{2}$ in. thick with glass fiber screen dividing the cavity |  | 0.48 |

SECTION D—APPROXIMATE APPLICATION FACTORS FOR WINDOWS  
MULTIPLY FLAT GLASS  $U$  VALUES BY THESE FACTORS

| WINDOW DESCRIPTION | SINGLE GLASS                  |        | DOUBLE GLASS <sup>b</sup>     |        | WINDOWS WITH STORM SASH <sup>c</sup> |                   |
|--------------------|-------------------------------|--------|-------------------------------|--------|--------------------------------------|-------------------|
|                    | Percent <sup>d</sup><br>Glass | Factor | Percent <sup>d</sup><br>Glass | Factor | Percent <sup>d</sup><br>Glass        | Factor            |
| Sheets             | 100                           | 1.00   | 100                           | 1.00   | 80                                   | 0.90              |
| Wood Sash          | 80                            | 0.90   | 80                            | 0.95   | 60                                   | 0.80              |
| Wood Sash          | 60                            | 0.80   | 60                            | 0.85   | 80                                   | 1.00 <sup>e</sup> |
| Steel Sash         | 80                            | 1.00   | 80                            | 1.20   | 80                                   | 1.10 <sup>f</sup> |
| Aluminum           | 80                            | 1.10   | 80                            | 1.30   | 80                                   | 1.10 <sup>f</sup> |

(See text p. 201.)

<sup>a</sup> For 1 in. or greater.

<sup>b</sup> From unpublished data recommended by ASHVE Tech. Adv. Comm. on Glass.

<sup>c</sup> Unit type double glazing (two lights or panes in same opening).

<sup>d</sup> Use with  $U$  values for two sheets with 1 in. air space.

<sup>e</sup> Based on area of exposed portion of sash; does not include frame or portions of sash concealed by frame.

<sup>f</sup> For metal storm sash or metal sash with attached storm pane.

the inside air temperature and the average outside air temperature). It should be noted that this may be appreciably reduced by insulating under the ground slab, and also along the edges between the floor and the abutting walls. See also sections on Basement Temperatures and Heat Loss, and on Floor Heat Loss in Basementless Houses, in Chapter 12. In most calculations if the perimeter loss is calculated accurately, no other floor loss need be considered.

### Glass Coefficients

The  $U$  values for glass sheets and hollow glass block, given in Sections A, B and C of Table 20, have been computed by methods and data given in an A.S.H.V.E. Research Paper.<sup>8</sup> It is assumed that the surface conductance for convection loss to the air is 4.0 Btu per (hr) (sq ft) (F deg). It is also assumed that the glass loses heat by radiation to the ground and to the clear sky, which together have an effective radiating temperature below the air temperature. It is therefore necessary to determine, by trial and error, the temperature of the outdoor glass surface such that the sum of the radiation and convection losses equals the heat conducted through the glass section, and equals the heat delivered to the glass from the heated space. This heat flow, divided by the air-to-air temperature difference, results in a  $U$  value which is used in the usual manner. The equivalent surface conductance for radiation and convection combined, based on air-to-surface temperature difference, therefore varies from about 5.5 for single glass to about 6.6 for double glass for exactly the same environmental design conditions.

It is assumed that the room air temperature equals the average temperature of the room surfaces seen by the glass. Special consideration should be given to those cases where the glass sees interior surfaces at temperatures differing greatly from the room air temperature, i.e., such cases as in sun rooms, greenhouses, and some panel heated rooms, or where there is an unusual amount of air motion in the vicinity of the glass. Although based on zero outdoor air, the values change only slightly with different design temperatures, being about 5 percent greater for a 30 F outdoor design temperature.

In computing the Table 20 values, consideration of the dependence of the indoor surface conductances upon temperature and direction of heat flow leads to surface conductances averaging about 1.50 for block and vertical glass, and about 1.80 for horizontal glass, as compared to the value of 1.65 used in computing  $U$  values given in other tables in this chapter. These values should therefore be used in estimating the temperature at which condensation on glass surfaces will occur.

The application factors given in Section D of Table 20 are based upon hot box tests summarized in a research bulletin,<sup>14</sup> and are approximate only. In practice, some variation in heat flow through windows having the same ratio of glass to sash area, may be expected because of difference in construction details and in air space edge effects. The high conductance of aluminum and steel sash must be taken into consideration where excessive amounts of metal sash and frames are involved. This is particularly important when they are in close proximity to radiation heat sources and are consequently subjected to high differential temperatures.

### Wind Velocity Correction for $U$ Values

Tables 7 to 9, and 15 to 19, present values of  $U$  for walls and other surfaces based on an outside wind velocity of 15 mph. Table 21 shows comparative values of  $U$  for other wind velocities.

**Example 3:** Find the coefficient of transmission  $U$  of a frame wall consisting of stucco,  $\frac{25}{32}$ -in. insulation board sheathing, 2 x 4-in. studs, gypsum lath and plaster, and with 2-in. blanket insulation between studs, for 25 mph wind velocity.

**Solution:** From Table 7, Wall No. 20, with no insulation between studs has a value of  $U = 0.19$ . From Table 6, Col. 4, this wall with 2-in. insulation added has a value of  $U = 0.084$ . Entering Table 21 in the 15 mph column, interpolate between 0.080 and 0.090 in 15 mph column and proceed horizontally to the 25 mph column where the  $U$  value is found by interpolation to be 0.085.

TABLE 21. CONVERSION TABLE FOR WALL COEFFICIENT  $U$  FOR VARIOUS WIND VELOCITIES

| $U$ FOR 15 MPH <sup>a</sup> | $U$ FOR 0 TO 30 MPH WIND VELOCITIES |       |       |       |       |       |
|-----------------------------|-------------------------------------|-------|-------|-------|-------|-------|
|                             | 0                                   | 5     | 10    | 20    | 25    | 30    |
| 0.050                       | 0.049                               | 0.050 | 0.050 | 0.050 | 0.050 | 0.050 |
| 0.060                       | 0.059                               | 0.059 | 0.060 | 0.060 | 0.060 | 0.060 |
| 0.070                       | 0.068                               | 0.069 | 0.070 | 0.070 | 0.070 | 0.070 |
| 0.080                       | 0.078                               | 0.079 | 0.080 | 0.080 | 0.080 | 0.080 |
| 0.090                       | 0.087                               | 0.089 | 0.090 | 0.090 | 0.091 | 0.091 |
| 0.100                       | 0.096                               | 0.099 | 0.100 | 0.100 | 0.101 | 0.101 |
| 0.110                       | 0.105                               | 0.108 | 0.109 | 0.110 | 0.111 | 0.111 |
| 0.120                       | 0.113                               | 0.117 | 0.119 | 0.121 | 0.123 | 0.123 |
| 0.130                       | 0.123                               | 0.127 | 0.129 | 0.131 | 0.131 | 0.131 |
| 0.140                       | 0.131                               | 0.136 | 0.139 | 0.141 | 0.141 | 0.141 |
| 0.150                       | 0.141                               | 0.146 | 0.149 | 0.151 | 0.151 | 0.151 |
| 0.160                       | 0.150                               | 0.155 | 0.159 | 0.161 | 0.161 | 0.161 |
| 0.170                       | 0.159                               | 0.164 | 0.169 | 0.171 | 0.172 | 0.172 |
| 0.180                       | 0.168                               | 0.173 | 0.179 | 0.181 | 0.182 | 0.182 |
| 0.190                       | 0.177                               | 0.182 | 0.189 | 0.191 | 0.192 | 0.193 |
| 0.200                       | 0.186                               | 0.191 | 0.199 | 0.201 | 0.203 | 0.203 |
| 0.210                       | 0.195                               | 0.200 | 0.209 | 0.211 | 0.213 | 0.213 |
| 0.220                       | 0.204                               | 0.209 | 0.219 | 0.221 | 0.223 | 0.224 |
| 0.230                       | 0.213                               | 0.218 | 0.229 | 0.231 | 0.233 | 0.234 |
| 0.240                       | 0.222                               | 0.227 | 0.239 | 0.241 | 0.243 | 0.244 |
| 0.250                       | 0.231                               | 0.236 | 0.249 | 0.251 | 0.253 | 0.254 |
| 0.260                       | 0.240                               | 0.245 | 0.259 | 0.261 | 0.263 | 0.265 |
| 0.270                       | 0.249                               | 0.254 | 0.269 | 0.271 | 0.273 | 0.275 |
| 0.280                       | 0.258                               | 0.263 | 0.279 | 0.281 | 0.283 | 0.285 |
| 0.290                       | 0.267                               | 0.272 | 0.289 | 0.291 | 0.293 | 0.295 |
| 0.300                       | 0.276                               | 0.281 | 0.299 | 0.301 | 0.303 | 0.305 |
| 0.310                       | 0.285                               | 0.290 | 0.309 | 0.311 | 0.313 | 0.315 |
| 0.320                       | 0.294                               | 0.299 | 0.319 | 0.321 | 0.323 | 0.325 |
| 0.330                       | 0.303                               | 0.308 | 0.329 | 0.331 | 0.333 | 0.335 |
| 0.340                       | 0.312                               | 0.317 | 0.339 | 0.341 | 0.343 | 0.345 |
| 0.350                       | 0.321                               | 0.326 | 0.349 | 0.351 | 0.353 | 0.355 |
| 0.360                       | 0.330                               | 0.335 | 0.359 | 0.361 | 0.363 | 0.365 |
| 0.370                       | 0.339                               | 0.344 | 0.369 | 0.371 | 0.373 | 0.375 |
| 0.380                       | 0.348                               | 0.353 | 0.379 | 0.381 | 0.383 | 0.385 |
| 0.390                       | 0.357                               | 0.362 | 0.389 | 0.391 | 0.393 | 0.395 |
| 0.400                       | 0.366                               | 0.371 | 0.399 | 0.401 | 0.403 | 0.405 |
| 0.410                       | 0.375                               | 0.380 | 0.409 | 0.411 | 0.413 | 0.415 |
| 0.420                       | 0.384                               | 0.389 | 0.419 | 0.421 | 0.423 | 0.425 |
| 0.430                       | 0.393                               | 0.398 | 0.429 | 0.431 | 0.433 | 0.435 |
| 0.440                       | 0.402                               | 0.407 | 0.439 | 0.441 | 0.443 | 0.445 |
| 0.450                       | 0.411                               | 0.416 | 0.449 | 0.451 | 0.453 | 0.455 |
| 0.460                       | 0.420                               | 0.425 | 0.459 | 0.461 | 0.463 | 0.465 |
| 0.470                       | 0.429                               | 0.434 | 0.469 | 0.471 | 0.473 | 0.475 |
| 0.480                       | 0.438                               | 0.443 | 0.479 | 0.481 | 0.483 | 0.485 |
| 0.490                       | 0.447                               | 0.452 | 0.489 | 0.491 | 0.493 | 0.495 |
| 0.500                       | 0.456                               | 0.461 | 0.499 | 0.501 | 0.503 | 0.505 |
| 0.510                       | 0.465                               | 0.470 | 0.509 | 0.511 | 0.513 | 0.515 |
| 0.520                       | 0.474                               | 0.479 | 0.519 | 0.521 | 0.523 | 0.525 |
| 0.530                       | 0.483                               | 0.488 | 0.529 | 0.531 | 0.533 | 0.535 |
| 0.540                       | 0.492                               | 0.497 | 0.539 | 0.541 | 0.543 | 0.545 |
| 0.550                       | 0.501                               | 0.506 | 0.549 | 0.551 | 0.553 | 0.555 |
| 0.560                       | 0.510                               | 0.515 | 0.559 | 0.561 | 0.563 | 0.565 |
| 0.570                       | 0.519                               | 0.524 | 0.569 | 0.571 | 0.573 | 0.575 |
| 0.580                       | 0.528                               | 0.533 | 0.579 | 0.581 | 0.583 | 0.585 |
| 0.590                       | 0.537                               | 0.542 | 0.589 | 0.591 | 0.593 | 0.595 |
| 0.600                       | 0.546                               | 0.551 | 0.599 | 0.601 | 0.603 | 0.605 |
| 0.610                       | 0.555                               | 0.560 | 0.609 | 0.611 | 0.613 | 0.615 |
| 0.620                       | 0.564                               | 0.569 | 0.619 | 0.621 | 0.623 | 0.625 |
| 0.630                       | 0.573                               | 0.578 | 0.629 | 0.631 | 0.633 | 0.635 |
| 0.640                       | 0.582                               | 0.587 | 0.639 | 0.641 | 0.643 | 0.645 |
| 0.650                       | 0.591                               | 0.596 | 0.649 | 0.651 | 0.653 | 0.655 |
| 0.660                       | 0.600                               | 0.605 | 0.659 | 0.661 | 0.663 | 0.665 |
| 0.670                       | 0.609                               | 0.614 | 0.669 | 0.671 | 0.673 | 0.675 |
| 0.680                       | 0.618                               | 0.623 | 0.679 | 0.681 | 0.683 | 0.685 |
| 0.690                       | 0.627                               | 0.632 | 0.689 | 0.691 | 0.693 | 0.695 |
| 0.700                       | 0.636                               | 0.641 | 0.699 | 0.701 | 0.703 | 0.705 |
| 0.710                       | 0.645                               | 0.650 | 0.709 | 0.711 | 0.713 | 0.715 |
| 0.720                       | 0.654                               | 0.659 | 0.719 | 0.721 | 0.723 | 0.725 |
| 0.730                       | 0.663                               | 0.668 | 0.729 | 0.731 | 0.733 | 0.735 |
| 0.740                       | 0.672                               | 0.677 | 0.739 | 0.741 | 0.743 | 0.745 |
| 0.750                       | 0.681                               | 0.686 | 0.749 | 0.751 | 0.753 | 0.755 |
| 0.760                       | 0.690                               | 0.695 | 0.759 | 0.761 | 0.763 | 0.765 |
| 0.770                       | 0.699                               | 0.704 | 0.769 | 0.771 | 0.773 | 0.775 |
| 0.780                       | 0.708                               | 0.713 | 0.779 | 0.781 | 0.783 | 0.785 |
| 0.790                       | 0.717                               | 0.722 | 0.789 | 0.791 | 0.793 | 0.795 |
| 0.800                       | 0.726                               | 0.731 | 0.799 | 0.801 | 0.803 | 0.805 |
| 0.810                       | 0.735                               | 0.740 | 0.809 | 0.811 | 0.813 | 0.815 |
| 0.820                       | 0.744                               | 0.749 | 0.819 | 0.821 | 0.823 | 0.825 |
| 0.830                       | 0.753                               | 0.758 | 0.829 | 0.831 | 0.833 | 0.835 |
| 0.840                       | 0.762                               | 0.767 | 0.839 | 0.841 | 0.843 | 0.845 |
| 0.850                       | 0.771                               | 0.776 | 0.849 | 0.851 | 0.853 | 0.855 |
| 0.860                       | 0.780                               | 0.785 | 0.859 | 0.861 | 0.863 | 0.865 |
| 0.870                       | 0.789                               | 0.794 | 0.869 | 0.871 | 0.873 | 0.875 |
| 0.880                       | 0.798                               | 0.803 | 0.879 | 0.881 | 0.883 | 0.885 |
| 0.890                       | 0.807                               | 0.812 | 0.889 | 0.891 | 0.893 | 0.895 |
| 0.900                       | 0.816                               | 0.821 | 0.899 | 0.901 | 0.903 | 0.905 |
| 0.910                       | 0.825                               | 0.830 | 0.909 | 0.911 | 0.913 | 0.915 |
| 0.920                       | 0.834                               | 0.839 | 0.919 | 0.921 | 0.923 | 0.925 |
| 0.930                       | 0.843                               | 0.848 | 0.929 | 0.931 | 0.933 | 0.935 |
| 0.940                       | 0.852                               | 0.857 | 0.939 | 0.941 | 0.943 | 0.945 |
| 0.950                       | 0.861                               | 0.866 | 0.949 | 0.951 | 0.953 | 0.955 |
| 0.960                       | 0.870                               | 0.875 | 0.959 | 0.961 | 0.963 | 0.965 |
| 0.970                       | 0.879                               | 0.884 | 0.969 | 0.971 | 0.973 | 0.975 |
| 0.980                       | 0.888                               | 0.893 | 0.979 | 0.981 | 0.983 | 0.985 |
| 0.990                       | 0.897                               | 0.902 | 0.989 | 0.991 | 0.993 | 0.995 |
| 1.000                       | 0.906                               | 0.911 | 0.999 | 1.001 | 1.003 | 1.005 |

<sup>a</sup>  $U$  in first column is from previous tables or as calculated for 15 mph wind velocity.

### CALCULATING SURFACE TEMPERATURES

In many heating and cooling load calculations it is necessary to determine the inside surface temperature or the temperature of the surfaces within the structure. As the resistance of any path of heat flow is expressed in Fahrenheit degrees per (Btu) (hour) (square foot), the resistances through any two paths of heat flow would be proportional to the temperature drop through these paths, and can be expressed as follows:

$$\frac{R_1}{R_2} = \frac{(t_i - t_x)}{(t_i - t_o)} \quad (6)$$

where

$R_1$  = the resistance from the inside air to any point in the structure at which the temperature is to be determined.

$R_2$  = the overall resistance of the wall from inside air to outside air.

$t_i$  = inside air temperature.

$t_x$  = temperature to be determined.

$t_o$  = outside air temperature.

**Example 4:** Determine the inside surface temperature for a wall having an overall coefficient of heat transmission  $U = 0.25$ , inside air temperature 70 F, outside air temperature -20 F.

**Solution:**

$$R_1 = 1/f_i = 1/1.65 = 0.606$$

$$R_2 = 1/U = 1/0.25 = 4.00$$

Then, by Equation 6

$$\frac{0.606}{4.00} = \frac{70 - t_x}{70 - (-20)}$$

$$t_x = 56.4 \text{ F}$$

The same procedure can be used for determining the temperature at any point within the structure.

A chart for determining inside wall surface temperature is given in Fig. 12 of Chapter 24, Panel Heating.

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## CHAPTER 10

## MOISTURE IN BUILDING CONSTRUCTION

Properties of Water in Air; Water in Building Materials; Movement of Moisture in Materials; Vapor Transmission; Permeance and Testing; Visible Condensation; Concealed Condensation in Heated Buildings; Control of Concealed Condensation; Condensation in Cooled Structures

THE behavior of moisture is too often overlooked or given scant attention in the design and construction of buildings. It is present as a vapor in all air and as adsorbed moisture in most building materials. It may be present also at times in the free liquid state or as ice, in the solid state, within the range of temperatures encountered in many buildings. Problems involving moisture may arise from changes in moisture content, from the presence of excessive moisture, or from effects associated with its changes in state.

Of particular interest here is the change from the vapor to the liquid or solid state, known as condensation. This may be associated with a reduction of temperature with time, or may occur as a result of migration of water vapor to regions of lower temperature. Moisture problems involving condensation are therefore most likely to occur in buildings in any climate in which there is a source of water vapor at temperatures above normal, or in cooled structures, and in buildings in cold climates.

Moisture problems in residences occur in winter and become increasingly important as homes are built smaller and tighter. Water vapor originates from such necessary living requirements as cooking, laundering, bathing, and the breathing and perspiration of people. In a typical family of four, the average daily production of water vapor from these sources may be as much as 25 lb, and may be much greater where such appliances as humidifiers, automatic washers, and dryers are used.<sup>1</sup> Another large source of water vapor is sometimes the bare earth in a crawl space or basement. All this water vapor must escape from the dwelling.

## PROPERTIES OF WATER VAPOR IN AIR

Water vapor in air is a gas which occupies all the space, along with the air present. In many ways, the water vapor can act independently of the air, since in general its properties do not depend on the presence of the air. It exerts its own vapor pressure, and can move about through air in a space, or move through materials under differences in its own vapor pressure, independently of the air. However, when the air is moved suddenly or is heated or cooled, the water vapor present is similarly affected, so that it is usually necessary to consider it as a part of an air-vapor mixture.

The properties of mixtures of air and water vapor are relatively well known and are dealt with fully in Chapter 3, Thermodynamics. Changes in these properties with heating and cooling can be followed readily with the aid of a psychrometric chart, shown in outline in Fig. 1. The satura-

tion line represents the limiting concentrations of water vapor which can exist as vapor at various temperatures.

A common condition inside buildings, 70 F. and 40 percent relative humidity, is represented by point A. This is a condition of partial saturation; i.e., less than 100 percent relative humidity. The vapor pressure of the water present in the air, although not shown on the chart, can be calculated readily from the vapor pressure at saturation and the relative humidity, since relative humidity is very nearly equal to the ratio of the actual vapor pressure to the saturation pressure at the existing temperature.

The increasing relative humidity accompanying cooling from the condition represented by A on the chart to point B can readily be followed. At B, however, at 44.6 F., the relative humidity becomes 100 percent, and the air-vapor mixture is said to be saturated. The temperature at which this particular air-vapor mixture, upon cooling, becomes saturated is its

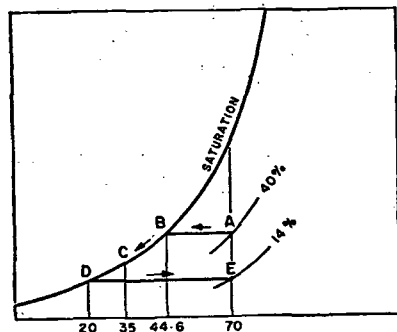


FIG. 1. TWO TYPICAL HEATING AND COOLING PROCESSES IN AIR WITHIN BUILDINGS SHOWN ON A.S.H.V.E. PSYCHROMETRIC CHART

dew-point temperature. Upon further cooling, to 35 F., the original amount of water vapor can no longer be retained and is reduced, in this case, to the condition represented by C, from 0.0633 lb per lb dry air to 0.0427 lb per lb dry air. The process ABC is typical of that which an air-vapor mixture experiences when it comes in contact with a cool window surface. Cooling from B to C results in visible condensation on the glass surface. If the point C were below 32 F., the condensation would be in the form of frost.

Once the temperature drops below the dew point, or frost point if below 32 F., the vapor pressure at the condensing surface is also reduced, thereby establishing a gradient of vapor pressure from the room air to the window surface. This gradient will operate, in conjunction with the convective action within the room, to move water vapor continuously to the window surface to be condensed, so long as the concentration of water vapor in the room is maintained.

A common winter process is that shown by DE, showing air at 20 F., saturated, being heated to 70 F. with a resulting large decrease in relative humidity. This explains, in part, the greatly reduced relative humidities

experienced in houses in extreme cold weather, when cold outside air enters the house and is heated.

### WATER IN BUILDING MATERIALS

The surfaces of most common materials have an affinity for water molecules. Molecular forces of attraction will hold water molecules to the surface, but decrease very rapidly with increase in distance of molecular proportions. The film thickness and therefore the amount of water held in equilibrium with the surrounding atmosphere is roughly proportional to relative humidity. Surface films of water molecules, at low humidities, may be only one molecule thick; at moderate humidities poly-molecular films may be established, while at humidities very close to 100 percent, the films become so thick, relatively, that small pores may become filled and larger capillaries may be partially filled. At saturation conditions all voids in the material may be completely filled.

Some materials such as silica gel, alumina and most natural fibrous materials present very large effective surfaces to the water molecules, so that the amount of water held on the effective surface in these materials may be relatively large, even at moderate humidities. These are said to be hygroscopic. Other materials, such as most metals, not penetrated by the water molecules, present relatively small surfaces and so may take only minute quantities of water, except when wetted directly by liquid.

Substances having a great affinity for water, and their use as dehumidifying agents, are described in Chapter 38. Data on the moisture contents of various common materials in equilibrium with the atmosphere at various relative humidities are given in Table 2 of Chapter 45, and equilibrium moisture content is further discussed in Chapter 47 on Industrial Drying Systems.

Significant dimensional changes take place in many materials used in buildings, with change in moisture content. Those which take place in wood, of the order of 0.1, 2, and 4 percent in the longitudinal, radial and tangential directions, respectively, on a change from air dry at 12 to 15 percent moisture content to oven dry are perhaps the best known. Most wood-fiber products, including papers, will exhibit moisture expansion consistent with the basic wood properties to a degree dependent on the fiber orientation and arrangement. Data on wood are available in publications on wood technology. Almost all plant and animal fibers experience appreciable moisture changes with changing relative humidity and undergo substantial dimensional changes of the same order as those in wood. Less generally recognized are the dimensional changes which can occur in masonry materials as a result of changes in moisture content.

Water is either an essential or a contributory factor in almost all cases of breakdown of building materials resulting from chemical changes such as the rusting of steel, physical changes such as the spalling of masonry by frost action, or biological processes such as the rotting of wood. The control of water in building constructions may be necessary to ensure adequate service from the materials involved.

Condensation of water vapor, although not the only means by which wetting may be brought about, is nevertheless a most insidious one particularly in respect of freeze-thaw breakdown, since from its nature it is most likely to occur at points of low temperature at which there may later be risk of freezing while the material remains in a saturated condition.

Moisture in building materials may have a marked effect upon the transmission of heat through them. It has been commonly assumed that moisture when present in a material will remain more or less stationary and will increase the conductivity largely by adding to the path available for heat flow. On this basis, the effect of moisture on heat flow can be accounted for quite simply by the use of suitable coefficients of conductivity in the usual heat-flow equations. The data presented in Chapter 9 on moist soils are of this type.

Evidence to date indicates, however, that in porous materials partially saturated with water there is likely to be a migration of moisture to the cold side under the influence of the temperature gradient. This can occur by a process of evaporation, vapor flow, and condensation within the material, a substantial amount of heat being transferred as latent heat of the vapor, particularly in the case of open fibrous materials. The transmission of heat through moist materials becomes complex whenever conditions are such as to produce any appreciable migration of the moisture, and, consequently, calculations by the usual heat-flow theory alone, are an approximation.

#### MOVEMENT OF MOISTURE IN MATERIALS

Moisture is caused to migrate in granular media or in porous solids by gradients in hydrostatic pressure, vapor pressure, capillary forces, concentration of salts, temperature, or electrical potential. Neither the various mechanisms nor the particular potentials involved are entirely unrelated. They are frequently combined in most complex ways not at all well understood. A temperature gradient in a moist material usually produces a vapor-pressure gradient with consequent vapor migration. Whether the temperature gradient is able to produce migration by other mechanisms is still being debated. There is a relationship between vapor pressure and capillary force, and with a condition of capillary-force gradient but uniform temperature, there will also be a vapor-pressure gradient. At high relative humidities small capillaries may be completely filled and larger capillaries partially filled, so that movement of liquid water may occur in combination with vapor movement. There is some evidence that under special conditions vapor movement and liquid movement through capillaries may occur simultaneously but in opposing directions.

#### VAPOR TRANSMISSION THROUGH MATERIALS

The equation presently used in calculating water-vapor transmission through materials is based on a form of Fick's Law, and is as follows:

$$w = -\mu \frac{dp}{dx} \quad (1)$$

where

- $w$  = weight of vapor transmitted through a unit area in unit time.
- $p$  = vapor pressure.
- $x$  = distance along the flow path.

and hence:

- $\frac{dp}{dx}$  = vapor pressure gradient.
- $\mu$  = permeability.

#### Moisture in Building Construction

The close parallel with Fourier's equation for heat flow will be noted. The actual transmission of vapor through a material is extremely complex, so that the coefficient,  $\mu$ , is not a simple one but is actually a function of relative humidity and temperature, and may vary along the flow path through the material in question.

Integrating Equation 1 from  $x = 0$  to  $x = l$  and from  $p_1$  to  $p_2$ , and rearranging, the following is obtained:

$$w = \frac{\int_{p_1}^{p_2} \mu dp}{p_1 - p_2} \times \frac{(p_1 - p_2)}{l} \quad (2)$$

Let

$$\bar{\mu} = \frac{\int_{p_1}^{p_2} \mu dp}{p_1 - p_2} \quad (3)$$

Then,

$$w = \bar{\mu} \frac{p_1 - p_2}{l} \quad (4)$$

where

$l$  = length of flow path (or thickness of material).

If Equation 1 had been integrated, assuming the coefficient  $\mu$  to be independent of vapor pressure (and temperature) along the flow path, Equation 4 would have been obtained, but with  $\bar{\mu}$  replaced by  $\mu$ . The coefficient  $\bar{\mu}$  is therefore an average permeability coefficient applicable to the varying conditions along the flow path of length  $l$ , while the coefficient  $\mu$  is the spot or differential permeability.

Equation 4 may be rewritten and units assigned:

$$W = \bar{\mu} A \theta \frac{\Delta p}{l} \quad (5)$$

where,

- $W$  = total weight of vapor transmitted, grains.
- $A$  = area of cross-section of the flow path, square feet.
- $\theta$  = time during which the transmission occurred, hours.
- $\Delta p$  = difference of vapor pressure between ends of the flow path, inches of mercury.
- $l$  = length of flow path, (or thickness of specimen), inches.

The basic units given are those now favored by the building industry. The permeability  $\mu$  or  $\bar{\mu}$  is therefore expressed in a unit of grains-inches per (square foot) (hour) (inch of mercury vapor pressure difference).

Whenever it is convenient to deal with a material of a stated or implied thickness other than the unit thickness to which  $\mu$  or  $\bar{\mu}$  refer, use may be made of the permeance coefficient  $M$ , where  $M = \mu/l$ . The designation perm for the unit of permeance is now widely used, and is a convenient substitute for the unit, 1 grain per (square foot) (hour) (inch of mercury vapor pressure difference).<sup>2</sup> The corresponding unit of permeability is perm-inch, since it is the permeance of unit thickness. The corresponding flow equation is:

$$W = M A \theta \Delta p \quad (6)$$

Resistance to vapor flow provided by a sheet or board is the reciprocal



of the permeance, and correspondingly, the over-all vapor resistance of an assembly (like a wall) of materials in series is the sum of the resistances of its component parts. The over-all permeance of the assembly may be found from the permeances of the individual components<sup>3, 4</sup> in a manner paralleling that used in calculating the over-all coefficient of thermal conductivity from the individual conductances:

$$M_t = \frac{1}{\left(\frac{1}{M_1} + \frac{1}{M_2} + \frac{1}{M_3} \cdots + \frac{1}{M_n}\right)} \quad (7)$$

This simple theory for vapor flow, as in the case of the corresponding

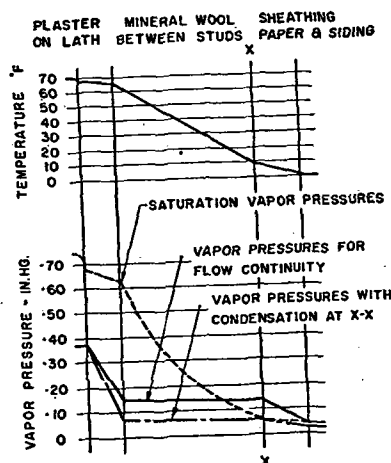


FIG. 2. TEMPERATURES AND VAPOR PRESSURES UNDER VAPOR FLOW CONDITIONS IN THE INSULATED FRAME WALL OF EXAMPLE 1.

simple heat-flow theory, assumes conditions of unidirectional, steady-state flow. Useful calculations can be made for an assembly or sub-assembly for which the inflow and outflow of vapor are equal (a condition at which no condensation occurs) if a permeance applicable to actual conditions can be assigned to each component part. Over-all permeances, vapor pressures and vapor flow can be calculated, and in conjunction with thermal calculations, relative humidities can be determined, and the imminence of condensation predicted. (See *Example 1*, and Fig. 2. See also Chapter 13, Cooling Load, for use of vapor-flow calculations.)

*Example 1:* A wood frame wall is exposed to inside conditions 70 F. and 50 percent relative humidity (0.37 in. Hg vapor pressure) and outside conditions 0 F. and 80 percent relative humidity (0.03 in. Hg vapor pressure). The wall consists of painted plaster on gypsum lath on the inside over 2 x 4 in. studs, mineral wool fill between

studs, 1 in. wood exterior sheathing, paper, and pine lap siding. Check for possible condensation.

To simplify the example, consider the paint, plaster and lath as a single element having a permeance  $M = 1.0$  perms and a thermal conductance  $C = 2.4$ , and the exterior sheathing, paper, siding and paint as another single element for which  $M = 2.0$  perms and  $C = 0.50$ . From Table 1 the value for the permeability of mineral wool fill may be found as  $\mu = 116$  perm-inches. The thermal conductivity for mineral wool,  $k = 0.27$ .

*Solution:* In this particular wall, insulated, and with moderate warm-side relative humidities, condensation is unlikely to occur until the sheathing is reached. To check directly for condensation on the warm side of the exterior sheathing (designated as plane X - X in Fig. 2 for convenient reference) proceed as follows:

Calculate according to the method of Chapter 9 the temperature at plane X - X. This is found to be 9 F. The saturation vapor pressure at this temperature is 0.06 in. Hg. If condensation is imminent or occurring at X - X, the vapor pressure there will be 0.06 in. Hg. Calculate the permeance for the portion of the wall from the warm side to X - X, and the vapor flow rate to X - X as follows:

$$\text{Permeance of wall to X - X} = \frac{1}{\frac{1}{1.0} + \frac{3.625}{116}} = 0.97 \text{ perms.}$$

$$\text{Vapor pressure drop to X - X} = 0.37 - 0.06 = 0.31 \text{ in. Hg.}$$

$$\text{Vapor flow to X - X} = 0.97 \times 0.31 = 0.30 \text{ grains per (sq ft) (hr).}$$

Calculate the vapor flow rate from X - X to outside as follows:

$$\text{Permeance of wall from X - X to outside} = 2.0 \text{ perms.}$$

$$\text{Vapor pressure drop from X - X to outside} = 0.06 - 0.03 = 0.03 \text{ in. Hg.}$$

$$\text{Vapor flow rate to outside} = 2.0 \times 0.03 = 0.06 \text{ grains per (sq ft) (hr).}$$

It is apparent that continuity of vapor flow is not possible, since at the highest vapor pressure at X - X permitted by the temperature, there is indicated a greater flow to plane X - X than from it to outside. Condensation is indicated at a rate of  $0.30 - 0.06 = 0.24$  grains per (sq ft) (hr).

Whether this condensation rate will be serious must still be decided, since it might readily be absorbed by the sheathing during the condensation period without excessive wetting. When the temperature at X - X is below freezing, as in this case, the condensation will be in the form of frost which may accumulate until released over a short period upon a rise in outside temperature.

Condensation will be reduced or avoided if the permeance of the warm side of the wall can be reduced so that the flow to X - X is limited to 0.06 grains per (sq ft) (hr). Permeance required for this is  $\frac{0.06}{0.37 - 0.06} = 0.19$  perms or less. A more resistant paint film on the plaster, reducing the paint-plaster-lath permeance to 0.19 perms would accomplish this.

When the critical plane for condensation is unknown, or for a more informative, graphical representation of the situation throughout the wall, temperatures and vapor pressures may be calculated and plotted as in Fig. 2. The vapor pressures throughout the wall, for continuity of flow, are calculated in a manner similar to the temperatures; the external vapor pressures are given, and the vapor pressure drops across each element are taken in proportion to resistance to vapor flow.

The curve for saturation vapor pressures at the various temperatures throughout the wall is also shown in Fig. 2 and is seen to fall below the curve for vapor pressures with continuity of flow, toward the outer portions of the wall. This indicates that with the given temperatures and vapor pressures, continuity of flow is not possible and that condensation will occur. Condensation on the sheathing is indicated as a definite possibility, and the new vapor pressure curve can be constructed for this condition, as shown. This new curve does not rise above the saturation-vapor-pres-

ure curve, thereby confirming that the critical plane for condensation was correctly assumed.

With the vapor pressures thus established, the relative humidities may be found, by reference to the saturation vapor pressures. The permeances originally assigned to the various elements may then be re-examined in the light of the service conditions of temperatures and relative humidities indicated, and the analysis repeated, if necessary, using more appropriate permeance values.

In a more detailed analysis, individual values might be assigned to the elements forming the outer portion of the wall, which is here dealt with as a composite, homogeneous element.

The transmission of water vapor as outlined is based on the assumption of a diffusion process. The possibility of vapor being transferred as part of a moving air stream has thus far been ignored, except in *Example 1* in which it is implied that the air circulation on either side of the wall will be sufficient to eliminate surface film resistances to vapor flow. Differences in total pressure of the air may result in a transfer of vapor with air, augmenting and at times over-riding the effects of the flow produced by vapor pressure gradients alone. This can be particularly important in the transfer of vapor through cracks and pinholes or through air-permeable building constructions.

This means of vapor transfer is similar to that of transfer of heat by air leakage in and through building constructions, requiring for purposes of calculation information on the nature and amount of the air leakage. It will seldom be important in constructions without air spaces and having parged or plastered surfaces. It may, however, be an important means of vapor transfer through constructions lacking in air tightness, and may contribute to condensation difficulties, since the mechanism of condensation is not dependent upon the way in which the vapor is transferred.

### PERMEANCE AND TESTING

The simplest method of finding the permeance of a specimen is to seal it over the top of a cup containing desiccant or water, placing it in a controlled atmosphere, and weighing it periodically. The steady rate of weight gain or loss is normally the water vapor transfer. When the cup contains a desiccant the procedure is called the *dry-cup method* and when the cup contains water, the *wet-cup method*. Usually the outside atmosphere is held at 50 percent relative humidity, thus providing, in either method, substantially the same difference of vapor pressure, but the results obtained by the two methods on the same specimens are likely to be much different, the wet cup method producing the higher values. The relationship between these values can best be understood by reference to Fig. 3, which shows a typical variation of spot permeability with relative humidity at one particular temperature (isothermal conditions) for a material such as wood. The vapor permeability is shown to vary only moderately at low humidities, but to increase at an increasing rate as higher humidities are reached. The dry-cup test of this material carried out with 0 percent relative humidity one side and 50 percent on the other, will experience throughout its thickness, because of the variation in relative humidity, a variation in spot permeability. The average permeability

$\bar{\mu}$ , is by definition (Equation 3), given by  $\frac{\int_{p_1}^{p_2} \mu dp}{p_1 - p_2}$ , and since at a fixed temperature there is a linear relationship between vapor pressure and relative humidity, this expression can be seen to correspond to the mean height of the area under the spot permeability curve, between the appro-

TABLE 1. PERMEANCE AND PERMEABILITY OF MATERIALS TO WATER VAPOR.

| MATERIAL                                              | PERMEANCE PERM    | PERMEABILITY PERM-INCH | % RH-RH <sub>2</sub> | Method | REF. |
|-------------------------------------------------------|-------------------|------------------------|----------------------|--------|------|
| AIR (still)                                           |                   |                        |                      |        |      |
| INSULATION                                            |                   | 120.                   | 92-73                | b      | 3    |
| Cellular glass                                        |                   |                        |                      |        |      |
| Corkboard                                             | 0.0               |                        |                      | d      | 4    |
| Corkboard                                             | 2.1-2.6           |                        | 75-0                 | d      | 9    |
| Structural Insulating Board (vegetable, uncoated)     | 9.5               |                        | 100-45               | w      | 7    |
| Mineral Wool (unprotected)                            | 20-50             |                        | 40-x                 | t      | 6    |
| 115.                                                  |                   |                        | 100-30               | w      |      |
| WOOD                                                  |                   |                        |                      |        |      |
| Sugar Pine                                            |                   | 0.4-5.4                | various              | tv     | 3    |
| Plywood (Exterior type 3 ply D.F.), 1/4 in.           | 0.72              |                        | 50-                  | 4      | 11   |
| Plywood (Interior type 3 ply D.F.), 1/4 in.           | 1.86              |                        | 50-                  | 4      | 11   |
| MASONRY                                               |                   |                        |                      |        |      |
| Concrete (1:2:4 Mix)                                  |                   | 3.2                    | 100-45               | w      | 9    |
| Concrete (8" cored block wall; limestone aggrt.)      | 2.4               |                        | 79-68                | t      | 3    |
| Brick wall—with mortar—4 in.                          | 0.8               |                        | 50-x                 | t      | 8    |
| Tile wall—with mortar—4 in.                           | 0.12              |                        | 50-x                 | t      | 8    |
| INTERIOR FINISH                                       |                   |                        |                      |        |      |
| Plaster on wood lath                                  | 11.               |                        | 100-30               | w      | 6    |
| Plaster on metal lath—3/4"                            | 15.               |                        | 40-x                 | t      | 7    |
| Plaster on plain gypsum lath (with studs)             | 20.               |                        | 40-85                | t      | 3    |
| Gypsum wall board—plain—1/2 in.                       | 50.               |                        | 50-20                | v      | 13   |
| Insulating wall board (uncoated)—1/2 in.              | 50-90             |                        | 40-x                 | t      | 7    |
| * PAINT—2 coats                                       |                   |                        |                      |        |      |
| Asphaltic paint on plywood                            | 0.4               |                        | 100-30               | w      | 6    |
| Aluminum in varnish on wood                           | 0.3-0.5           |                        | 95-0                 | d      | 10   |
| Enamels, brushed on smooth plaster                    | 0.5-1.5           |                        | 92-0                 | b      | 3    |
| Primers or Sealers on insulating wall board           | 0.9-2.1           |                        | 40-x                 | t      | 7    |
| Various Primers + 1 coat flat paint on plaster        | 1.6-3.            |                        | 40-x                 | t      | 7    |
| Flat paint (alone) on insulating wall board           | 1.                |                        | 40-x                 | t      | 7    |
| Water Emulsions on insulating wall board              | 30.-85.           |                        | 40-x                 | t      | 7    |
| * PAINT—Exterior, 3 coats                             |                   |                        |                      |        |      |
| White lead & oil prepared paint on wood siding        | 0.3-1.0           |                        | 50-0                 | d      | 13   |
| White lead-sine oxide & linseed oil on wood           | 0.9               |                        | 95-0                 | d      | 10   |
|                                                       | Lb. per 500 sq ft | PERMEANCE-PERMS        |                      |        |      |
|                                                       |                   | dry cup                | wet cup              |        |      |
| * BUILDING PAPERS AND FELTS                           |                   |                        |                      |        |      |
| Duplex sheet, asphalt laminas, aluminum foil one side | 43                | 0.002                  | 0.176                |        | 12   |
| Saturated and coated felt heavy roll roofing          | 326               | 0.05                   | 1.5                  |        | 12   |
| Kraft and asphalt laminas, Reinforced 30-120-30       | 34                | 0.3                    | 0.24                 |        | 12   |
| Insulation back up, asphalt-sat., one side glossy     | 31                | 0.4                    | 0.9-4.2              |        | 12   |
| Asphalt-saturated and coated sheathing paper          | 43                | 0.3                    | 0.6                  |        | 12   |
| 15-pound asphalt felt                                 | 22                | 3.3                    | 20.2                 |        | 12   |
| 15-pound tar felt                                     | 70                | 1.0                    | 5.6                  |        | 12   |
| Single sheet Kraft, double infused                    | 16                | 4.0                    | 18.2                 |        | 12   |
|                                                       |                   | 30.8                   | 41.9                 |        | 12   |

\* Description is a guide only, and does not insure permeance.

† Methods: d—dry cup; w—wet cup; t—two temperatures; b—special cell; v—air velocity both sides; —average of four methods.

‡ References. No. 7 also includes Bulletin 22 and 25 of the Engineering Experiment Station, University of Minnesota. No. 13 includes data to be published by the Engineering Experiment Station, The Pennsylvania State College.

prate relative humidity limits. The average permeability as found for the dry-cup conditions should therefore have the value  $\bar{\mu}_1$ . Similarly for the wet-cup test between 50 percent and 100 percent relative humidity, the value should be  $\bar{\mu}_2$ . It is not uncommon for these values for wood and wood-fiber materials to be in the ratio of 1 to 3, or higher. (See Table 1.) The average permeability  $\bar{\mu}$  for any other relative humidities at a particular temperature is given by the mean height of the area under the curve of spot permeability for the material at that temperature, between

the appropriate limits of relative humidity. Only average permeabilities (or permeances) are measurable directly in practical tests. However, if several average permeabilities at different relative humidities are known, and can be plotted as for the wet-cup and dry-cup tests shown in Fig. 3, it is possible to construct, by trial and error, a spot permeability curve which will satisfy the condition that the average height of the curve between the appropriate limits for each test must equal the value found in each test. Separate curves are required for each temperature so that a large number of permeance cup tests would be required to cover a range of conditions of both temperature and humidity.

Experience to date shows that the effect of temperature is quite moderate and, for some purposes, differences in temperature at which tests are run

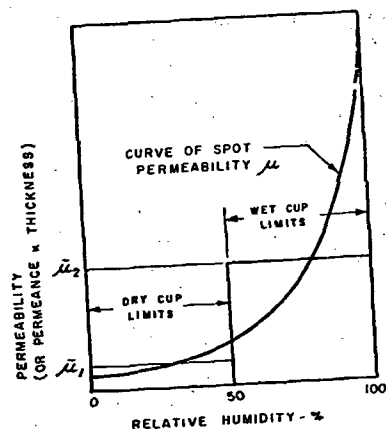


FIG. 3. RELATION BETWEEN DRY AND WET CUP TESTS AND THE SPOT PERMEABILITY FOR A MATERIAL SUCH AS WOOD

may be ignored. Corrections for temperature have been made with some success by the use of an equation based on activation energy<sup>5</sup> which states:

$$\mu = \mu_0 e^{-\frac{E}{RT}} \quad (8)$$

where, in appropriate units,

$\mu_0$  = permeability at  $T = \infty$

$R$  = gas constant

$E$  = activation energy

$e$  = Napierian base of logarithms = 2.718

$T$  = absolute temperature.

Through the use of this equation, spot permeability curves for a variety of temperatures can be constructed from a curve for one temperature, provided only that two tests at different temperatures can be run, from which  $E$ , the activation energy, can be evaluated. In this way it becomes pos-

sible to describe the permeability of a material reasonably completely from the results of as few as five single tests at carefully selected conditions.

No method has yet been found, other than by direct testing for a particular set of conditions, of predicting the effective permeabilities for conditions of temperature gradient along with a humidity (or vapor pressure) gradient, from data obtained under other conditions, even though this is the general situation in practice. A very considerable amount of information is available on the permeances and permeabilities of various materials, but these are frequently obtained at different conditions so that the results cannot be compared directly, nor do they often give a coverage of a range of conditions to permit construction of basic curves of spot permeability or permeance.

Since dry-cup and wet-cup tests are much easier to carry out than tests at intermediate humidities, many of the data available have been obtained in this way. In the absence of data obtained from tests duplicating the conditions of temperature and relative humidity in service the permeance of a piece of material may be judged adequately for many purposes if it is tested by both dry and wet methods. It is obvious that any statement of permeance of a specimen should include the conditions of test.

Method of test E96-53T of the *American Society for Testing Materials* describes procedures for testing for water vapor transmission of materials in sheet form under five different test conditions. These include the dry-cup and wet-cup methods, based on 50 percent relative humidity outside the cup, at either 73.4 or 90 F, and a fifth condition at an elevated temperature of 100 F, with relative humidities of 0 and 90 percent on either side of the sheet. Standard T448m-49 of the *Technical Association of the Pulp and Paper Industry* covers the determination of water vapor transmission of paper and paperboard, and calls for the dry-cup method at 73.4 F., based on 50 percent relative humidity outside the cup.

Unfortunately, there is no general agreement as yet to report results as coefficients of permeance, or of permeability where appropriate, as adopted in this chapter, or to use the same basic units. Test data are frequently reported in terms of weight transmitted per (unit area) (unit time). Such data may be called *water vapor transmission data* or WVT data and values are either high or low depending on the difference of vapor pressure chosen for the test. When this difference is known, WVT data can be converted to permeance, care being taken if conversion of the basic units (weight, area and time) is also required. The following formula applies:

$$\text{Permeance} = \frac{\text{WVT rating}}{\Delta p} \quad (9)$$

where,

WVT rating = weight of vapor transmitted, grains per (sq ft) (hour).

$\Delta p$  = vapor pressure difference in the test, in inches of mercury.

Permeance is expressed in perms.

Table 2 presents the conversion factors applicable to the commonly used units and test methods. Table 1 presents some data on typical building materials showing, in each case, the source and method and, where applicable, the thickness tested.

Water-proofed building papers are listed in *Federal Specifications UU-P-147*, May 24, 1948, according to water vapor resistance required as:

- Class A. For uses where a high degree of water vapor resistance is required.  
 Class B. For uses where a lower degree of water vapor resistance and of water resistance is required.  
 Class C. For uses where a moderate degree of water resistance is required.  
 Class D. For uses where low resistance to water vapor is required.

It may be noted that a paper may be *water-proof*, i.e. possess water resistance, and still have low water vapor resistance.

Detail requirements in these specifications are given as follows, the specified WVT Test being a dry method at 73 F:

Class A paper shall have a minimum tensile strength in each direction of either 35

TABLE 2. CONVERSION FACTORS FOR VAPOR TRANSFER UNITS

| MULTIPLY NUMBER OF<br>BY<br>TO OBTAIN ↓ |                      | WVT UNITS                                            |                        |
|-----------------------------------------|----------------------|------------------------------------------------------|------------------------|
|                                         |                      | grains<br>(24 hrs) (sq m)                            | grains<br>(hr) (sq ft) |
| grains<br>(24 hrs) (sq m)               | by same method*      | 1                                                    | 16.7                   |
| grains<br>(hr) (sq ft)                  | by same method*      | 0.0597                                               | 1                      |
| Perms by same method*                   | method A & B, 73.4 F | 0.144                                                | 2.41                   |
|                                         | method C & D, 90 F   | 0.0846                                               | 1.41                   |
|                                         | method E, 100 F      | 0.0344                                               | 0.575                  |
| NOMINAL TEST CONDITIONS                 |                      | % RELATIVE HUMIDITY ON THE TWO<br>SIDES OF SPECIMEN: |                        |
| Method                                  | Temperature-F        | In cup                                               | Outside cup            |
| A                                       | 73.4                 | 0                                                    | 50                     |
| B                                       | 73.4                 | 100                                                  | 50                     |
| C                                       | 90                   | 0                                                    | 50                     |
| D                                       | 90                   | 100                                                  | 50                     |
| E                                       | 100                  | 0                                                    | 90                     |

\* Data obtained by one method cannot be reliably converted to another method.

To convert  $\frac{\text{grains}}{(24 \text{ hr}) (\text{sq m})}$  to perms multiply by 1.52.

lb per inch width, or 20 lb per inch width, as specified in the invitation for bids. Paper of both strengths shall have a minimum water resistance of 24 hr, and a maximum water vapor permeability (WVT) of 4 grams per (square meter) (24 hr) i.e. 0.576 perm.

Class B paper shall have a minimum tensile strength in each direction of either 35 lb per inch width, or 20 lb per inch width, as specified in the invitation for bids. Paper of both strengths shall have a minimum water resistance of 16 hr, and a maximum water vapor permeability (WVT) of 6 grams per (square meter) (24 hr) i.e. 0.864 perm.

Class C paper shall have a minimum tensile strength in each direction of either 35 lb per inch width, or 20 lb per inch width, as specified in the invitation for bids. Paper of both strengths shall have a minimum water resistance of 8 hr.

Class D paper shall have a minimum tensile strength in each direction of 20 lb per inch width. The paper shall have a minimum water resistance of 10 min., a minimum water vapor permeability (WVT) of 35 grams per (square meter) (24 hr) i.e. 5.04 perms.

## VISIBLE CONDENSATION

Just as moisture collects on the outer surface of a glass of cold water, so does it also condense on other cold materials. In winter, visible condensation may collect on cold closet walls and attic roofs and is commonly observed on frosted window panes. Although condensation, if liquid, may enter an unpainted surface as fast as it forms and thus be unseen, any condensation on a visible surface will for convenience here be called *visible condensation* to distinguish it from *concealed condensation*. Within residences and public buildings, visible condensation occurs in winter and may damage decorative finishes and window sash.

Interior visible condensation occurs when any surface is colder than the dew point of the near-by air. The temperature of any such surface—wall, roof, or glass—is dependent upon the air temperature inside and out-

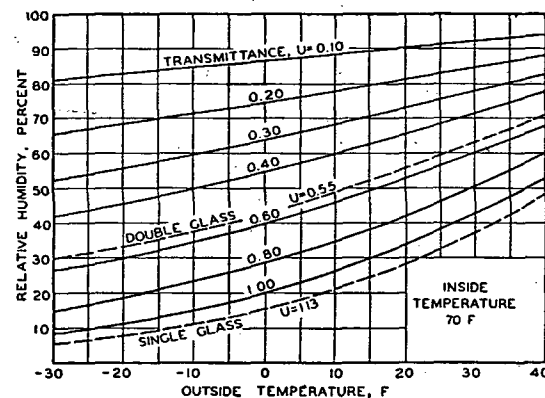


FIG. 4. RELATIVE HUMIDITY AT WHICH VISIBLE CONDENSATION WILL APPEAR ON INSIDE SURFACE

side the building and the heat transfer coefficient  $U$  of the surface structure. Based on a value of 1.65 for the inside surface conductance, Fig. 4 shows the relative humidity in a room at 70 F when visible condensation will appear at various  $U$ -values. The curves for single and double glass at their usual  $U$ -values are included. It should be noted that  $U$ -values as commonly used are an average for a large area within which there may be spots, such as the studs in an insulated wall, where the transmittance is higher. The inside surface temperature of a wall will, in general, be lower at the bottom due to such things as stratification of inside air and the effects of air leakage and of convection in walls with air spaces. Since condensation seeks the coldest spot, values from Fig. 4 can be applied only with caution. As a result, the limit of relative humidity for a non-homogeneous wall is lower than might be inferred from its average  $U$ -value.

Normally, glass is the most likely spot in a heated room for appearance of condensation, but an uninsulated wall surface shielded from radiation by furniture, may be equally cold. In some cases where condensation is barely avoided, the surface, being but little warmer than the dew-point tempera-

ture, is exposed to moisture damage—such as swelling, mold or discoloration.

Visible condensation may occur also in summer. It is often seen on basement concrete walls and floors which are cooled by the earth and which being massive, tend to hold a constant temperature from day to day while the weather dew-point temperature rises. When no water vapor is released in the space, the dew point tends to equal that of the outside (though it is likely to lag when there is slight ventilation). At times the dew-point temperature rises above the temperature of walls and floors and condensation results. If the basement is decorated the trouble may be serious. As an operating problem, the solution may be to reduce ventilation at times of high weather dew point, to warm the walls, or to dehumidify

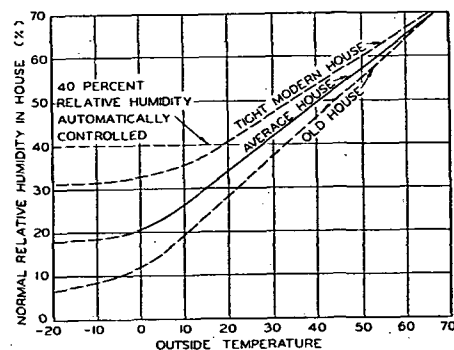


FIG. 5. RELATIVE HUMIDITY IN DWELLINGS

the space. Warming the walls, a slow process at best, is generally accomplished in favorable climates by excess ventilation. In a climate having low temperature at night, it may be feasible to ventilate only at night and thus reduce the moisture content of hygroscopic materials which will then act as a desiccant to retard the dew-point rise during the day. In basement walls and floors insulation should be applied in the concrete or on its outside. Insulation placed on the inside of such walls eliminates visible condensation but fosters concealed condensation. The control of the latter will be discussed. A practical and fully effective technique for such control has, however, not been developed. Usually, sub-surface dwellings should be designed for occupancy and should be dehumidified.

A similar situation is seen in dwellings with concrete floor slabs laid on the ground where such slabs are not a part of the heating system. In a northern climate where high dew-point temperatures occur in summer, condensation or very high relative humidity may damage rugs which are themselves contributors to the trouble since they reduce the floor slab temperature. Slab floors above grade are not so serious a problem as floor slabs on grade but their response to air temperature change is slow. Faster warming is accomplished by the removal of rugs and abundant ventilation at proper times. In their design, floor slabs should have as low specific heat and as high thermal resistance as is consistent with other requirements. Suitable insulation below the slab, especially well drained gravel, will help

somewhat. A top surface cover of insulating value that is unaffected by water on its lower side would be desirable in the less favorable northern climates.

The avoidance of interior visible condensation is partly a construction and partly an operating problem. It is accomplished by reducing the interior dew-point temperature or by raising the surface temperatures that are below the dew-point, or both. The dew-point temperature may be lowered by giving attention to the sources of the moisture, and in winter, may be controlled by ventilation, or possibly by some moisture absorption process. The temperatures of the inside room surfaces in winter may be increased by adding insulation to outside walls, by double glazing of windows, by circulating warm air over the surface, or perhaps by direct heating of the surface. The most expedient method of overcoming a surface condensation difficulty will depend upon special conditions surrounding the problem.

### CONCEALED CONDENSATION IN HEATED BUILDINGS

Water vapor produced in a building necessarily raises the vapor pressure above that outside thus providing the force that causes its diffusion into exterior walls. The amount of vapor pressure rise in the building depends on the amount of vapor produced and inversely on its chance to escape. The resulting balance may be expressed in terms of relative humidity if the inside temperature is 70 F. The relative humidity in heated buildings covers nearly all of the possible range. In zero weather it may be only 10 percent in an office, and 85 percent in an industrial plant where humidification is required for a process, or where vapor release is incidental to a process. In residences the relative humidity in cold winter weather ranges from 10 percent to 60 percent, the latter figure applying to a very small, crowded and unventilated dwelling. A 40 percent level is considered representative of a substantial number of modern tightly constructed small houses although the average house relative humidity is probably below 25 percent. Surveys in residences show that the relative humidity increases as would be expected in warmer weather. Fig. 5 represents the results of one such survey.<sup>5</sup>

When water vapor is allowed to enter a wall and condensation occurs on its outer cold elements, it appears as frost or liquid. If the weather temperature rises frequently, frost melts and becoming liquid, is likely to penetrate capillary materials like wood, or run down when the surface is non-absorbing or is already saturated with water. In weather that is continuously cold for a long period, the frost may build back into a cavity or fibrous insulation and, when it reaches a warmer plane, will run to lower, cooler levels where it forms a mass of ice. Water seepage to the weather side may occur harmlessly in masonry walls when the weather is above freezing but water seepage into the building must obviously be avoided. In typical frame construction with wood sheathing which has large water absorbing capacity, seepage is rare and occurs only after a long period of steady cold weather. More generally, moisture accumulates in wood sheathing and siding through the colder months and reaches a peak in late winter, after which the drying of spring and summer completes the annual cycle. The average winter temperature and its duration are factors in the condensation problem. In Fig. 6 the map of the United States is divided into condensation zones based on winter weather conditions. The solid lines separating the zones follow state lines, and are those recommended by the

*Housing and Home Finance Agency* for the guidance of owners, builders, and architects.<sup>14</sup> The dotted lines are the  $-20^{\circ}\text{F}$ ,  $0^{\circ}\text{F}$ , and  $+20^{\circ}\text{F}$  isotherms of winter design temperature taken from Fig. 1, Chapter 12. It will be noted that there is reasonably good correlation between the zones determined by the two sets of lines. Zone I roughly includes those areas where the design temperature is  $-20^{\circ}\text{F}$  or colder; zone II those for which the design temperature is zero to  $-20^{\circ}\text{F}$ , and zone III those at zero and warmer. Within each zone, similar degrees of condensation trouble are to be expected, and similar corrective measures apply.

In roofs, the condensation problem is much the same as in walls. The roof covering may be even more resistant to the escape of vapor than wall

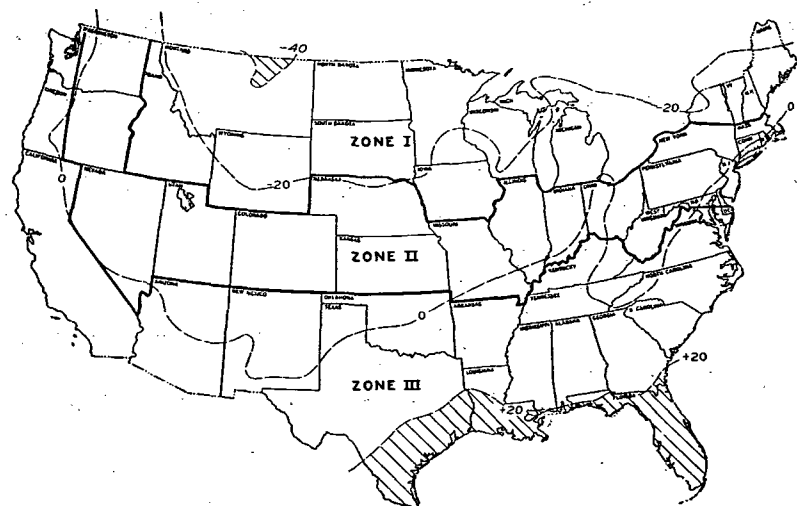


FIG. 6. CONDENSATION ZONES IN THE UNITED STATES

(Zones Include Areas with Design Temperatures about as follows: Zone I,  $-20^{\circ}\text{F}$  and lower; Zone II,  $0^{\circ}\text{F}$  to  $-20^{\circ}\text{F}$ ; and Zone III, above  $0^{\circ}\text{F}$ . Note that cross hatched areas are outside of Zones I and III.)

coverings such as paint; and while paint is likely to be ruptured by excessive moisture, no such relief occurs in roofs. Thus roofs furnish conspicuous examples of rapid decay in lumber.

In crawl spaces over uncovered damp ground, a large water evaporation sometimes occurs and causes condensation on the outer ends of floor joists and other members that are below the floor line and near to the outside. Water vapor from the crawl space may also enter walls, be transported by rising air in a stack effect, and even reach the attic by this route when the wall structure permits. Ventilation, as discussed later in this chapter, is an important correction factor in these cases.

Insulation in a wall or roof reduces heat loss and lowers the temperature of the outer elements of the structure, thus increasing the possibility of condensation if the vapor path to the cold surface is not blocked. Since low vapor resistance is a characteristic of fibrous insulation, the needed vapor resistance must be provided by other means. It is to be noted that,

in typical residential conditions, condensation does not occur in fibrous insulation itself, except when frost has formed on sheathing and gradually built backward among the fibers. Wet insulation may result from this condition or from liquid condensation seeping down from a higher level.

### CONTROL OF CONCEALED CONDENSATION

An excessive accumulation of moisture in walls (or roofs) can be prevented by one or more of the following measures: (1) provide a vapor barrier to limit vapor entrance into the wall, (2) ventilate the building to reduce vapor pressure therein, (3) ventilate the wall cavity to remove vapor that has entered.

1. *Vapor Barrier.* A vapor barrier is the principal and most obvious correction, but each measure is more effective if aided by the effect of another. In habitations, some ventilation of the living space, either incidental or planned, is necessary. Also, a small amount of cavity ventilation is essential in cases where the vapor inflow is not completely stopped and the moisture storing capacity of the outer wall elements is slight. This applies to some prefabricated designs using metal siding.

Vapor barrier sheets are often built into the wall near the warm surface. In wood frame walls they may be applied to the inside surface of the studs. They are sometimes attached to the warm side of the insulating materials, or they may be applied on the cold side of plaster base materials. Special designs may be attached like wall paper to the inside of the wall, when satisfactory from the decorative view point. Sheet barriers often contain asphalt as the vapor resisting ingredient; metal foils, so placed that they are not too cold, may also be used.

The interior wall board or finish material may itself be vapor resistant, or a barrier coating may be applied to its concealed side when that side will not be too cold. The interior finished surface may be coated with a suitable paint having the required vapor resistance and also serving as the decorative finish, or it may be covered by another coat.

A paint coat on the interior finish, though of adequate resistance, is not likely to be so effective as a sheet barrier properly applied during the wall construction. This applies especially to houses of more than one story having cavities in ceilings which open into the outside walls. Such cavities allow vapor entering the ceiling to diffuse or be transported to the cold areas. Stoppage of this path is difficult, requiring normally the painting of the ceiling as well as the walls. Similar treatment may be required on internal partitions, or at least the first stud space adjacent to the cold wall.

The necessary barrier resistance depends on a number of factors. When the vapor flow occurs in annual cycles as in heated buildings, the requirement is not so exacting as it is for a cold storage room where there is no chance for drying out an accumulation of moisture. In a heated structure covered on the outside with materials highly resistant to water vapor such as paint or roll roofing, the winter season is a time of moisture accumulation in the cold outer elements and their safe moisture holding capacity is an important factor in determining the barrier requirement. A house without sheathing requires a better barrier; and a prefabricated design with only a sheet of metal outside of insulation requires very high barrier resistance. The interior vapor pressure and the length and severity of the winter are also important.

For typical frame dwellings with wood sheathing and siding in the northern United States, a barrier permeance of one perm or less has been found



satisfactory. There are cases, however, in residential construction where a one perm barrier would not be adequate and there are also many industrial applications in which a very much higher vapor resistance is required. In any event, the choice of an adequate barrier implies that its permeance be definitely established. The usually accepted test procedure for this purpose is a dry method at a temperature of 70 F to 80 F. If obtainable at reasonable cost (including good application), a barrier better than required should be chosen for any construction. Despite the theoretical possibility of safely discharging some vapor through a wall, a higher than minimum permeance is not preferred.

An exact statement showing which buildings require a vapor barrier is not readily formulated. However, in view of the distressing results its

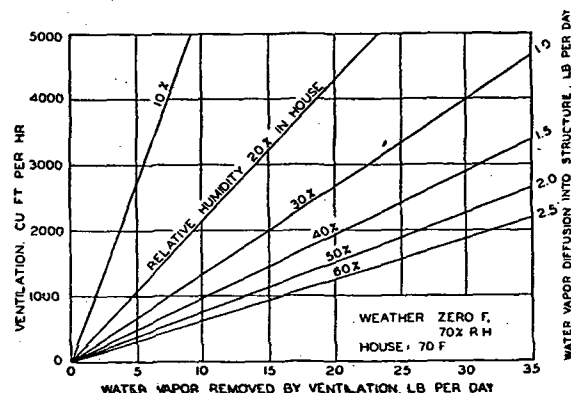


FIG. 7. WATER VAPOR BALANCE IN A DWELLING  
(Vapor Barrier, 1 perm; Wall and Ceiling Area 2000 sq ft Insulated)

omission may bring, it is tentatively recommended that the walls of every well constructed modern dwelling include a vapor barrier when the construction includes any material that would be damaged by moisture or its freezing. This applies to all condensation zones in Fig. 6 when the  $U$  value for the wall is lower than 0.25 Btu per (sq ft) (hr) (F deg), and it applies in Zone I and Zone II to walls of higher transmittance.

In applying vapor resistance to a wall, there are certain fundamental principles which should be followed. First, the vapor barrier should be placed as near to the warm surface of the wall as practicable. Second, it should be continuous with no direct openings through the barrier. Good workmanship and application are very important. Workmanship that leaves two openings through the barrier, or around its margin, at different levels, connecting air spaces at only slightly different temperatures, leaves a path for thermosyphon air rotation which will transport large amounts of water vapor from the warmer space to the colder. If a membrane barrier is used back of the plaster or interior finish, its joints should be made over some solid framing member, and not between the studs or in similar places. Usually a two-inch lap over a framing member will make a sufficiently tight joint when the interior finish is applied. Such a lap, however, without backing would not be adequate. Barriers attached to the warm side of

insulation should form a continuous unbroken membrane over the entire insulated area. Edges should be lapped over framing members; ends of strips should be fastened by lapping over plates or headers. All openings for electrical fixtures and joints around window and door casings should be carefully sealed. Holes accidentally made in the barrier should be sealed.

2. *Ventilation of Living Space.* The second measure listed for the control of concealed condensation is ventilation of the house. This measure is obviously necessary as an accompaniment to a vapor barrier since, if the barrier blocks entrance into the walls, the water vapor must be removed

TABLE 3. RECOMMENDED GOOD PRACTICE<sup>a</sup>—LOFT AND ATTIC VENTILATION<sup>a</sup>

FLAT ROOF—SLOPE LESS THAN 3 INCHES IN 12 INCHES

Condensation Zone I<sup>b</sup>: Total net area of ventilation should be  $\frac{1}{2}$ sooth<sup>b</sup>, distributed uniformly at the eaves plus a vapor barrier in the top story ceiling. Free circulation must be provided through all spaces.  
Condensation Zone II and III: Same as for Zone I.

GABLE ROOF—SLOPE OVER 3 INCHES IN 12 INCHES

Condensation Zone I: Total net area of at least 2 louvers on opposite sides located near the ridge to be  $\frac{1}{2}$ sooth<sup>b</sup> plus a vapor barrier in the top story ceiling.  
Condensation Zone II: Same ventilation as for Zone I. A vapor barrier is not considered necessary.  
Condensation Zone III: Same as for Zone II.

HIP ROOF

Condensation Zone I: Total net area of ventilation should be  $\frac{1}{2}$ sooth<sup>b</sup> with  $\frac{1}{2}$ sooth<sup>b</sup> distributed uniformly at the eaves and  $\frac{1}{2}$ sooth<sup>b</sup> located at the ridge with all spaces interconnected. A vapor barrier should also be used in the top story ceiling.  
Condensation Zone II: Same ventilation as for Zone I. A vapor barrier is not considered necessary.  
Condensation Zone III: Same as for Zone II.

GABLE OR HIP ROOF—WITH OCCUPANCY CONTEMPLATED

Condensation Zone I: Total net area of ventilation should be  $\frac{1}{2}$ sooth<sup>b</sup> with  $\frac{1}{2}$ sooth<sup>b</sup> distributed uniformly at the eaves and  $\frac{1}{2}$ sooth<sup>b</sup> located at the ridge with all spaces interconnected. A vapor barrier should also be used on the warm side of the top full story ceiling, the dwarf walls, the sloping part of the roof, and the attic story ceiling.  
Condensation Zone II: Same as for Zone I.  
Condensation Zone III: Same as for Zone I except that a vapor barrier is not considered necessary if insulation is omitted.

<sup>a</sup> It is recognized that in many areas increased ventilation may be desirable for summer comfort. For winter comfort, insulation is recommended between a living space and a loft or attic ventilated at these rates.

<sup>b</sup> Refers to area enclosed within building lines at eave level.

<sup>c</sup> The zone numbers refer to Fig. 6.

by other means. No great volume of air change is necessary, however, and normal infiltration alone is frequently all that is required in winter weather.

The effectiveness of ventilation is shown in Fig. 7, which also shows the small amount of water vapor escaping into the barrier-equipped, well-insulated walls and ceilings (2000 sq ft) of a typical small dwelling, the floor being neglected. Evidently, ventilation of 2000 cu ft per hr will remove 21 lbs of vapor per day with the relative humidity at 40 percent, while at the same time 1.5 lbs escapes into the structure. The total vapor production (22.5 lb) is a typical amount. Double glass will be barely safe from visible condensation as will be seen in Fig. 4. By reference to Chapter 6, 2000 cu ft per hr appears to be near the minimum for odor control, and ventilation would have to be higher when cooking is done. By reference to Chapter 11, it appears that usual infiltration will normally supply the necessary air change, but that supplementary ventilation may be neces-



sary in kitchen and laundry for proper vapor control and for the reduction of peaks in relative humidity which would otherwise occur in those areas.

3. *Ventilation of Structure.* The third measure listed for the control of concealed condensation, ventilation of the structure itself, is effective in certain cases especially as a supplement to warm side vapor resistance which is considerable but not of itself fully adequate. Air from outside is used. The vents must be shielded from the entrance of rain and insects.

Attics and crawl spaces may be considered as parts of the structure, and for these portions ventilation is practically a necessity. Attic ventilation has long been an established practice but its effectiveness is likely to be diminished by the newer practice of adding insulation to ceilings. Insulation requires added ventilation which in turn necessitates adequate insulation. The recommended ventilation shown in Table 3 for dwellings<sup>14</sup> is based on such insulation. The *net area* refers to the total of all openings free from obstructions. The use of louvers and 8-mesh screen (usually recommended) requires a gross area 2.25 times that listed. In Zone I of Fig. 6 a ceiling vapor barrier is recommended for all constructions. It is also necessary that stray openings from walls into the attic, or around a loose fitting attic door be avoided. The *stack effect* allows a large inflow of warm air from the dwelling, transporting much vapor to a danger area. More desirable ventilation of the house can be arranged.

Crawl spaces under dwellings where the earth is damp and uncovered require a high rate of ventilation. At least four openings, one at each corner, as high as possible, should be provided.<sup>14</sup> Their total net area may be calculated by the formula:

$$a = \frac{2L}{100} + \frac{A}{300} \quad (10)$$

where:

$L$  = the perimeter of the crawl space, linear ft.

$A$  = the area of the crawl space, square feet.

$a$  = the total net area of all vents, (or the gross area if a 4-mesh screen is used), square feet.

This ventilation is usually sufficient but cools the first floor so much that insulation is needed. A better treatment is a cover on the damp ground. This cover may be a concrete slab, or merely heavy roll roofing laid on a graded surface with its edges lapped 2 in. (but not necessarily cemented). With this barrier, the vent area may be reduced to 10 percent of that calculated by Equation 10.

In building walls, cavity ventilation can be applied in a moderate climate as the sole vapor control system. In general, however, air passages in walls designed to remove an unrestricted vapor supply are unduly large and may waste considerable heat. On the other hand, a barrier as the only control measure would, in some cases, require so high a resistance as to be impractical. Ventilation of the structure in conjunction with a vapor barrier, is a procedure with important applications, but its general utility has not been fully investigated. Ventilation is most effective when each structural space has a clearly defined air passage with an inlet and outlet. In walls a small thermosyphon effect may be utilized by locating one vent at the bottom and one at the top of each space.

The best time to vapor-proof a building is during its construction. After a building is completed, ventilation of the occupied space is the most easily applied of the three basic control measures. Paint that is chosen for its low vapor permeance can be applied as a barrier on the interior with good results, care being taken that all areas, including parts of partitions and ceilings which offer an indirect vapor path to the cold wall, are covered. Ventilation of the wall cavity is effective in certain cases especially to supplement the foregoing measures. When such venting is required, each cavity space isolated by framing should be separately vented with an inlet and outlet judiciously placed, to accomplish proper air change.

### CONDENSATION IN COOLED STRUCTURES

Water vapor is sometimes an even greater problem in cooled structures than in those which are heated, but the basic facts of its migration and condensation on cold surfaces are the same. Refrigerators, cold pipes and cold vessels all require insulation and should be provided with a vapor barrier. The barrier, as always, should be placed on the warm side of the insulation and as close as possible to the warm surface of any enclosure. It resists the movement of water vapor toward the colder parts of the structure, and its job is even more exacting than that required in residential construction. In the case of an insulated cold pipe line, the process is likely to be uninterrupted for years and there is no chance for vapor that enters the insulation to dry out periodically. Also, no vapor can escape from the cold side, if this is a metal (vapor tight) pipe. For such an application vapor control requires insulating material that is itself very highly resistant to water vapor or a coating whose permeance is the minimum obtainable, not over 0.1 perm. Metal coverings are desirable but difficult to apply.

Similar considerations apply in the case of cold rooms whether constructed inside a heated building or as a separate building. In the latter case, cold rooms operating above freezing provide some periods of vapor reversal in winter but such drying can be of little help. Refrigerators, however, if lined with cement or other vapor permeant material, will allow slight amounts of vapor to pass and to that extent reduce the accumulation of moisture that may have penetrated the barrier. While this is helpful, emphasis must be placed on an adequate warm side barrier not greater than 0.1 perm.

Summer air cooling for comfort does not involve serious vapor problems and vapor control measures are not essential. Normally the cooled air is little, if any, colder than the dew-point temperature of the outside atmosphere and there are no areas of condensation. However, the interior vapor pressure is often below that outside and therefore, vapor, which diffuses inward, adds to the cooling load. Vapor barriers in walls installed for winter needs, are a help in reducing this element of the cooling load.

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## CHAPTER 11

## INFILTRATION AND VENTILATION

Causes of Infiltration, Infiltration Due to Wind Pressure, Infiltration Due to Temperature Difference, Sealing of Vertical Openings, Infiltration Measurement, Natural Ventilation, Wind Forces, Temperature Difference Forces, Heat Removal, Effect of Unequal Openings, Combined Wind and Temperature Forces, Types of Openings, General Ventilation Rules, Ventilation of Animal Shelters, Garage Ventilation

Infiltration is the air leakage through cracks and interstices, around windows and doors, and through floors and walls. Its magnitude depends on the structural design, workmanship, and condition of the building. The rate of infiltration cannot be controlled by the inhabitants of the building to any considerable extent. Natural ventilation is the controlled displacement of air through openings, such as windows, doors and ventilators as well as through combustion heating devices.

### CAUSES OF INFILTRATION

The air leakage which takes place through various apertures in buildings must be estimated in heating and cooling calculations and enough heating or cooling capacity provided to offset the heat lost or gained by the air leakage. The rate of air flow into and out of a building depends on the magnitude of the pressure difference between the inside and outside of the structure and on the resistances presented to this pressure difference. The pressure difference exerted on the building walls by the air may be caused either by wind or by a difference in density of the air inside and outside the building. The effect of the wind depends on the interrelation of the speed and direction of the wind and the exposure of the building. The effect of the difference in the density of the air depends on the magnitude of the inside-outside temperature difference, the height of the rooms, the shape of the openings, and their elevation in the room or building. The effect of the difference in density is often referred to as the chimney or stack effect. The pattern of air flow through any part of the structure depends on both the pressure difference and the openings. In general, when the pressure difference is the result of wind pressure, air will enter the building through openings in the windward walls and leave through openings in the leeward walls or through ventilating ducts in the roof. When the pressure difference is caused by the inside-outside temperature difference the flow will be along the path of least resistance from inlets at lower levels to outlets at higher levels in a heated building or in the opposite direction for an air-conditioned building.

An exact estimate of the amount of infiltration under design conditions is difficult to make. The complicating factors include (1) variations in building construction, particularly as to width of crack or size of openings through which air leakage takes place; (2) the variations in wind velocity and direction; (3) the exposure of the building with respect to air leakage openings, and with respect to adjoining buildings; (4) the

variations in outside temperatures which influence the chimney effect; (5) the relative area and resistance of openings on the windward and leeward sides, and on the lower floors and on the upper floors; and (6) the influence of a planned air supply and the related outlet vents. Tight construction is essential for preventing large heat loss due to infiltration.

### INFILTRATION DUE TO WIND PRESSURE

The wind causes a pressure to be exerted on one or two sides of a building. As a result, air comes into the building on the windward side through cracks or porous construction, and a similar quantity of air leaves on the leeward side through like openings. In general, the resistance to air movement is similar on the windward to that on the leeward side. This causes a building up of pressure within the building, and a lesser air leakage than that experienced in single wall tests as determined in the laboratory. It is assumed

TABLE 1. INFILTRATION THROUGH WALLS<sup>a</sup>  
Expressed in cubic feet per square foot per hour

| TYPE OF WALL                                       | WIND VELOCITY, MILES PER HOUR |      |      |      |      |      |
|----------------------------------------------------|-------------------------------|------|------|------|------|------|
|                                                    | 5                             | 10   | 15   | 20   | 25   | 30   |
| 8½ in. Brick Wall <sup>b</sup> ...                 | 2                             | 4    | 8    | 12   | 19   | 23   |
|                                                    |                               |      |      |      |      |      |
| Plain.....                                         | 0.02                          | 0.04 | 0.07 | 0.11 | 0.16 | 0.24 |
| Plastered <sup>c</sup> .....                       |                               |      |      |      |      |      |
| 13 in. Brick Wall <sup>b</sup> ...                 | 1                             | 4    | 7    | 12   | 16   | 21   |
|                                                    | 0.01                          | 0.01 | 0.03 | 0.04 | 0.07 | 0.10 |
|                                                    | 0.03                          | 0.10 | 0.21 | 0.36 | 0.53 | 0.72 |
| Frame Wall, with lath and plaster <sup>e</sup> ... | 0.03                          | 0.07 | 0.13 | 0.18 | 0.23 | 0.26 |

<sup>a</sup> The values given in this table are 20 percent less than test values to allow for building up of pressure in rooms, and are based on test data reported in the papers listed in chapter footnotes.

<sup>b</sup> Constructed of porous brick and lime mortar—workmanship poor.

<sup>c</sup> Two coats prepared gypsum plaster on brick.

<sup>d</sup> Furring, lath, and two coats prepared gypsum plaster on brick.

<sup>e</sup> Wall construction: Bevel siding painted or cedar shingles, sheathing, building paper, wood lath and three coats gypsum plaster.

that actual building leakages, owing to this building up of pressure, will be 80 percent of laboratory test values. While there are cases where this is not true, tests in actual buildings substantiate the factor for the general case. Mechanical ventilating systems are frequently designed to produce positive or negative pressures in an enclosure, which are greater or lower than prevalent wind pressures. In such designs, if the specified rate at which air is to be supplied to, or removed from, the enclosure by positive means, exceeds the infiltration rate, it is common practice to use the greater value in determining the heating capacity to warm the outside air.

### Infiltration Through Walls

Data on infiltration through brick and frame walls are given in Table 1.<sup>1</sup> The brick walls listed in this table are walls which show poor workmanship, and which are constructed of porous brick and lime mortar. For good workmanship, the leakage through hard brick walls with cement-lime mortar does not exceed one-third the values given. These tests indicate that plastering reduces the leakage by about 96 percent; a heavy

coat of cold water paint, 50 percent; and three coats of oil paint carefully applied, 28 percent. The infiltration through walls ranges from 6 to 25 percent of that through windows and doors in a 10-story office building, with imperfect sealing of plaster at the baseboards of the rooms. With perfect sealing the range is from 0.5 to 2.7 percent; or a practically negligible quantity, which indicates the importance of good workmanship in proper sealing at the baseboard. It will be noted from Table 1 that the infiltration through properly plastered walls can be neglected.

The value of building paper, when applied between sheathing and shingles, is indicated by Fig. 1, which represents the effect on outside construction only, without lath and plaster. The effectiveness of plaster properly applied is no justification for the use of low grade building paper, or of the poor construction of the wall containing it. Not only is it diffi-

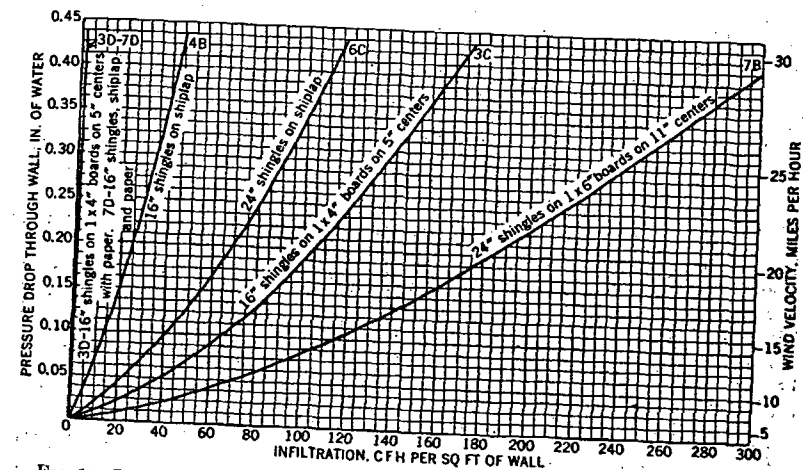


FIG. 1. INFILTRATION THROUGH VARIOUS TYPES OF SHINGLE CONSTRUCTION

cult to secure and maintain the full effectiveness of the plaster, but also it is highly desirable to have two points of high resistance to air flow with an air space between them. The infiltration indicated in Fig. 1 is that determined in the laboratory, and should be multiplied by the factor 0.80 to give proper working values.

### Window and Door Leakage

There are two methods of estimating air leakage through window and door cracks, namely, (1) the crack method, and (2) the air change method. The crack method is generally regarded as being more accurate than the air change method, provided the variables, such as crack width and clearance, can be properly evaluated.

### Crack Method

The crack method is based on known air leakage factors for various types of windows, and widths of crack and clearance. The wind velocity and length of crack are also considered when the crack method is employed.

TABLE 2. INFILTRATION THROUGH WINDOWS  
Expressed in Cubic Feet per Foot of Crack per Hour<sup>a</sup>

| TYPE OF WINDOW                                 | REMARKS                                                                                                                                         | WIND VELOCITY, MILES PER HOUR |     |     |     |     |     |
|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-----|-----|-----|-----|-----|
|                                                |                                                                                                                                                 | 5                             | 10  | 15  | 20  | 25  | 30  |
| Double-Hung Wood Sash Windows (Unlocked)       | Around frame in masonry wall—not calked <sup>b</sup>                                                                                            | 3                             | 6   | 14  | 20  | 27  | 35  |
|                                                | Around frame in masonry wall—calked <sup>b</sup>                                                                                                | 1                             | 2   | 3   | 4   | 5   | 6   |
|                                                | Around frame in wood frame construction                                                                                                         | 2                             | 6   | 11  | 17  | 23  | 30  |
|                                                | Total for average window, non-weatherstripped, 1/4-in. crack and 3/4-in. clearance. <sup>c</sup> Includes wood frame leakage <sup>d</sup>       | 7                             | 21  | 39  | 59  | 80  | 104 |
|                                                | Ditto, weatherstripped <sup>e</sup>                                                                                                             | 4                             | 13  | 24  | 36  | 49  | 63  |
|                                                | Total for poorly fitted window, non-weatherstripped, 3/4-in. crack and 3/4-in. clearance. <sup>c</sup> Includes wood frame leakage <sup>d</sup> | 27                            | 69  | 111 | 154 | 199 | 249 |
|                                                | Ditto, weatherstripped <sup>e</sup>                                                                                                             | 8                             | 19  | 34  | 51  | 71  | 92  |
|                                                | Non-weatherstripped, locked                                                                                                                     | 20                            | 45  | 70  | 96  | 125 | 154 |
| Double-Hung Metal Windows <sup>f</sup>         | Non-weatherstripped, unlocked                                                                                                                   | 20                            | 47  | 74  | 104 | 137 | 170 |
|                                                | Weatherstripped, unlocked                                                                                                                       | 6                             | 19  | 32  | 46  | 60  | 76  |
| Rolled Section Steel Sash Windows <sup>g</sup> | Industrial pivoted, 1/4-in. crack <sup>h</sup>                                                                                                  | 52                            | 108 | 176 | 244 | 304 | 372 |
|                                                | Architectural projected, 1/4-in. crack <sup>h</sup>                                                                                             | 15                            | 36  | 62  | 88  | 112 | 139 |
|                                                | Architectural projected, 3/4-in. crack <sup>h</sup>                                                                                             | 26                            | 52  | 88  | 118 | 152 | 182 |
|                                                | Residential casement, 1/4-in. crack <sup>i</sup>                                                                                                | 6                             | 18  | 33  | 47  | 60  | 74  |
|                                                | Residential casement, 3/4-in. crack <sup>i</sup>                                                                                                | 14                            | 32  | 52  | 76  | 100 | 128 |
|                                                | Heavy casement section, projected, 1/4-in. crack <sup>j</sup>                                                                                   | 3                             | 10  | 18  | 26  | 36  | 48  |
|                                                | Heavy casement section, projected, 3/4-in. crack <sup>j</sup>                                                                                   | 8                             | 24  | 38  | 54  | 73  | 92  |
|                                                | Hollow Metal, vertically pivoted window <sup>k</sup>                                                                                            | 30                            | 88  | 145 | 186 | 231 | 243 |

<sup>a</sup> The values given in this table, with the exception of those for double-hung and hollow metal windows are 20 percent less than test values to allow for building up of pressure in rooms, and are based on test data, reported in the papers listed in chapter footnotes.

<sup>b</sup> The values given for frame leakage are per foot of sash perimeter, as determined for double-hung wood windows. Some of the frame leakage in masonry walls originates in the brick wall itself, and cannot be prevented by calking. For the additional reason that calking is not done perfectly and deteriorates with time, it is considered advisable to choose the masonry frame leakage values for calked frames as the average determined by the calked and non-calked tests.

<sup>c</sup> The fit of the average double-hung wood window was determined as 1/4-in. crack and 3/4-in. clearance by measurements on approximately 600 windows under heating season conditions.

<sup>d</sup> The values given are the totals for the window opening per foot of sash perimeter, and include frame leakage and so-called elsewhere leakage. The frame leakage values included are for wood frame construction, but apply as well to masonry construction assuming a 50 percent efficiency of frame calking.

<sup>e</sup> A 1/4-in. crack and clearance represent a poorly fitted window, much poorer than average. <sup>f</sup> Windows tested in place in building, so that no reduction from test values is necessary, as mentioned in footnote <sup>a</sup>.

<sup>g</sup> Industrial pivoted window generally used in industrial buildings. Ventilators horizontally pivoted at center or slightly above, lower part swinging out.

<sup>h</sup> Architecturally projected made of same sections as industrial pivoted, except that outside framing member is heavier, and it has refinements in weathering and hardware. Used in semi-monumental buildings such as schools. Ventilators swing in or out and are balanced on side arms. 1/4-in. crack is obtainable in the best practice of manufacture and installation, 3/4-in. crack considered to represent average practice.

<sup>i</sup> Of same design and section shapes as so-called heavy section casement, but of lighter weight. 1/4-in. crack is obtainable in the best practice of manufacture and installation, 3/4-in. crack considered to represent average practice.

<sup>j</sup> Made of heavy sections. Ventilators swing in or out and stay set at any degree of opening. 1/4-in. crack is obtainable in the best practice of manufacture and installation, 3/4-in. crack considered to represent average practice. Known as Intermediate Windows by steel window manufacturers.

<sup>k</sup> With reasonable care in installation, leakage at contacts where windows are attached to steel frame-work and at mullions, is negligible. With 3/4-in. crack, representing poor installation, leakage at contact with steel framework is about one third, and at mullions, about one-sixth of that given for industrial pivoted windows in the table.

The amount of infiltration for various types of windows is given in Table 2.<sup>3</sup> The fit of double-hung wood windows is determined by crack and clearance. Crack thickness is equivalent to one-half the difference between the inside window frame dimension and the outside sash width. The difference between the width of the window frame guide and the sash thickness is considered as the clearance. The length of the perimeter opening or crack for a double-hung window is equal to three times the width, plus two times the height, or in other words, it is the outer sash perimeter length, plus the meeting rail length. All of the window crack in any given

room is not necessarily used in estimating the infiltration heat loss by the crack method. The length of crack to be selected in any given case depends on the number of exposed sides, as explained in Chapter 12.

Values of leakage shown in Table 2 for the average double-hung wood window were determined by using, on nine windows tested in the laboratory, the average measured crack and clearance of a large number of windows found in a field survey. In addition, the table gives figures for a poorly fitted window. All of the figures for double-hung wood windows are for the unlocked condition. Just how a window is closed, or fits when it is closed, has considerable influence on the leakage. The leakage will be high if the sash are short, if the meeting rail members are warped, or if the frame and sash are not fitted squarely to each other. It is possible to have a window with approximately the average crack and clearance that will have a leakage at least double that of the figures shown. Values for the average double-hung wood window in Table 2 are considered to be easily obtainable figures, provided the workmanship on the window is good. Should it be known that the windows under consideration are poorly fitted, the larger leakage values should be used. Locking a window generally decreases its leakage, but in some cases may push the meeting rail members apart and increase the leakage. On windows with large clearances, locking will usually reduce the leakage.

Wood casement windows may be assumed to have the same unit leakage as for the average double-hung wood window when properly fitted. Locking, a normal operation in the closing of this type of window, maintains the crack at a low value.

For metal pivoted sash, the length of crack is the total perimeter of the movable or ventilating sections. Frame leakage on steel windows may be neglected when they are properly grouted with cement mortar into brick work or concrete. When they are not properly sealed, the linear feet of sash section in contact with steel work at mullions should be figured at 25 percent of the values given in Table 2 for industrial pivoted windows.

When storm sash are applied to well fitted windows, some reduction in infiltration is secured; the application of the sash provides an air space which reduces the heat transmission and helps prevent the frosting of the windows.<sup>3</sup> By applying storm sash to poorly fitted windows, a reduction in leakage of 50 percent may be obtained, the effect, so far as air leakage is concerned, being roughly equivalent to that obtained by the installation of weatherstrips.

### Door Leakage

Doors vary greatly in fit because of their large size and tendency to warp. For a well fitted door, the leakage values for a poorly fitted double-hung wood window may be used. If poorly fitted, twice this figure should be used. If weatherstripped, the values may be reduced one-half. A single door which is frequently opened, as might be the case in a store, should have a value applied which is three times that for a well fitted door. This extra allowance is for opening and closing losses, and is kept from being greater by the fact that doors are not used as much in the coldest and windiest weather.

The infiltration rate through swinging and revolving doors is generally a matter of judgment by the engineer making cooling load determinations, and in the absence of adequate research data, the values given in Table 3 represent current engineering practice. Some tests of infiltration through swinging and revolving doors have been reported.<sup>4</sup> The data in Table 3

are indicative of what might be expected in this connection, but it should be noted that Table 3 is based on a no-wind condition, and therefore not directly applicable to heating design.

A wide range of infiltration rates would be expected for swinging doors because of variations in the indoor-outdoor pressure difference caused by wind, temperature differences, and the degree to which a heating or an air-conditioning system tended to raise or lower the inside pressure by blower action. The frequency of door usage would also affect the amount of leakage per passage.

### Air Change Method

The amount of air leakage may be estimated by assuming a certain number of air changes per hour for each room, the number of changes assumed being dependent upon the type, use, and location of the room, as

TABLE 3. INFILTRATION THROUGH 72-INCH REVOLVING DOOR AND 36-INCH SWINGING DOOR<sup>a,b</sup>

(Cubic Feet per Person per Passage)

| USAGE                      | FREELY-REVOLVING DOOR | DOOR EQUIPPED WITH BRAKE |
|----------------------------|-----------------------|--------------------------|
| Infrequent.....            | 75                    | 60                       |
| Average.....               | 60                    | 50                       |
| Heavy.....                 | 40                    | 40                       |
| 36-Inch Swinging Door..... | 20 to 100             |                          |

<sup>a</sup> These figures are based on the assumption that there is no wind pressure and that swinging doors are in use in one wall only. Any swinging doors in other walls should be kept closed to insure air conditioning in accordance with these recommended standards.

<sup>b</sup> From Application Engineering Standards for Air Conditioning for Comfort 1947, Air Conditioning & Refrigeration Institute, Inc., Washington, D. C. and from experimental data of National Bureau of Standards. Used by permission.

indicated in Table 4. Where it is not possible to determine or pre-determine with accuracy the width of crack or clearance of windows, or when other sources of air leakage cannot readily be evaluated, as is often the case, the use of the air change method may be justified.<sup>5</sup>

The values in Table 4 may be used with reasonable accuracy for residences, and are the requirements for each room. The total infiltration allowance for the entire building should be one-half the sum of the infiltration allowances of the individual rooms, since whatever air enters on the windward side, generally leaves the building on the leeward side, and the infiltration requirements therefore do not exist simultaneously on all sides or in all rooms. An allowance of one air change per hour for all sources of air leakage for the entire volume may be considered average for a well constructed residence.

The air leakage, due to opening and closing of doors in vestibules, is sometimes based on the air change method, even though the air leakage estimates for other rooms are based on the crack method. Except for vestibules and reception halls, it is not advisable to attempt to apply the air change method to factories and industrial and commercial buildings, because of wide variations in the type and percentage of fenestration which is the principal source of air leakage in such buildings.

### INFILTRATION DUE TO TEMPERATURE DIFFERENCE

The air exchange due to temperature difference, inside to outside, is a chimney effect, causing air to enter through openings at lower levels, and to leave at higher levels<sup>6</sup> when the building is heated or causing flow in the reverse direction when the building is cooled. This air exchange is usually of considerable importance in tall, single-story buildings with openings near the ground level and near the ceiling; it should also be considered in tall, multi-story buildings unless the sealing between various floors is nearly perfect; and may be appreciable in one-story buildings with basements and attics.

The flow of air through a building under the influence of indoor-outdoor temperature difference is quite complex except for single-story structures without a basement or attic. It can best be understood by visualizing the building as a complex chimney with a number of passages and a number of restrictions. The basement represents the lower section of this imaginary chimney with air moving inward through cracks in the walls and around

TABLE 4. AIR CHANGES TAKING PLACE UNDER AVERAGE CONDITIONS IN RESIDENCES, EXCLUSIVE OF AIR PROVIDED FOR VENTILATION<sup>a</sup>

| KIND OF ROOM OR BUILDING    | NUMBER OF AIR CHANGES TAKING PLACE PER HOUR | KIND OF ROOM OR BUILDING                    | NUMBER OF AIR CHANGES TAKING PLACE PER HOUR |
|-----------------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|
| Rooms, 1 side exposed.....  | 1                                           | Rooms with no windows or outside doors..... | 1/2 to 3/4                                  |
| Rooms, 2 sides exposed..... | 1 1/2                                       | Entrance Halls.....                         | 2 to 3                                      |
| Rooms, 3 sides exposed..... | 2                                           | Reception Halls.....                        | 2                                           |
| Rooms, 4 sides exposed..... | 2                                           | Bath Rooms.....                             | 2                                           |

<sup>a</sup> For rooms with weatherstripped windows or storm sash, use 1/2 these values, where applicable, but never less than 1/2 air change.

windows and doors. The air then moves upward through cracks and openings in the floor which acts like a damper in the chimney. Above the floor the chimney has many parallel passages consisting of the several rooms and the hollow wall spaces in certain types of construction. These separate passages are all interconnected by cracks and also communicate with the outside through cracks and fissures. The ceiling acts as another damper with air flowing upward through various cracks and openings. This condition is repeated in every story of a multi-story building and can be further complicated by open stairways, elevator shafts, and utility ducts. The attic finally represents the union of all the parallel passages in the chimney with the outward flow of air being again restricted by the roof construction.

Since the chimney effect in a building produces a negative pressure and an inward flow of air at the lower levels and positive pressure and outward flow at the higher levels, a neutral zone<sup>7</sup> exists near midheight where there is no pressure difference between indoors and outdoors, if the openings are about uniformly distributed in a vertical direction. At the neutral zone there would be no air flow through openings in the outside walls as a result of temperature differences.

The infiltration caused by the indoor-outdoor temperature differences can be calculated by means of the crack method described earlier in this chapter for determining the infiltration caused by wind pressure. This is done by determining the equivalent wind velocity that would produce the same rate of infiltration as was caused by the prevailing temperature difference. It is recommended that one-half the total crack length of the

building be used for this computation. To determine the infiltration caused by the temperature difference, one-half the crack length of the building is multiplied by the infiltration coefficient from Table 2 corresponding to the equivalent wind velocity computed from the following equation developed from basic relationships between velocity, pressure, density and temperature.

$$V_e = B\sqrt{h(t_i - t_o)} \quad (1)$$

where

- $V_e$  = equivalent wind velocity corresponding to the temperature difference ( $t_i - t_o$ ), miles per hour.
- $h$  = height of rooms, feet.
- $t_i$  = inside temperature, Fahrenheit.
- $t_o$  = outside temperature, Fahrenheit.
- $B$  = a constant to account for leakage through floor and ceiling and for the number of stories in the building.

The constant  $B$  would be 0.12 for a single-story building or for any story of a multi-story building whose floor and ceiling were impervious to air, whereas the value of  $B$  was found to be approximately unity for a single-story frame building with basement and attic having double wood flooring, plastered ceiling, and the walls finished with plasterboard on the inside. The value of this constant would increase as the the number of stories increased and for stories farther removed from the neutral zone in either direction in buildings that lacked perfect sealing between stories.

### Sealing of Vertical Openings

In tall, multi-story buildings, every effort should be made to seal off vertical openings, such as stair-wells and elevator shafts, from the remainder of the building. Stair-wells should be equipped with self-closing doors, and, in exceptionally high buildings, should be closed off into sections of not over 10 floors each. Plaster cracks should be filled. Elevator enclosures should be tight, and solid doors should be used.

If the sealing of the vertical openings is made effective, no allowance need be made for the chimney effect. Instead, the greater wind movement at the greater heights makes it advisable to install additional heating surface on the upper floors above the level of neighboring buildings, this additional surface being increased as the height is increased. One arbitrary rule is to increase the heating surface on floors above neighboring buildings by an amount ranging from 5 percent to 20 percent. This extra heating surface is required only on the windward side and on windy days, and hence, automatic temperature control is especially desirable with such installations.

In stair-wells that are open through many floor levels, although closed off from the remainder of each floor by doors and partitions, the stratification of air makes it advisable to increase the amount of heating surface at the lower levels, and to decrease the amount at higher levels. One rule is to calculate the heating surface of the entire stair-well in the usual way, and to place 50 per cent of this in the bottom third, the normal amount in the middle third, and the balance in the top third.

### Infiltration and Air for Combustion

Infiltration in buildings normally supplies the air required for combustion by fuel-burning appliances, but in some cases weatherstripping, sealing and calking may reduce infiltration to the point that special openings must be provided to supply adequate air to the heating appliances. This need for combustion air is recognized in various building codes. For instance, the State Building Construction Code of New York State for One- and Two-Family Dwellings<sup>8</sup> requires that an air inlet area not less than the area of the smoke pipe connection be provided if adequate air supply at all times is not assured. Similarly the same code for multiple

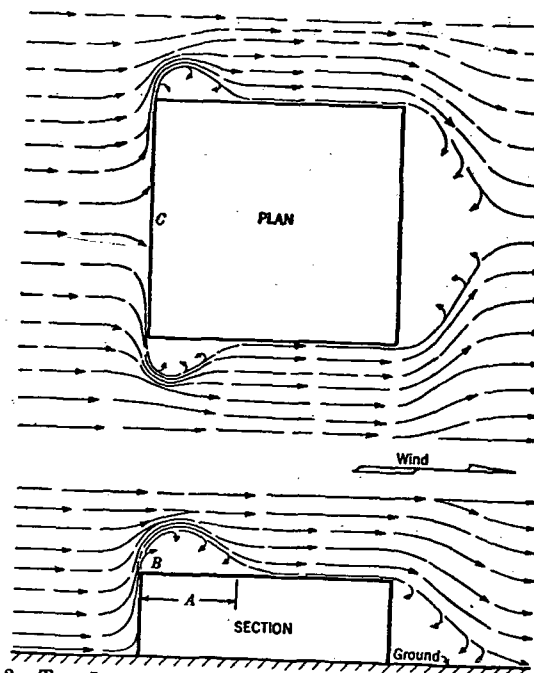


FIG. 2. THE JUMP OF WIND FROM WINDWARD FACE OF BUILDING. (A—LENGTH OF SUCTION AREA; B—POINT OF MAXIMUM INTENSITY OF SUCTION; C—POINT OF MAXIMUM PRESSURE)

dwellings requires a permanent opening to the outdoor air for rooms containing fuel-burning appliances having a gross capacity in excess of 250,000 Btu per hour.

### NATURAL VENTILATION

Ventilation by natural forces finds application in industrial plants, public buildings, schools, dwellings, garages, and in farm buildings.

The natural forces available for moving air into, through, and out of buildings are: (a) wind forces, and (b) the difference in temperature between the air inside and outside a building. The air movement may be caused by either of these forces acting alone, or by a combination of the two, depending upon atmospheric conditions, building design, and location.



The ventilating results obtained will vary, from time to time, due to variation in the velocity and direction of the wind, and the temperature difference. The arrangement, location, and control of the ventilating openings should be such that the two forces act cooperatively rather than in opposition.

### WIND FORCES

In considering the use of natural wind forces for producing ventilation, account must be taken of: (1) average wind velocity; (2) prevailing wind direction; (3) seasonal and daily variations in velocity and direction; and (4) local wind interference by nearby buildings, hills or other obstructions of similar nature.

Values are given in Table 3, Chapter 13 for the average wind velocities for the months June to September in various localities throughout the United States, while Table 1, Chapter 12, lists similar values for the winter. In almost all localities, the summer wind velocities are lower than those in the winter, and in about two-thirds of the localities the prevailing direction is different during the summer and winter. While the tables give no average velocities below 5 mph, there will be times when the velocity is lower, even in localities where the seasonal average is considerably above 5 mph. There are relatively few places where the velocity falls below one-half of the average for many hours per month. Consequently, if the natural ventilating system is designed for wind velocities of one-half of the average seasonal velocity, it should prove satisfactory in almost every case.

Equation 3 may be used for calculating the quantity of air forced through ventilation openings by the wind, or for determining the proper size of such openings to produce given results:

$$Q = EAV \quad (3)$$

where

- $Q$  = air flow, cubic feet per minute.  
 $A$  = free area of inlet openings, square feet.  
 $V$  = wind velocity, feet per minute, = miles per hour  $\times 88$ .  
 $E$  = effectiveness of openings. ( $E$  should be taken at 0.50 to 0.60 for perpendicular winds, and 0.25 to 0.35 for diagonal winds.)<sup>9</sup>

The precision of results obtained by the use of Equation 3, depends upon the placing of the openings, as the formula assumes that ventilating openings have a flow coefficient slightly greater than that of a square-edged orifice. If the openings are not advantageously placed with respect to the wind, the flow per unit area of the openings will be less and, if unusually well placed, the flow will be slightly more than that given by the formula. Inlets should be placed to face directly into the prevailing wind, while outlets should be placed in one of the five places listed:

1. On the side of the building directly opposite the direction of the prevailing wind.
2. On the roof in the low pressure area caused by the jump of the wind (see Fig. 2).
3. On the sides adjacent to the windward face where low pressure areas occur.
4. In a monitor on the side opposite from the wind.
5. In roof ventilators or stacks.

### TEMPERATURE DIFFERENCE FORCES<sup>7</sup>

The stack effect produced within a building, when the outdoor temperature is lower than the indoor temperature, is due to the difference in weight

of the warm column of air within the building and cooler air outside. The flow due to stack effect is proportional to the square root of the draft head, or approximately

$$Q = 9.4A \sqrt{h(t_i - t_o)} \quad (4)$$

where

- $Q$  = air flow, cubic feet per minute.  
 $A$  = free area of inlets or outlets (assumed equal), square feet.  
 $h$  = height from inlets to outlets, feet.  
 $t_i$  = average temperature of indoor air in height  $h$ , Fahrenheit.  
 $t_o$  = temperature of outdoor air, Fahrenheit.  
 9.4 = constant of proportionality, including a value of 65 percent for effectiveness of openings. This should be reduced to 50 percent (constant = 7.2) if conditions are not favorable.

### HEAT REMOVAL

In problems of heat removal, knowing the amount of heat to be removed and having selected a desirable temperature difference, the amount of air to be passed through the building per minute, to maintain this temperature difference, can be determined by means of Equation 5.

$$Q = \frac{H}{C_p \times \rho \times 60(t_i - t_o)} = \frac{H}{1.08(t_i - t_o)} \quad (5)$$

where

- $Q$  = air removed, cubic feet per minute.  
 $H$  = heat removed, Btu per hour.  
 $C_p$  = specific heat of air at constant pressure, 0.24.  
 $\rho$  = density of standard air, 0.075 pounds per cubic foot.  
 $t_i - t_o$  = indoor-outdoor temperature differences, Fahrenheit.

### EFFECT OF UNEQUAL OPENINGS

The largest flow per unit area of openings is obtained when inlets and outlets are equal, and the preceding equations are based on this condition. Increasing outlets over inlets, or vice-versa, will increase the air flow, but not in proportion to the added area. When solving problems having an unequal distribution of openings, use the smaller area, either inlet or outlet, in the equations, and add the increase as determined from Fig. 3.

### COMBINED FORCES OF WIND AND TEMPERATURE

Equations have already been given for determining the air flow due to temperature difference and wind. It must be remembered that when both forces are acting together, even without interference, the resulting air flow is not equal to the sum of the two estimated quantities. The flow through any opening is proportional to the square root of the sum of the heads acting on that opening.

When the two heads are about equal in value, and the ventilating openings are operated so as to coordinate them, the total air flow through the building is about 10 percent greater than that produced by either head acting independently under conditions ideal to it. This percentage decreases rapidly as one head increases over the other. The effect of the larger head will predominate.

The wind velocity and direction, the outdoor temperature, or the indoor



distribution, cannot be predicted with certainty, and refinement in calculations is not justified; consequently, a simplified method can be used. This may be done by using the equations and calculating the flows produced by each force separately, under conditions of openings best suited for coordination of the forces. Then, by determining the ratio of the flow produced by temperature difference to the sum of the two flows, the actual flow due to the combined forces can be approximated from Fig. 4.

**Example 1:** Assume a drop forge shop, 200 ft long, 100 ft wide, and 30 ft high. The cubical content is 600,000 cu ft, and the height of the air outlet over that of the inlet is 30 ft. Oil fuel of 18,000 Btu per lb is used in this shop at the rate of 15 gph (7.75 lb per gal). Desired summer temperature difference is 10 deg, and the prevailing wind is 8 mph perpendicular to the long dimension. What is the necessary area for the inlets and outlets, and what is the rate of air flow through the building?

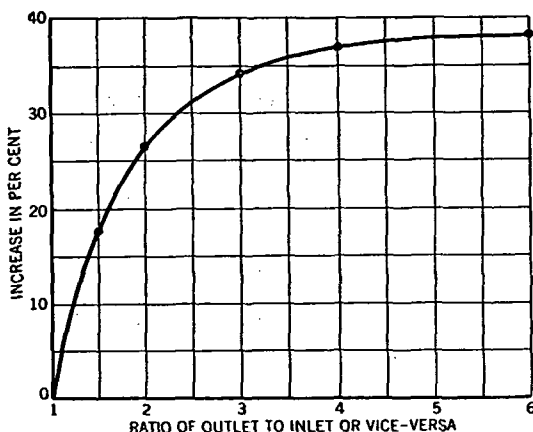


FIG. 3. INCREASE IN FLOW CAUSED BY EXCESS OF ONE OPENING OVER ANOTHER

**Solution for Temperature Difference Only:** The heat  $H = 15 \times 7.75 \times 18,000 = 2,092,500$  Btu per hr.

By Equation 5, the air flow required to remove this heat with an average temperature difference of 10 deg is

$$Q = \frac{H}{1.08(t_i - t_o)} = \frac{2,092,500}{1.08 \times 10} = 193,750 \text{ cfm.}$$

This is equal to about 20 air changes per hour. From Equation 4, the inlet (or outlet) opening area should be

$$A = \frac{Q}{9.4\sqrt{h(t_i - t_o)}} = \frac{193,750}{9.4\sqrt{30 \times 10}} = 1190 \text{ sq ft.}$$

The flow per square foot of inlet or outlet would be  $193,750 \div 1190 = 162.5$  cfm, with all windows open.

**Solution for Wind Only:** With 1,190 sq ft of inlet openings distributed around the sidewalls, there will be about 400 sq ft in each long side and 195 sq ft in each end. The outlet area will be equally distributed on the two sides of the monitor, or 595 sq ft on each side. With the wind perpendicular to the long side, there will be 400 sq

ft of opening in its path for inflow, and 595 in the lee side of the monitor for outflow with the windward side closed. The air flow, as calculated by Equation 3, will be:

$$Q = 0.60 \times 400 \times 704 = 168,960 \text{ cfm.}$$

This gives 16.9 air changes per hour, which should be more than ample when there is no heat to be removed.

**Solution for Combined Heads:** Since the windward side of the monitor is closed when the wind is blowing, the flow due to temperature difference must be calculated for this condition, using Fig. 3. This chart shows that, when inlets are twice the size of the outlets, in this case 1,190 sq ft in the sidewalls and 595 sq ft in the monitor, the flow will be increased 26.5 percent over that produced by equal openings. Using

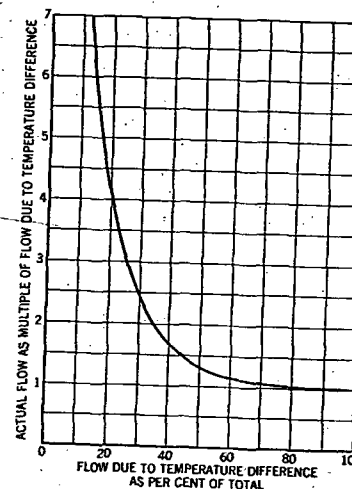


FIG. 4. DETERMINATION OF FLOW CAUSED BY COMBINED FORCES OF WIND AND TEMPERATURE DIFFERENCE

the smaller opening and the flow per square foot obtained previously, the calculated amount for this condition will be

$$595 \times 163 \times 1.265 = 122,700 \text{ cfm.}$$

Adding the two computed flows:

$$\begin{array}{rcl} \text{Temperature Difference} & = & 122,700 = 42 \text{ percent.} \\ \text{Wind} & = & 168,960 = 58 \text{ percent.} \end{array}$$

$$\begin{array}{rcl} \text{Total} & = & 291,660 = 100 \text{ percent.} \end{array}$$

From Fig. 4 it is determined that, when the flow due to temperature difference is 42 percent of the total, the actual flow due to the combined forces, will be about 1.6 times that calculated for temperature difference alone, or 196,300 cfm.

The original flow due to temperature difference alone was 193,750 cfm with all openings in use. The effect of the wind is to increase this to 196,300 cfm, even though half of the outlets are closed.

A factor of judgment is necessary in the location of the openings in a building, especially those in the roof, where heat, smoke, and fumes are to be removed. Usually, windward monitor openings should be closed, but if

the wind is low enough for the temperature head to overcome it, all windows may be opened.

### TYPES OF OPENINGS

Types of openings may be classified as: (1) windows, doors, monitor openings and skylights; (2) roof ventilators; (3) stacks connecting to registers; and (4) specially designed inlet or outlet openings. The various types and principles of operation are discussed in following paragraphs.

#### Windows, Doors and Skylights

Windows have the advantage of transmitting light, as well as providing ventilating area, when open. Their movable parts are arranged to open in various ways; they may open by sliding either vertically or horizontally, by tilting on horizontal pivots at or near the center, or by swinging on pivots at the top, bottom or side. Regardless of their design, the air flow per square foot of opening may be considered to be the same under the same conditions. The type of pivoting should receive consideration from the standpoint of weather protection, and certain types may be advantageous in controlling the distribution of incoming air. Deflectors are sometimes used for the same purpose, and these devices should be considered a part of the ventilation system.

#### Roof Ventilators

The function of a roof ventilator is to provide a storm and weather-proof air outlet. These are actuated by the same forces of wind and temperature head which create flow through other types of openings. The capacity of a ventilator depends upon four things: (1) its location on the roof; (2) the resistance it and the duct work offer to air flow; (3) the height of draft; and (4) the efficiency of the ventilator in utilizing the kinetic energy of the wind for inducing flow by centrifugal or ejector action.

For maximum flow induction, a ventilator should be located on that part of the roof where it will receive the full wind without interference. If ventilators are installed within the suction region created by the wind passing over the building, or in a light court, or on a low building between two high buildings, their performance will be seriously influenced. Their normal ejector action, if any, may be completely lost.

The base of the ventilator should be of a taper-cone design to produce the effect of a bell-mouth nozzle whose coefficient of flow is considerably higher than that of a square-entrance orifice. If a grille is provided at the base, or if the base or structural members present obstructions, additional resistance is introduced, and the base opening should be increased in size accordingly.

Air inlet openings located at lower levels in the building, should be at least equal to, and preferably larger than, the combined throat areas of all roof ventilators. The air discharged by a roof ventilator depends on wind velocity and temperature difference, and, in general, its performance will be the same as any monitor opening located in the same place but, due to the four capacity factors already mentioned, no simple formula can be devised for expressing ventilator capacity.

Roof ventilators may be classified as stationary, pivoting or oscillating, and rotating. Generally, these have a round throat, but the continuous-ridge ventilator would fall in the stationary classification. When selecting roof ventilators, some attention should be given to ruggedness of construc-

tion, storm-proofing features, dampers and damper operating mechanisms, possibility of noise, original cost, and maintenance.

Natural ventilation units may be used to supplement power-driven supply fans, and under favorable weather conditions it may be possible to stop the power-driven units. Units are not subject to code tests for ratings. Generally, they must be selected from manufacturers' tables. It is, therefore, very important to consider the reliability of the ratings used.

#### Controls

Gravity ventilators may have dampers controlled by hand, thermostat, or wind velocity, in combination with a fan. The thermostat station may be located anywhere in the building, or it may be located within the ventilator itself. The purpose of wind velocity control is to obtain a definite volume of exhaust regardless of the natural forces, the fan motor being energized when the natural exhaust capacity falls below a certain minimum, and again shut off when the wind velocity rises to the point where this minimum volume can be supplied by natural forces.

#### Stacks

Stacks or vertical flues are really chimneys which function through the effects of the wind and temperature difference. Like the roof ventilator, the stack outlet should be located so that the wind may act upon it from any direction. With little or no wind, the chimney effect depends entirely on temperature difference to produce a removal of air from the rooms where the inlet openings are located.

### GENERAL VENTILATION RULES

A few of the important considerations, in addition to those already outlined, are:

1. Inlet openings in the building should be well distributed, and should be located on the windward side near the bottom, while outlet openings are located on the leeward side near the top. Outside air will then be supplied to the zone to be ventilated.
2. Inlet openings should not be obstructed by buildings, trees, sign boards, etc., outside, nor by partitions inside.
3. Greatest flow per square foot of total opening is obtained by using inlet and outlet openings of nearly equal areas.
4. In the design of window ventilated buildings, where the direction of the wind is quite constant and dependable, the orientation of the building, together with amount and grouping of ventilation openings, can be readily arranged to take full advantage of the force of the wind. Where the wind's direction is quite variable, the openings should be arranged in sidewalls and monitors so that, as far as possible, there will be approximately equal areas on all sides. Thus, no matter what the wind's direction, there will always be some openings directly exposed to the pressure force, and others to a suction force, and effective movement through the building will be assured.
5. Direct short circuits between openings on two sides at a high level may clear the air at that level without producing any appreciable ventilation at the level of occupancy.
6. In order that temperature difference may produce a motive force, there must be vertical distance between openings. That is, if there are a number of openings available in a building, but all are at the same level, there will be no motive head produced by temperature difference, no matter how great that difference might be.
7. In order that the force of temperature difference may operate to maximum advantage, the vertical distance between inlet and outlet openings should be as great as possible. Openings in the vicinity of the neutral zone are less effective for ventilation.
8. In the use of monitors, windows on the windward side should usually be kept closed, since, if they are open, the inflow tendency of the wind counteracts the outflow

tendency of temperature difference. Openings on the leeward side of the monitor result in cooperation of wind and temperature difference.

9. In an industrial building where furnaces that give off heat and fumes are to be installed, it is better to locate them in the end of the building exposed to the prevailing wind. The strong suction effect of the wind at the roof near the windward end will then cooperate with temperature difference, to provide for the most active and satisfactory removal of the heat and gas-laden air.

10. In case it is impossible to locate furnaces in the windward end, that part of the building in which they are to be located should be built higher than the rest, so that the wind, in splashing therefrom, will create a suction. The additional height also increases the effect of temperature difference to cooperate with the wind.

11. The intensity of suction, or the vacuum produced by the jump of the wind, is greatest just back of the building face. The area of suction does not vary with the wind velocity, but the flow due to suction is directly proportional to wind velocity.

12. Openings much larger than the calculated areas are sometimes desirable, especially when an increase in occupancy may occur, or when extremely hot days may be anticipated. In the former case, free openings should be located at the level of occupancy for psychological reasons.

13. In single story industrial buildings, particularly those covering large areas, natural ventilation must be accomplished by taking air in and out of the roof openings. Openings in the pressure zones can be used for inflow, and openings in the suction zone, or openings in zones of less pressure, can be used for outflow. The ventilation is accomplished by the manipulation of openings to get air flow through the zones to be ventilated.

### VENTILATION OF ANIMAL SHELTERS<sup>10</sup>

Animal shelters require ventilation to remove moisture, odors and, in the case of dairy stables, excess heat.

**Outlets.** Outlet flues for natural draft systems should be round or approximately square. A thermal resistance ( $1/U$ ) of not less than two is required in their side walls. They should extend at least two feet above the highest part of the roof. Only one outlet is recommended for each room or pen. The use of several outlet flues may result in excessive up-drafts in some flues, and down-drafts in others.

If flues have roofs or covers, these should be high enough to provide unobstructed openings on all sides, equal in height to one-half the least dimension of the flue, Fig. 5. A level, heavily insulated ceiling under the flue roof, and over the entire area of the flue, is important.

**Inlets.** Inlets should direct the incoming air vertically upward so as to avoid drafts on the animals, and to insure immediate mixing of incoming air with the room air. A reasonably uniform distribution around the stable or pen is desirable. Inlet flues, that deliver air close to the side walls, stimulate convection currents, which is desirable. When so placed, they also tend to bathe the side walls with cool air, thus reducing temperature difference between the inside and outside of the wall.

From the standpoint of air movement, insulation of inlet flues is not important. Condensation is, however, likely to occur on them, unless the thermal resistance of their walls is at least two.

Controls or throttling devices in inlet flues are seldom required. If used, they are best applied to the inlets and limited to the side of the building facing prevailing winter winds. They should be so made that an opening, at least one inch wide by the width of the flue, will always remain open.

Amounts of heat and water produced by livestock vary not only with the different kinds of animals, but also with age, weight, feed consumption and production. These facts, and the vagaries of the weather, make exact

calculations impossible. The following practical recommendations are based on numerous, carefully checked observations.

It is desirable to keep the relative humidity of livestock shelters below 85 percent. Temperatures may be as indicated in the discussion for each kind of animal.

### Dairy Stables

The most usually accepted temperatures for dairy stables, where cows are confined in stanchions or tie stalls, are from 45 to 55 F. These temperatures are readily maintained in winter weather by the body heat of the herd in well constructed, well stocked and well ventilated stables. Stable volume in excess of 600 cu ft, and exposed wall area in excess of 130 sq ft per 1000 lb animal weight are, in general, undesirable.

Side walls should have an overall thermal resistance of from 2 to 5, depending on the temperature zone and wind exposure. Thermal re-

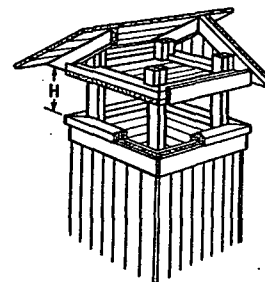


FIG. 5. RECOMMENDED TYPE OF COVER FOR WOODEN OUTLET FLUE

The opening  $H$  should equal one-half the least dimension of the flue. Heavy insulation of the level deck is essential.

distance of the ceiling should be 50 percent greater than that of the side walls. In stables of this size and so insulated, a ventilation rate of 3200 to 3800 cu ft per (hr) (1000 lb of animal) usually insures good conditions.

The following recommendations do not apply to so-called pen stables or loafing barns in which there is a thick manure and bedding pack on the floor, and in which doors are normally kept open.

**Outlets.** One flue will serve a stable 200 ft long. In stables over 120 ft long, the flue should be about midway between the ends or, if the stable is L-shaped, near the angle. In shorter stables, it may be at any convenient location.

The exhaust point in the stable should be not more than 18 in. above the floor. This permits removal of only the coolest air, and prevents rapid fluctuations in stable temperature.

A basic rule for finding the cross-section of the outlet flue is

$$A_o = \frac{176 N}{\sqrt{h}} \quad (6)$$

where

$A_o$  = area of the outlet flue, square inches.

$N$  = weight of animal population, thousands of pounds.  
 $h$  = vertical distance from top of inlet flues to top of outlet flue, feet.

For large flues the flue area obtained from the basic formula may well be reduced according to the chart, Fig. 6, because of a decrease in friction.

**Example 2:** Assume a stable in which the vertical height from the top of the inlets to the top of the outlet flue is 32.5 ft, and in which 38 cows, averaging 1300 lb, will be housed. Determine required size of outlet flue.

**Solution:** From Equation 6

$$A_o = \frac{176 \times (38 \times 1,300)}{\sqrt{32.5}} = 1525 \text{ sq in.}$$

From Fig. 6 the factor to be applied to this area is 94.5 percent. Therefore, the area of flue required is  $1525 \times 0.945 = 1441 \text{ sq in.}$

**Inlets.** Inlet flues, each approximately 60 sq. in. in area, have given good results. One such flue should be provided for each 3500 lb animal weight. They should deliver air from points 12 to 18 in. below the ceiling.

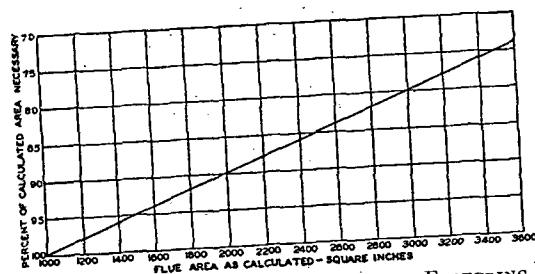


FIG. 6. MODIFICATION OF FLUE AREA FOR OUTLETS EXCEEDING 1000 Sq IN.

### Sheep Barns

Shelters used for breeding and feeding stock usually have enough openings, so that no special provision for ventilation is required. Barns for winter lambing flocks, however, require ventilation systems. Fermentation in the floor pack of manure produces heat, vapor and odor. These must be added to the ventilation load regularly produced by the animals.

**Outlets.** In practice, results obtained by the basic formula, Equation 7, when modified by the use of the chart, Fig. 6 have given good results:

$$A_o = \frac{4A_i}{\sqrt{h}} \quad (7)$$

where

$A_o$  = area of the outlet, square inches.

$A_i$  = floor area, square feet.

$h$  = vertical height from top of inlet openings to top of outlet flue, feet.

The bottom of the outlet flue should be 15 to 24 in. above the surface of the manure pack.

**Inlets.** Provide one inlet, 60 sq in. in area, for each 150 sq-ft of floor

### Infiltration and Ventilation

area. Inlets should be well distributed around the side walls, and designed to deliver air near the ceiling (see section on Dairy Stables).

### Swine Barns

Community swine barns, because of the extent of slop feeding and the absence of daily cleaning of the pens, are the most difficult farm buildings to ventilate satisfactorily. Farrowing pens, to which supplemental heat is supplied, present less of a problem. In all cases, good floor drainage to remove urine and excess spilled water is important.

Temperatures of from 50 to 55 F are usually recommended for farrowing pens. It is desirable to maintain temperatures above freezing in all other pens in community houses. For barns that are well stocked and adequately ventilated, this requires walls with an overall thermal resistance of from 3 to 6, and ceilings with 40 to 50 percent greater resistance.

**Outlets.** The outlet flue should draw air from a level of 15 to 18 in. above the floor. Equation 8 is the basic formula for flue area, and gives reasonably good results when modified according to the chart, Fig. 6.

$$A_o = \frac{5 \times A_i}{\sqrt{h}} \quad (8)$$

**Inlets.** At least one inlet flue should be used for each pen. Swine are given or select definite nesting places, and care must be exercised to avoid having inlets located over them.

Total inlet area should be approximately 70 percent of outlet area. The area of individual inlets is best determined from the total area required, and the number that can be so installed as to meet previous specifications. Inlets should deliver air from points 12 to 15 in. below the ceiling, or from a level deflector on a sloping ceiling.

### Poultry Laying Houses

From the standpoint of ventilation, poultry laying houses may be divided into cold houses and warm houses. The former are uninsulated, except in the ceiling. The inside-outside temperature difference is seldom more than 5 F deg. In the warm house, because of insulation or supplemental heat, the temperature seldom falls below 32 F, and is usually above 45 F.

**Outlets.** The outlet flue is best placed near the middle of the pen. It is advisable to limit the length of pens to 80 ft.

The area of the outlet flue may be determined from Equation 9, and modified according to the chart, Fig. 6.

$$A_o = \frac{2.5 \times A_i}{\sqrt{h}} \quad (9)$$

For a cold house, the bottom of the flue should be at the level of the insulated ceiling. In warm houses, the bottom of the flue should be 12 to 15 in. above the level of the floor litter.

**Inlets.** Inlets may be approximately 60 sq in. in area. The total inlet area may be equal to 70 percent of the outlet area. Inlets in cold and in warm houses should deliver air from points 12 to 24 in. above the floor. In cold houses which normally do not have storm sash, windows may be

raised enough to give the desired area, and be fitted with baffle boards to direct the air straight and upward.

In houses less than 20 ft in width, all inlets may be on one side. In wider houses, a rather uniform distribution of inlets is essential.

### GARAGE VENTILATION

Because of hazards resulting from carbon monoxide and other physiologically harmful or combustible gases or vapors in garages, the importance of proper ventilation of these buildings cannot be over-emphasized. During the warm months of the year, garages are usually ventilated adequately because the doors and windows are kept open. The A.S.H.A.E. Code of Minimum Requirements for Heating and Ventilating Garages,<sup>11</sup> adopted in 1935, specifies that openings for natural ventilation shall be distributed as uniformly as possible in at least two outside walls, and that the total area of such openings shall be equivalent to at least 5 percent of the floor area. The code further states that where it is impracticable to operate such a system of natural ventilation, a mechanical system shall be used, and shall provide for either the supply of 1 cfm of outdoor air for each square foot of floor area, or for exhaust of the same amount of air, discharging it to the outside as a means of flushing the garage.

Cooperative research<sup>12</sup> on garage ventilation, undertaken by the A.S.H.A.E. Committee on Research at Washington University, St. Louis, Mo., and at the University of Kansas, and tests conducted at the A.S.H.A.E. Research Laboratory, have resulted in authoritative papers on the subject.

Some of the conclusions based on work at these laboratories are:

1. Upward ventilation results in a lower concentration of carbon monoxide at the breathing line and a lower temperature above the breathing line, than does downward ventilation for the same rate of carbon monoxide production, air change, and the same temperature at the 30-in. level.
2. A lower rate of air change and a smaller heating load are required with upward than with downward ventilation.
3. In the average case, upward ventilation results in a lower concentration of carbon monoxide in the occupied portion of a garage, than that obtained with mixing of the exhaust gases and the air supplied. However, the variations in concentration from point to point, together with the possible failure of the advantages of upward ventilation to accrue, suggest the basing of garage ventilation on complete mixing, and an air change sufficient to dilute the exhaust gases to the allowable concentration of carbon monoxide.
4. The rate of carbon monoxide production by an idling car is shown to vary from 25 to 50 cfh, with an average rate of 35 cfh.
5. An air change of 350,000 cfh per idling car is required to keep the carbon monoxide concentration down to one part in 10,000 parts of air.

### Individual Exhaust Ducts

Motor vehicle servicing areas may be provided with underground or overhead exhaust systems discharging outdoors. Each service location should be provided with a flexible branch duct, the inlet end of which is sized to slip over the tail pipe of the engine, or over any deflector attached to the tail pipe. The minimum branch size and ventilation rate for the largest class of vehicle regularly serviced at each location are shown in Table 4.

Where each tail pipe exhaust branch is provided with an automatic device to close the branch inlet when it is not in use, the capacity of the fan for the system should be based on the maximum number of branches in simultaneous use. Where the branch inlets are open when not in use, the

### Infiltration and Ventilation

TABLE 4. MINIMUM TAIL PIPE CONNECTION SIZE AND VENTILATION RATE

| CLASS OF VEHICLE | TAIL PIPE DIAMETER, IN. | VENTILATION RATE, CFM | FLEXIBLE PIPE, DIAM, IN. | DIAMETER OF RIGID BRANCH CONNECTION TO FLEXIBLE PIPE, IN. |
|------------------|-------------------------|-----------------------|--------------------------|-----------------------------------------------------------|
| Auto.            | Under 2                 | 100                   | 3                        | 4                                                         |
| Truck            | 2 to 3                  | 150                   | 4                        | 4½                                                        |
| Bus              | 3 and over              | 250                   | 4½                       | 5½                                                        |

system capacity should be based on the total number of branches connected to the main.

Individual straight lengths of gas tight duct, not over 20 feet in length, terminating outdoors, may be provided where exhaust systems are not installed. The duct should fit tightly over the tail pipe and be of a diameter not less than the diameter of the tail pipe.

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## CHAPTER 12

### HEATING LOAD

General Procedure, Design Outdoor Weather Conditions, Inside Temperatures, Attic Temperatures, Temperatures in Unheated Spaces, Ground Temperatures, Basement Temperatures and Heat Loss, Heat Losses from Floor Slabs, Transmission Heat Loss, Infiltration Heat Loss, Selection of Wind Velocities, Auxiliary Heat Sources, Intermittently Heated Buildings, Residence Heat Loss Problems

PRIOR to designing a heating system, an estimate must be made of the maximum probable heat loss of each room or space to be heated, based on maintaining a selected inside air temperature during periods of design outdoor weather conditions. The heat losses may be divided into two groups, namely: (1) the transmission losses or heat transmitted through the confining walls, floor, ceiling, glass or other surfaces; and (2) the infiltration losses or heat required to warm outside air which leaks in through cracks and crevices, around doors and windows, opening of doors and windows, or heat required to warm outside air used for ventilation.

### GENERAL PROCEDURE

The general procedure for calculating heat losses of a structure is:

1. Select the design outdoor weather conditions: temperature, wind direction and wind velocity. The data on climatic conditions given in Table 1 and the isotherms of average design temperature in Fig. 1 will be helpful, but should be used with judgment as suggested in the section Design Outdoor Weather Conditions.

2. Select the inside air temperature, which is to be maintained in each room during the coldest weather. (See Table 2).

3. Estimate temperatures in adjacent unheated spaces and the attic. The attic temperature need not be estimated if the combined roof and ceiling coefficient is used.

4. Select or compute the heat transmission coefficients for outside walls and glass; also for inside walls, floors, or top-floor ceilings, if these are next to unheated space; include roof if next to heated space. (See Chapter 9. If the design wind velocity is appreciably different from 15 mph, the appropriate change in the heat transmission coefficients in Tables 6 to 9 and 15 to 19 of Chapter 9 can be found in Table 21 of that chapter.)

5. Measure net area of outside wall, glass and roof next to heated spaces, as well as any cold walls, floors or ceilings next to unheated space. Such measurements are made from building plans, or from the actual building, using inside dimensions.

6. Compute the heat transmission losses for each kind of wall, glass, floor, ceiling and roof in the building by multiplying the heat transmission coefficient in each case by the area of the surface in square feet, and the temperature difference between the inside and outside air. (See Items 1, 2, and 3).

7. Select unit values and compute the heat equivalent of the infiltration of cold air taking place around outside doors and windows. These unit values depend on the kind or width of crack, wind velocity, and the temperature difference between the inside and outside air; the result expresses the heat required to warm up the cold air leaking into the building per hour. (See Chapter 11).

8. When positive ventilation using outdoor air is provided by an air heating or an air conditioning unit, the heat required to warm the outside air to room temperature must be provided by the unit; if mechanical exhaust from the room is provided, in amount equal to the outside air drawn in by the unit, the natural infiltration losses must also be provided for by the unit. If no mechanical exhaust is used, and the



outdoor air supply equals or exceeds the amount of natural infiltration which would occur without ventilation, the natural infiltration may be neglected.

9. The sum of the heat losses by transmissions (Item 6) through the outside walls and glass, as well as through any cold floors, ceilings or roof plus the heat equivalent (Item 7) of the cold air entering by infiltration, or required to replace mechanical exhaust, represents the total heat loss equivalent for any building.

10. In buildings which have a reasonably steady internal heat release of appreciable magnitude from sources other than the heating system, a computation of this heat release under design conditions should be made for deduction from the total of the heat losses computed in items 1-9. This is especially important for heating systems of high initial cost or those for which a demand charge is based on installed capacity.

### DESIGN OUTDOOR WEATHER CONDITIONS

There are no hard and fast rules for selecting the design outdoor weather conditions to be used for a given locality or type of building or heating system, and the selection is to some extent a matter of judgment and experience. The appropriate design temperature in a given locality may vary with heat capacity and degree of insulation of a particular structure, the amount of protection from the wind, the length of time that nightly minimum temperatures persist, whether the particular building is being used day and night, and perhaps other factors. For heating systems that depend primarily on electrical energy as a source of heat it will often be desirable, for economic reasons, to make a more careful analysis of the factors that affect design weather conditions than would otherwise be justified.

The outside design temperature seldom is taken as the lowest temperature, or even the lowest daily mean temperature ever recorded in a given locality. Such temperatures rarely recur in successive years. Likewise the wind direction and velocity occurring at the time of design outside temperature may be different from the average velocity and prevailing direction during the winter.

The A.S.H.A.E. Technical Advisory Committee on Weather Design Conditions has recommended the adoption for heating load calculations of an outside design temperature which is equalled or exceeded during 97½ percent of the hours in December, January, February and March. Complete design temperature data based on this formula are not available, but Column 8, Table 1, lists this recommended design temperature based on airport station readings for the period indicated, generally the five years, 1935-1939. In most cases these stations are outside of the city and these data apply primarily to rural areas. In general the use of the airport data for buildings within an adjacent city will not make an appreciable difference in design load.

Because of the limited data available in Column 8 of Table 1, design temperatures in common use are listed in Column 10 for the United States. Many of those values were furnished by A.S.H.A.E. members, the remainder were taken from an *ACRMA* Bulletin,<sup>1</sup> manufacturers' publications, and other sources,<sup>2</sup> and a few were estimated.

The map in Fig. 1 shows isotherms of outdoor winter design temperature which are based on the values in Column 10 of Table 1 with some modifications where other data indicated that Column 8 furnishes a more reasonable design temperature. These isotherms have also been modified slightly in accordance with the elevations of the various cities. The isotherms are drawn on 10 deg temperature intervals, in most cases, and are so placed that interpolation between isotherms will provide the proper design temperature for cities between the isotherms. Thus, a city located half-way be-

TABLE 1. WINTER CLIMATIC CONDITIONS\*

| COL. 1 | COL. 2               | COL. 3                       | COL. 4                              | COL. 5                                                       | COL. 6                                                          | COL. 7                             | COL. 8                                                                        | COL. 9                                                 | COL. 10                                                                   | COL. 11                                             |
|--------|----------------------|------------------------------|-------------------------------------|--------------------------------------------------------------|-----------------------------------------------------------------|------------------------------------|-------------------------------------------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------|
| STATE  | STATION <sup>b</sup> | ELEVATION <sup>c</sup><br>FT | PERIOD<br>OF<br>RECORD <sup>d</sup> | LOW-<br>EST<br>TEMP.<br>ON<br>REC.<br>ORD <sup>e</sup><br>°F | AVER-<br>AGE<br>AN-<br>NUAL<br>MIN.<br>TEMP. <sup>e</sup><br>°F | AVG.<br>WIN-<br>TER<br>TEMP.<br>°F | DESIGN<br>DRY-<br>BULB<br>TEMP.<br>ON TAC<br>97½%<br>BASIS <sup>f</sup><br>°F | WIND<br>VEL. AT<br>DESIGN<br>TEMP. <sup>h</sup><br>MPH | DESIGN<br>DRY-<br>BULB<br>TEMP.<br>IN<br>COMMON<br>USE <sup>i</sup><br>°F | AVG.<br>WIND<br>VEL.<br>DEC.<br>JAN.<br>FEB.<br>MPH |
| Ala.   | Anniston.....        | C 733                        | 1893-1947                           | -10                                                          |                                                                 | 52.3                               |                                                                               |                                                        |                                                                           |                                                     |
|        | Birmingham.....      | C 711                        | 1893-1945                           | -10                                                          | 12                                                              | 53.8                               |                                                                               |                                                        | 5                                                                         |                                                     |
|        | Birmingham.....      | A 615                        | 1939-1947                           | -10                                                          |                                                                 | 51.8                               |                                                                               |                                                        | 10                                                                        | 8.0                                                 |
|        | Mobile.....          | C 143                        | 1872-1947                           | -1                                                           | 22                                                              | 58.9                               | 21                                                                            | 7.4                                                    |                                                                           |                                                     |
|        | Mobile.....          | A 219                        | 1940-1947                           | 13                                                           |                                                                 |                                    | 30                                                                            | 8.5                                                    | 15                                                                        | 9.9                                                 |
|        | Montgomery.....      | C 293                        | 1872-1947                           | -5                                                           | 18                                                              | 56.4                               |                                                                               |                                                        |                                                                           |                                                     |
|        | Montgomery.....      | A 225                        | 1938-1944                           | 9                                                            | 19                                                              |                                    |                                                                               |                                                        | 10                                                                        | 7.5                                                 |
| Aris.  | Flagstaff.....       | C 6857                       | 1899-1947                           | -25                                                          | -15                                                             | 35.9                               |                                                                               |                                                        |                                                                           |                                                     |
|        | Kingman.....         | C 3473                       | 1935-1939 <sup>d</sup>              | 8                                                            |                                                                 |                                    |                                                                               |                                                        | -10                                                                       | 7.7                                                 |
|        | Phoenix.....         | C 1122                       | 1895-1947                           | 16                                                           | 26                                                              | 59.5                               | 22                                                                            | 8.6                                                    |                                                                           |                                                     |
|        | Phoenix.....         | A 1112                       | 1937-1947                           | 21                                                           |                                                                 |                                    |                                                                               |                                                        | 25                                                                        | 5.4                                                 |
|        | Tucson.....          | C                            | Up to 1946                          | 6                                                            |                                                                 | 57.7                               | 31                                                                            | 5.6                                                    |                                                                           |                                                     |
|        | Tucson.....          | A 2561                       | 1935-1939 <sup>d</sup>              | 10                                                           |                                                                 | 57.2                               |                                                                               |                                                        | 25                                                                        | 5.2                                                 |
|        | Winslow.....         | C 4853                       | Up to 1946                          | -19                                                          | -1                                                              | 43.6                               | 30                                                                            | 6.3                                                    |                                                                           |                                                     |
|        | Winslow.....         | A 4899                       | 1932-1947                           | -18                                                          |                                                                 | 43.5                               |                                                                               |                                                        | -10                                                                       |                                                     |
|        | Yuma.....            | C 146                        | 1876-1946 <sup>e</sup>              | 22                                                           | 27                                                              | 62.5                               | 6                                                                             | 7.5                                                    |                                                                           |                                                     |
| Ark.   | Fort Smith.....      | C 545                        | 1882-1945                           | -15                                                          | 6                                                               | 50.4                               |                                                                               |                                                        |                                                                           |                                                     |
|        | Fort Smith.....      | A 463                        | 1945-1947                           | 7                                                            |                                                                 |                                    |                                                                               |                                                        | 30                                                                        | 6.7                                                 |
|        | Little Rock.....     | C 451                        | 1879-1942                           | -12                                                          | 10                                                              | 51.6                               |                                                                               |                                                        | 10                                                                        | 8.3                                                 |
|        | Little Rock.....     | A 282                        | 1942-1947                           | 7                                                            |                                                                 |                                    |                                                                               |                                                        | 5                                                                         | 8.3                                                 |
| Cal.   | Bakersfield.....     | A 499                        | 1937-1946 <sup>e</sup>              | 19                                                           | 25                                                              | 55.5                               | 21                                                                            | 6.6                                                    |                                                                           |                                                     |
|        | Burbank.....         | A 740                        | 1931-1947                           | 21                                                           |                                                                 | 57.5                               | 33                                                                            | 5.6                                                    | 25                                                                        |                                                     |
|        | Daggett.....         | A 1925                       | 1935-1939 <sup>e</sup>              | 20                                                           | 29                                                              | 49.3                               | 35                                                                            | 4.9                                                    |                                                                           | 7.3                                                 |
|        | Eureka.....          | C 115                        | 1886-1947                           | 17                                                           | 28                                                              | 53.8                               | 27                                                                            | 8.5                                                    | 30                                                                        | 5.4                                                 |
|        | Fresno.....          | C 387                        | 1887-1939                           | 23                                                           |                                                                 |                                    |                                                                               |                                                        | 25                                                                        |                                                     |
|        | Fresno.....          | A 281                        | 1939-1947                           | 28                                                           | 37                                                              | 59.3                               | 32                                                                            | 4.5                                                    |                                                                           |                                                     |
|        | Los Angeles.....     | C 634                        | 1877-1947                           | 23                                                           |                                                                 | 51.9                               | 36                                                                            | 7.5                                                    | 35                                                                        | 6.4                                                 |
|        | Oakland.....         | A 21                         | 1929-1947                           | 17                                                           |                                                                 | 53.9                               |                                                                               |                                                        | 30                                                                        |                                                     |
|        | Red Bluff.....       | C 341 <sup>e</sup>           | 1877-1934                           | 25                                                           |                                                                 | 52.9                               |                                                                               |                                                        |                                                                           | 6.1                                                 |
|        | Red Bluff.....       | A 579                        | 1935-1939 <sup>e</sup>              | 17                                                           |                                                                 |                                    |                                                                               |                                                        |                                                                           |                                                     |
|        | Redding.....         | C 116                        | 1877-1947                           | 22                                                           | 28                                                              | 53.0                               | 32                                                                            | 7.1                                                    |                                                                           |                                                     |
|        | Sacramento.....      | A 22                         | 1935-1947                           | 25                                                           | 37                                                              | 58.2                               |                                                                               |                                                        | 30                                                                        | 7.2                                                 |
|        | Sacramento.....      | C 90                         | 1871-1940                           | 34                                                           |                                                                 |                                    |                                                                               |                                                        | 35                                                                        | 6.3                                                 |
|        | San Diego.....       | A 34                         | 1939-1947                           | 27                                                           | 37                                                              | 54.2                               | 43                                                                            | 5.8                                                    |                                                                           |                                                     |
|        | San Diego.....       | C 164                        | 1875-1947                           | 22                                                           |                                                                 | 53.5                               |                                                                               |                                                        | 35                                                                        | 7.5                                                 |
|        | San Jose.....        | C 100 <sup>e</sup>           | Up to 1946                          | 22                                                           |                                                                 |                                    |                                                                               |                                                        | 25                                                                        |                                                     |
|        | Williams.....        | A 124                        | 1935-1939 <sup>e</sup>              | -29                                                          | -11                                                             | 39.0                               | 29                                                                            | 8.3                                                    |                                                                           |                                                     |
| Col.   | Denver.....          | C 5398                       | 1871-1947                           | -30                                                          | -2                                                              | 37.0                               | 0                                                                             | 8.8                                                    | -10                                                                       | 7.5                                                 |
|        | Grand Junction.....  | A 5379                       | 1934-1947                           | -21                                                          |                                                                 | 39.9                               |                                                                               |                                                        | -15                                                                       | 4.4                                                 |
|        | Pueblo.....          | C 4587 <sup>e</sup>          | 1889-1945 <sup>e</sup>              | -27                                                          |                                                                 | 41.1                               |                                                                               |                                                        | -20                                                                       | 7.9                                                 |
|        | Pueblo.....          | A 4770                       | 1889-1935 <sup>e</sup>              | -28                                                          |                                                                 |                                    |                                                                               |                                                        |                                                                           |                                                     |
| Conn.  | Hartford.....        | C 4810                       | 1939-1947                           | -18                                                          |                                                                 | 36.4                               | 2                                                                             | 6.4                                                    |                                                                           |                                                     |
|        | Hartford.....        | A 229                        | 1905-1940                           | -24                                                          |                                                                 |                                    | 4                                                                             | 8.3                                                    | 0                                                                         | 8.7                                                 |
|        | New Haven.....       | C 180                        | 1872-1946 <sup>e</sup>              | -15                                                          | -1                                                              | 38.4                               |                                                                               |                                                        | 0                                                                         | 9.4                                                 |
|        | New Haven.....       | A 17                         | 1943-1947                           | -4                                                           |                                                                 |                                    | 11                                                                            | 8.1                                                    |                                                                           |                                                     |
| D.C.   | Washington.....      | C 128                        | 1871-1947                           | -15                                                          | -1                                                              | 43.4                               |                                                                               |                                                        | 0                                                                         | 7.8                                                 |
|        | Washington.....      | A 20                         | 1935-1939 <sup>e</sup>              | 18                                                           |                                                                 | 60.9                               | 14                                                                            | 7.4                                                    |                                                                           |                                                     |
| Fla.   | Apalachicola.....    | C 23                         | 1922-1947                           | 10                                                           | 29                                                              | 62.0                               |                                                                               |                                                        | 25                                                                        | 8.4                                                 |
|        | Jacksonville.....    | C 104                        | 1871-1947                           | 16                                                           |                                                                 | 60.8                               | 31                                                                            | 7.0                                                    | 25                                                                        | 9.0                                                 |
|        | Jacksonville.....    | A 23                         | 1871-1947                           | 41                                                           |                                                                 | 73.1                               |                                                                               |                                                        | 45                                                                        | 10.6                                                |
|        | Key West.....        | C 23                         | 1871-1947                           | 42                                                           |                                                                 | 72.5                               |                                                                               |                                                        |                                                                           |                                                     |
|        | Key West.....        | A 48                         | 1939-1947                           | 27                                                           |                                                                 | 71.4                               |                                                                               |                                                        | 35                                                                        | 10.1                                                |
|        | Miami.....           | C 253                        | 1896-1947                           | 28                                                           | 38                                                              |                                    | 45                                                                            | 7.3                                                    | 20                                                                        | 10.9                                                |
|        | Miami.....           | A 13                         | 1940-1947                           | 7                                                            |                                                                 | 59.7                               |                                                                               |                                                        | 30                                                                        | 8.6                                                 |
|        | Pensacola.....       | C 67                         | 1879-1947                           | 20                                                           | 32                                                              | 66.0                               |                                                                               |                                                        |                                                                           |                                                     |
|        | Pensacola.....       | A 113                        | 1943-1947                           | 19                                                           |                                                                 |                                    |                                                                               |                                                        |                                                                           |                                                     |
|        | Tampa.....           | C 111                        | 1890-1940 <sup>e</sup>              | 37 <sup>e</sup>                                              |                                                                 |                                    |                                                                               |                                                        |                                                                           |                                                     |
|        | Tampa.....           | A 12                         | 1941-1946                           |                                                              |                                                                 |                                    |                                                                               |                                                        |                                                                           |                                                     |
|        | Titusville.....      | A 52                         | 1935-1939 <sup>e</sup>              | -8                                                           | 12                                                              | 51.3                               | 38                                                                            | 6.5                                                    | 10                                                                        | 11.7                                                |
|        | Atlanta.....         | C 1020                       | 1878-1945 <sup>e</sup>              | 3                                                            |                                                                 | 54.2                               | 22                                                                            | 10.2                                                   | 10                                                                        | 6.5                                                 |
|        | Augusta.....         | A 195                        | 1871-1946 <sup>e</sup>              | 10                                                           |                                                                 |                                    |                                                                               |                                                        | 15                                                                        | 6.7                                                 |
|        | Augusta.....         | A 424                        | 1939-1947                           | 7                                                            |                                                                 | 54.7                               |                                                                               |                                                        | 20                                                                        | 9.5                                                 |
|        | Macon.....           | C 408                        | 1899-1947                           | 8                                                            |                                                                 |                                    |                                                                               |                                                        |                                                                           |                                                     |
|        | Macon.....           | A 432                        | 1939-1947                           | 22                                                           |                                                                 | 58.5                               | 29                                                                            | 7.7                                                    |                                                                           |                                                     |
|        | Savannah.....        | C 115                        | 1871-1945                           | 16                                                           |                                                                 | 56.7                               |                                                                               |                                                        | -10                                                                       | 9.1                                                 |
|        | Savannah.....        | A 56                         | 1939-1947                           | -28                                                          | -1                                                              | 39.8                               | 5                                                                             | 4.5                                                    |                                                                           |                                                     |
|        | Boise.....           | C 2818                       | 1864-1939 <sup>e</sup>              | -13                                                          |                                                                 | 36.9                               | 2                                                                             | 8.8                                                    |                                                                           |                                                     |
|        | Burley.....          | A 2849                       | 1939-1947                           | -18                                                          |                                                                 |                                    | -7                                                                            | 7.6                                                    |                                                                           |                                                     |
|        | Idaho Falls.....     | A 4150                       | 1935-1939 <sup>e</sup>              | -23                                                          | 1                                                               | 42.7                               |                                                                               |                                                        | 5                                                                         | 4.1                                                 |
|        | Lewiston.....        | A 4744                       | 1935-1939 <sup>e</sup>              | -28                                                          | -12                                                             | 37.1                               |                                                                               |                                                        | -5                                                                        | 8.9                                                 |
|        | Pocatello.....       | C 763                        | 1900-1944                           | -23                                                          |                                                                 | 44.7                               |                                                                               |                                                        | 0                                                                         | 9.8                                                 |
|        | Pocatello.....       | A 4467                       | 1935-1947                           | -16                                                          |                                                                 | 46.4                               | 6                                                                             | 7.2                                                    | -10                                                                       | 12.0                                                |
|        | Pocatello.....       | C 319                        | 1872-1947                           | -23                                                          | -8                                                              | 37.6                               |                                                                               |                                                        |                                                                           |                                                     |
| Ill.   | Cairo.....           | C 601 <sup>e</sup>           | Up to 1946                          |                                                              |                                                                 |                                    |                                                                               |                                                        |                                                                           |                                                     |
|        | Chicago.....         | C                            |                                     |                                                              |                                                                 |                                    |                                                                               |                                                        |                                                                           |                                                     |

Blank spaces indicate data not yet completed.



TABLE 1. WINTER CLIMATIC CONDITIONS<sup>a</sup>—(CONTINUED)

| STATE   | COL. 2<br>STATION <sup>b</sup> | COL. 3<br>ELEVATION <sup>c</sup><br>FT | COL. 4<br>PERIOD<br>OF RECORD <sup>d</sup> | COL. 5<br>LOW-<br>EST<br>TEMP.<br>ON<br>REC.<br>ORD <sup>d</sup><br>°F | COL. 6<br>AVER-<br>AGE<br>ANNUAL<br>TEMP.<br>°F | COL. 7<br>AVER-<br>AGE<br>WINTER<br>TEMP.<br>°F | COL. 8<br>DESIGN<br>DRY-<br>BULB<br>TEMP.<br>ON TAC<br>97.4%<br>BASIS <sup>e</sup><br>°F | COL. 9<br>WIND<br>VEL. AT<br>DESIGN<br>TEMP. <sup>h</sup><br>MPH | COL. 10<br>DESIGN<br>DRY-<br>BULB<br>TEMP.<br>IN<br>COMMON<br>USE <sup>i</sup><br>°F | COL. 11<br>AVER-<br>AGE<br>WIND<br>VEL.<br>DEC.<br>JAN.<br>FEB. <sup>j</sup><br>MPH |
|---------|--------------------------------|----------------------------------------|--------------------------------------------|------------------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Ill.    | Chicago.....                   | A 615                                  | 1935-1939*                                 | -19                                                                    | -6                                              | 35.1                                            | -3                                                                                       | 11.7                                                             | -10                                                                                  | 11.7                                                                                |
|         | Moline.....                    | A 594                                  | 1935-1939*                                 | -20                                                                    | -8                                              | 34.6                                            | -6                                                                                       | 10.8                                                             | -10                                                                                  | 10.8                                                                                |
|         | Peoria.....                    | A 660                                  | 1935-1939*                                 | -20                                                                    | -8                                              | 37.3                                            | -6                                                                                       | 10.7                                                             | -10                                                                                  | 8.3                                                                                 |
|         | Springfield.....               | C 603                                  | 1879-1947                                  | -24                                                                    | -7                                              | 39.8                                            | -2                                                                                       | 11.6                                                             | -10                                                                                  | 11.9                                                                                |
|         | Springfield.....               | A 608                                  | 1930-1947                                  | -19                                                                    | -1                                              | 45.1                                            | -2                                                                                       | 11.6                                                             | -10                                                                                  | 9.6                                                                                 |
| Ind.    | Evansville.....                | C 464                                  | 1897-1940                                  | -16                                                                    | 1                                               | 37.7                                            | -2                                                                                       | 11.6                                                             | -10                                                                                  | 10.4                                                                                |
|         | Fort Wayne.....                | C 885                                  | 1911-1941                                  | -24                                                                    | -1                                              | 37.6                                            | -1                                                                                       | 11.5                                                             | -10                                                                                  | 10.4                                                                                |
|         | Helmer.....                    | A 970                                  | 1935-1939*                                 | -25                                                                    | -6                                              | 39.6                                            | -1                                                                                       | 11.5                                                             | -10                                                                                  | 11.3                                                                                |
|         | Indianapolis.....              | A 816                                  | 1871-1946*                                 | -18                                                                    | -5                                              | 41.7                                            | 2                                                                                        | 11.4                                                             | -10                                                                                  | 10.3                                                                                |
|         | Terre Haute.....               | C 1146                                 | 1893-1946*                                 | -11                                                                    | -11                                             | 31.2                                            | -11                                                                                      | 7.9                                                              | -15                                                                                  | 10.5                                                                                |
| Iowa... | Charles City.....              | C 1023                                 | 1891-1945*                                 | -34                                                                    | -22                                             | 37.0                                            | -8                                                                                       | 14.5                                                             | -15                                                                                  | 10.1                                                                                |
|         | Davenport.....                 | C 648                                  | 1872-1947                                  | -27                                                                    | -13                                             | 37.0                                            | -8                                                                                       | 14.5                                                             | -15                                                                                  | 10.1                                                                                |
|         | Des Moines.....                | C 805                                  | 1878-1945*                                 | -30                                                                    | -17                                             | 35.4                                            | -8                                                                                       | 14.5                                                             | -20                                                                                  | 7.1                                                                                 |
|         | Des Moines.....                | A 979                                  | 1935-1939*                                 | -32                                                                    | -17                                             | 34.6                                            | -8                                                                                       | 14.5                                                             | -20                                                                                  | 8.3                                                                                 |
|         | Dubuque.....                   | C 740                                  | 1871-1947                                  | -27                                                                    | -12                                             | 39.3                                            | -8                                                                                       | 14.5                                                             | -20                                                                                  | 11.5                                                                                |
|         | Keokuk.....                    | C 637                                  | 1871-1945*                                 | -35                                                                    | -20                                             | 32.6                                            | -8                                                                                       | 14.5                                                             | -20                                                                                  | 11.5                                                                                |
|         | Sioux City.....                | C 1093 <sup>c</sup>                    | 1889-1944                                  | -24                                                                    | -13                                             | 40.7                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 7.7                                                                                 |
|         | Sioux City.....                | A 1098                                 | 1940-1946*                                 | -25                                                                    | -10                                             | 41.4                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10.6                                                                                |
| Kan.    | Concordia.....                 | C 1425                                 | 1885-1947                                  | -25                                                                    | -13                                             | 40.7                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 7.7                                                                                 |
|         | Dodge City.....                | C 2515                                 | 1942-1947                                  | -26                                                                    | -10                                             | 41.4                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10.6                                                                                |
|         | Dodge City.....                | A 2599                                 | 1874-1942                                  | -26                                                                    | -10                                             | 42.1                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.2                                                                                 |
|         | Topeka.....                    | C 991                                  | 1887-1947                                  | -25                                                                    | -10                                             | 42.1                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.2                                                                                 |
|         | Topeka.....                    | A 883                                  | 1946-1947                                  | -21                                                                    | -4                                              | 43.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.4                                                                                |
|         | Wichita.....                   | C 1423                                 | 1939-1947                                  | -10                                                                    | -4                                              | 43.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.4                                                                                |
|         | Wichita.....                   | A 1423                                 | 1939-1947                                  | -10                                                                    | -4                                              | 43.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.4                                                                                |
| Ky.     | Louisville.....                | C 583                                  | 1871-1947                                  | -20                                                                    | -5                                              | 45.1                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.8                                                                                 |
|         | Louisville.....                | A 544                                  | 1937-1947                                  | -15                                                                    | -5                                              | 43.9                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.8                                                                                 |
| La.     | New Orleans.....               | C 85                                   | 1874-1947                                  | 7                                                                      | 26                                              | 61.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.6                                                                                 |
|         | New Orleans.....               | A 8                                    | 1937-1947                                  | 19                                                                     | 16                                              | 60.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.8                                                                                 |
|         | Shreveport.....                | A 179                                  | 1935-1939*                                 | -23                                                                    | -15                                             | 31.5                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.6                                                                                |
| Maine   | Eastport.....                  | C 100                                  | 1873-1947                                  | -23                                                                    | -15                                             | 31.5                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10.4                                                                                |
|         | Portland.....                  | C 70                                   | 1885-1940                                  | -21                                                                    | -6                                              | 33.8                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.2                                                                                 |
|         | Portland.....                  | A 66                                   | 1940-1947                                  | -39                                                                    | -8                                              | 33.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.2                                                                                 |
| Md.     | Baltimore.....                 | C 114                                  | 1871-1947                                  | -7                                                                     | 8                                               | 44.1                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.4                                                                                |
|         | Baltimore.....                 | A 43                                   | 1935-1939*                                 | -18                                                                    | -3                                              | 38.1                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.3                                                                                |
| Mass.   | Boston.....                    | C 356                                  | 1870-1935*                                 | -14                                                                    | -3                                              | 39.3                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 14.8                                                                                |
|         | Boston.....                    | A 45                                   | 1936-1947                                  | -14                                                                    | -3                                              | 39.3                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 14.8                                                                                |
|         | Nantucket.....                 | C 45                                   | 1886-1947                                  | -6                                                                     | 12                                              | 29.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 11.0                                                                                |
|         | Nantucket.....                 | A 48                                   | 1946-1947                                  | -12                                                                    | -12                                             | 29.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 11.0                                                                                |
| Mich.   | Alpena.....                    | C 615                                  | Up to 1946                                 | -28                                                                    | -11                                             | 36.5                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.0                                                                                |
|         | Detroit.....                   | C 1000                                 | 1873-1933                                  | -24                                                                    | -11                                             | 36.5                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.0                                                                                |
|         | Detroit.....                   | A 632                                  | 1935-1939*                                 | -32                                                                    | -27                                             | 27.3                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.5                                                                                 |
|         | Escanaba.....                  | C 645                                  | 1878-1945*                                 | -24                                                                    | -10                                             | 36.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.1                                                                                |
|         | Grand Rapids.....              | C 706                                  | 1891-1946*                                 | -25                                                                    | -10                                             | 34.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.8                                                                                 |
|         | Lansing.....                   | C 861                                  | 1910-1947                                  | -10                                                                    | -13                                             | 28.3                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10.6                                                                                |
|         | Lansing.....                   | A 721                                  | 1874-1947                                  | -27                                                                    | -22                                             | 26.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.9                                                                                 |
|         | Marquette.....                 | C 724 <sup>c</sup>                     | 1888-1942*                                 | -37                                                                    | -22                                             | 26.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 13.4                                                                                |
|         | Sault St. Marie.....           | C 1133                                 | 1874-1947                                  | -41                                                                    | -28                                             | 24.3                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 11.3                                                                                |
| Minn.   | Duluth.....                    | A 1413                                 | 1947-1947                                  | -33                                                                    | -23                                             | 29.4                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 11.3                                                                                |
|         | Duluth.....                    | C 945                                  | 1890-1947                                  | -34                                                                    | -23                                             | 29.4                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.5                                                                                 |
|         | Minneapolis.....               | A 873                                  | 1938-1947                                  | -31                                                                    | -25                                             | 29.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 6.3                                                                                 |
|         | St. Paul.....                  | C 951                                  | 1871-1933                                  | -41                                                                    | -25                                             | 29.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 6.3                                                                                 |
|         | St. Paul.....                  | A 708                                  | 1937-1947                                  | -26                                                                    | -18                                             | 54.8                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10                                                                                  |
|         | Meridian.....                  | C 410                                  | 1889-1947                                  | -6                                                                     | 15                                              | 54.8                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.3                                                                                 |
|         | Meridian.....                  | A 293                                  | 1939-1947                                  | -7                                                                     | 18                                              | 56.8                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.9                                                                                 |
|         | Vicksburg.....                 | C 316                                  | 1874-1947                                  | -1                                                                     | 18                                              | 56.8                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.9                                                                                 |
| Mo.     | Columbia.....                  | A 266                                  | 1941-1947                                  | 10                                                                     | 42.3                                            | 41.1                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10.3                                                                                |
|         | Columbia.....                  | C 739                                  | 1869-1947                                  | -26                                                                    | -6                                              | 41.5                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10.3                                                                                |
|         | Columbia.....                  | A 787                                  | 1939-1947                                  | -18                                                                    | -2                                              | 43.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 11.8                                                                                |
|         | Kansas City.....               | C 741 <sup>c</sup>                     | 1889-1940                                  | -22                                                                    | -6                                              | 41.5                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 11.8                                                                                |
|         | Kansas City.....               | A 780                                  | 1935-1939*                                 | -22                                                                    | -2                                              | 43.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 11.8                                                                                |
|         | St. Louis.....                 | C 646                                  | 1871-1947                                  | -19                                                                    | -5                                              | 43.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 11.0                                                                                |
|         | St. Louis.....                 | A 597                                  | 1930-1947                                  | -19                                                                    | -5                                              | 43.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 12.4                                                                                |
| Mont.   | Springfield.....               | A 1270                                 | 1935-1939*                                 | -34                                                                    | -30                                             | 34.9                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.1                                                                                 |
|         | Billings.....                  | A 3584                                 | 1935-1939*                                 | -34                                                                    | -30                                             | 34.9                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.1                                                                                 |
|         | Butte.....                     | C 5700 <sup>c</sup>                    | 1894-1931                                  | -52                                                                    | -36                                             | 27.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 4.8                                                                                 |
|         | Butte.....                     | A 5538                                 | 1931-1947                                  | -52                                                                    | -36                                             | 27.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 4.8                                                                                 |
|         | Havre.....                     | C 2498                                 | 1880-1947                                  | -57                                                                    | -36                                             | 28.4                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 9.4                                                                                 |
|         | Helena.....                    | C 4175 <sup>c</sup>                    | 1880-1940*                                 | -42                                                                    | -24                                             | 31.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 5.2                                                                                 |
|         | Kalispell.....                 | C 3004                                 | 1897-1947                                  | -34                                                                    | -17                                             | 31.6                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 5.6                                                                                 |
|         | Miles City.....                | C 2400                                 | 1892-1942*                                 | -49                                                                    | -30                                             | 29.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 8.4                                                                                 |
|         | Miles City.....                | A 2629 <sup>c</sup>                    | 1935-1939*                                 | -29                                                                    | -13                                             | 37.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10.6                                                                                |
| Neb.    | Lincoln.....                   | C 1189                                 | 1887-1947                                  | -29                                                                    | -13                                             | 37.0                                            | -8                                                                                       | 14.5                                                             | -10                                                                                  | 10.6                                                                                |

TABLE 1. WINTER CLIMATIC CONDITIONS<sup>a</sup>—(CONTINUED)

| COL. 1   | COL. 2               | COL. 3                 | COL. 4                        | COL. 5                                 | COL. 6                                | COL. 7                         | COL. 8                                                | COL. 9                                  | COL. 10                                          | COL. 11                                     |
|----------|----------------------|------------------------|-------------------------------|----------------------------------------|---------------------------------------|--------------------------------|-------------------------------------------------------|-----------------------------------------|--------------------------------------------------|---------------------------------------------|
| STATE    | STATION <sup>b</sup> | ELEVATION <sup>c</sup> | PERIOD OF RECORD <sup>d</sup> | LOW-EST TEMP. ON REC. ORD <sup>d</sup> | AVERAGE ANNUAL MIN. TEMP <sup>e</sup> | AVG. WINTER TEMP. <sup>f</sup> | DESIGN DRY-BULB TEMP. ON TAC 97.4% BASIS <sup>g</sup> | WIND. VEL. AT DESIGN TEMP. <sup>h</sup> | DESIGN DRY-BULB TEMP. IN COMMON USE <sup>i</sup> | AVG. WIND. VEL. DEC. JAN. FEB. <sup>j</sup> |
|          |                      | FT                     |                               | °F                                     | °F                                    | °F                             | °F                                                    | MPH                                     | °F                                               | MPH                                         |
| Neb.     | Lincoln.....         | A 1185                 | 1933-1947                     | -26                                    | -17                                   | 35.6                           | -2                                                    | 12.7                                    | -20                                              | 7.9                                         |
|          | North Platte.....    | C 2815                 | 1874-1947                     | -35                                    | -17                                   | 35.4                           | -2                                                    | 12.7                                    | -20                                              | 7.9                                         |
|          | North Platte.....    | A 2788                 | 1935-1939*                    | -32                                    | -14                                   | 36.4                           | -2                                                    | 12.7                                    | -20                                              | 9.7                                         |
|          | Omaha.....           | C 1219                 | 1873-1935                     | -32                                    | -14                                   | 36.4                           | -2                                                    | 12.7                                    | -20                                              | 9.7                                         |
|          | Omaha.....           | A 1009                 | 1935-1947                     | -21                                    | -22                                   | 33.6                           | -4                                                    | 4.0                                     | -25                                              | 9.2                                         |
|          | Valentine.....       | C 2627                 | 1889-1947                     | -38                                    | -22                                   | 33.6                           | -4                                                    | 4.0                                     | -25                                              | 9.2                                         |
| Nev....  | Elko.....            | A 5079                 | 1935-1939                     | 8                                      | 16                                    | 53.8                           | 23                                                    | 5.3                                     | -5                                               | 6.0                                         |
|          | Las Vegas.....       | A 1882                 | 1937-1947                     | -19                                    | -10                                   | 38.0                           | 7                                                     | 3.6                                     | -15                                              | 8.1                                         |
|          | Reno.....            | C 4588                 | 1905-1942                     | -16                                    | -15                                   | 33.2                           | 7                                                     | 3.6                                     | -15                                              | 6.2                                         |
|          | Reno.....            | A 4417                 | 1940-1947                     | -36                                    | -10                                   | 38.0                           | 7                                                     | 3.6                                     | -15                                              | 6.2                                         |
| N. H.... | Winnemucca.....      | C 4293                 | 1871-1947                     | -37                                    | -9                                    | 42.3                           | 12                                                    | 9.5                                     | 5                                                | 15.8                                        |
|          | Concord.....         | C 343                  | 1871-1941                     | -35                                    | -15                                   | 33.2                           | 12                                                    | 9.5                                     | 5                                                | 15.8                                        |
|          | Concord.....         | A 359                  | 1941-1947                     | -37                                    | -9                                    | 42.3                           | 12                                                    | 9.5                                     | 5                                                | 15.8                                        |
| N. J.... | Atlantic City.....   | C 45                   | 1874-1947                     | -9                                     | 6                                     | 42.3                           | 12                                                    | 9.5                                     | 5                                                | 15.8                                        |
|          | Camden.....          | A 20                   | 1935-1939*                    | -14                                    | -11                                   | 35.2                           | 10                                                    | 11.6                                    | 0                                                | 16.1                                        |
|          | Newark.....          | C 15                   | 1931-1947                     | -11                                    | -11                                   | 35.2                           | 10                                                    | 11.6                                    | 0                                                | 10.9                                        |
|          | Sandy Hook.....      | C 19                   | 1914-1938*                    | -11                                    | -11                                   | 35.2                           | 10                                                    | 11.6                                    | 0                                                | 7.3                                         |
| N. M.... | Trenton.....         | C 144                  | 1866-1946                     | -14                                    | 2                                     | 42.0                           | 16                                                    | 7.1                                     | -6                                               | 4.6                                         |
|          | Albuquerque.....     | C 5022                 | 1931-1933                     | 5                                      | 5                                     | 44.3                           | 16                                                    | 7.1                                     | -6                                               | 4.6                                         |
|          | Albuquerque.....     | A 5319                 | 1933-1947                     | -6                                     | -19                                   | 51.4                           | 25                                                    | 8.4                                     | -5                                               | 8.4                                         |
|          | El Morro.....        | A 7120                 | 1940-1947                     | -25                                    | -19                                   | 51.4                           | 25                                                    | 8.4                                     | -5                                               | 8.4                                         |
|          | Rodeo.....           | A 4116                 | 1935-1939*                    | -29                                    | -11                                   | 35.2                           | 13                                                    | 9.2                                     | -10                                              | 7.1                                         |
|          | Roswell.....         | C 3643                 | 1905-1947                     | -29                                    | -11                                   | 35.2                           | 13                                                    | 9.2                                     | -10                                              | 7.1                                         |
| N. Y.... | Tucuman.....         | A 4054                 | 1935-1939*                    | -24                                    | -11                                   | 35.2                           | 13                                                    | 9.2                                     | -10                                              | 10.5                                        |
|          | Albany.....          | C 114                  | 1874-1947                     | -22                                    | -11                                   | 34.7                           | 0                                                     | 9.6                                     | -10                                              | 6.8                                         |
|          | Albany.....          | A 280                  | 1938-1947                     | -22                                    | -11                                   | 34.7                           | 0                                                     | 9.6                                     | -10                                              | 6.8                                         |
|          | Binghamton.....      | C 915                  | 1891-1946                     | -28                                    | -11                                   | 34.7                           | 0                                                     | 9.6                                     | -10                                              | 6.8                                         |
|          | Binghamton.....      | A 836                  | 1942-1947                     | -17                                    | -4                                    | 34.8                           | 3                                                     | 14.0                                    | -25                                              | 10.5                                        |
|          | Buffalo.....         | C 693 <sup>c</sup>     | 1873-1945*                    | -20                                    | -4                                    | 34.8                           | 3                                                     | 14.0                                    | -25                                              | 10.5                                        |
|          | Buffalo.....         | A 726                  | 1935-1939*                    | -43                                    | -26                                   | 29.5                           | 5                                                     | 8.0                                     | -15                                              | 11.3                                        |
|          | Canton.....          | C 458                  | 1889-1947                     | -24                                    | -10                                   | 34.9                           | 5                                                     | 8.0                                     | -15                                              | 11.3                                        |
|          | Elmira.....          | A 948                  | 1935-1939*                    | -24                                    | -10                                   | 34.9                           | 5                                                     | 8.0                                     | -15                                              | 11.3                                        |
|          | Ithaca.....          | C 888                  | 1879-1937                     | -14                                    | -3                                    | 41.1                           | 0                                                     | 16.8                                    | -10                                              | 12.1                                        |
|          | New York.....        | C 425                  | 1871-1947                     | -23                                    | -9                                    | 34.4                           | -5                                                    | 9.6                                     | -5                                               | 9.6                                         |
|          | Oswego.....          | C 363                  | 1871-1943                     | -22                                    | -4                                    | 35.1                           | 4                                                     | 11.9                                    | -10                                              | 11.2                                        |
|          | Rochester.....       | C 609                  | 1872-1947                     | -22                                    | -4                                    | 35.1                           | 4                                                     | 11.9                                    | -10                                              | 11.2                                        |
|          | Rochester.....       | A 560                  | 1935-1939*                    | -16                                    | -1                                    | 34.8                           | 4                                                     | 11.9                                    | -10                                              | 9.5                                         |
|          | Syracuse.....        | C 465                  | 1928-1940                     | -24                                    | 6                                     | 46.1                           | 22                                                    | 7.5                                     | 10                                               | 7.3                                         |
|          | Syracuse.....        | A 404                  | 1940-1947                     | -26                                    | 6                                     | 46.1                           | 22                                                    | 7.5                                     | 10                                               | 7.3                                         |
| N. C.... | Asheville.....       | C 2280                 | 1902-1947                     | -6                                     | 12                                    | 50.6                           | 22                                                    | 7.5                                     | 10                                               | 7.3                                         |
|          | Charlotte.....       | C 809                  | 1878-1947                     | -5                                     | 12                                    | 50.6                           | 22                                                    | 7.5                                     | 10                                               | 7.3                                         |
|          | Charlotte.....       | A 757                  | 1939-1947                     | -3                                     | 13                                    | 50.0                           | 20                                                    | 8.5                                     | -30                                              | 9.1                                         |
|          | Greensboro.....      | A 896                  | 1928-1947                     | -7                                     | 13                                    | 50.0                           | 20                                                    | 8.5                                     | -30                                              | 9.1                                         |
|          | Raleigh.....         | C 405                  | 1944-1947                     | -2                                     | 18                                    | 54.6                           | 15                                                    | 9.4                                     | -30                                              | 9.1                                         |
|          | Raleigh.....         | A 446                  | 1935-1939*                    | 5                                      | 18                                    | 54.6                           | 15                                                    | 9.4                                     | -30                                              | 9.1                                         |
| N. D.... | Wilmington.....      | C 78                   | 1871-1947                     | -45                                    | -31                                   | 25.3                           | 22                                                    | 7.1                                     | -30                                              | 10.1                                        |
|          | Bismarck.....        | C 1675                 | 1875-1940                     | -45                                    | -31                                   | 25.3                           | 22                                                    | 7.1                                     | -30                                              | 10.1                                        |
|          | Bismarck.....        | A 1655                 | 1940-1947                     | -38                                    | -33                                   | 25.6                           | -20                                                   | 12.4                                    | -25                                              | 10.9                                        |
|          | Devils Lake.....     | C 1                    | 1934-1947                     | -46                                    | -33                                   | 21.7                           | -20                                                   | 12.4                                    | -25                                              | 10.9                                        |
|          | Dickinson.....       | A 2599                 | 1905-1939*                    | -25                                    | -33                                   | 25.6                           | -20                                                   | 12.4                                    | -25                                              | 10.9                                        |
|          | Fargo.....           | C 890                  | 1935-1939*                    | -25                                    | -33                                   | 25.6                           | -20                                                   | 12.4                                    | -25                                              | 10.9                                        |
|          | Fargo.....           | A 830                  | 1935-1939*                    | -25                                    | -33                                   | 25.6                           | -20                                                   | 12.4                                    | -25                                              | 10.9                                        |
|          | Pembina.....         | C 830                  | 1935-1939*                    | -25                                    | -33                                   | 25.6                           | -20                                                   | 12.4                                    | -25                                              | 10.9                                        |
|          | Williston.....       | C 1919                 | 1879-1947                     | -50                                    | -24                                   | 24.5                           | -30                                                   | 11.9                                    | -35                                              | 8.6                                         |
| Ohio...  | Akron.....           | C 1040                 | 1887-1931*                    | -20                                    | -2                                    | 37.3                           | 9                                                     | 10.6                                    | -5                                               | 8.5                                         |
|          | Akron.....           | A 1040                 | 1935-1939*                    | -17                                    | -2                                    | 43.0                           | 7                                                     | 8.0                                     | 0                                                | 14.7                                        |
|          | Cincinnati.....      | C 772                  | 1870-1947                     | -17                                    | -2                                    | 37.2                           | 6                                                     | 13.8                                    | -10                                              | 11.6                                        |
|          | Cincinnati.....      | A 458                  | 1931-1947                     | -14                                    | -2                                    | 37.2                           | 6                                                     | 13.8                                    | -10                                              | 11.6                                        |
|          | Cleveland.....       | C 689                  | 1871-1946*                    | -6                                     | -3                                    | 40.4                           | 4                                                     | 10.5                                    | 0                                                | 11.1                                        |
|          | Cleveland.....       | A 813                  | 1930-1946*                    | -20                                    | -3                                    | 38.2                           | 4                                                     | 10.5                                    | 0                                                | 11.1                                        |
|          | Columbus.....        | C 812                  | 1878-1946*                    | -15                                    | -3                                    | 40.4                           | 4                                                     | 10.5                                    | 0                                                | 11.1                                        |
|          | Columbus.....        | A 820                  | 1939-1947                     | -28                                    | -3                                    | 40.4                           | 4                                                     | 10.5                                    | 0                                                | 11.1                                        |
|          | Dayton.....          | C 1086                 | 1883-1943                     | -17                                    | -3                                    | 40.4                           | 4                                                     | 10.5                                    | 0                                                | 11.1                                        |
|          | Dayton.....          | A 1002                 | 1940-1947                     | -16                                    | -5                                    | 37.2                           | 4                                                     | 12.1                                    | -10                                              | 12.1                                        |
|          | Sandusky.....        | C 608                  | 1878-1946*                    | -16                                    | -5                                    | 37.2                           | 4                                                     | 12.1                                    | -10                                              | 12.1                                        |
|          | Toledo.....          | C 668                  | 1871-1947                     | -16                                    | -5                                    | 37.2                           | 4                                                     | 12.1                                    | -10                                              | 12.1                                        |
| Okla...  | Toledo.....          | A 626                  | 1940-1947                     | -13                                    | -5                                    | 35.7                           | 4                                                     | 12.1                                    | -10                                              | 12.1                                        |
|          | Admore.....          | C 762                  | 1935-1939*                    | -17                                    | 2                                     | 47.9                           | 18                                                    | 9.7                                     | 0                                                | 11.5                                        |
|          | Oklahoma City.....   | C 1294                 | 1890-1947                     | -17                                    | 2                                     | 47.9                           | 18                                                    | 9.7                                     | 0                                                | 11.5                                        |
|          | Oklahoma City.....   | A 1311                 | 1939-1947                     | -10                                    | -5                                    | 49.0                           | 14                                                    | 14.7                                    | 0                                                | 11.5                                        |
|          | Tulsa.....           | C 686                  | 1932-1947                     | -5                                     | -5                                    | 49.0                           | 13                                                    | 11.3                                    | 0                                                | 11.5                                        |
| Ore....  | Wynoka.....          | A 1529                 | 1935-1939*                    | -10                                    | -5                                    | 49.0                           | 10                                                    | 11.3                                    | 0                                                | 11.5                                        |
|          | Arlington.....       | A 881                  | 1935-1939*                    | -25                                    | -17                                   | 35.2                           | 7                                                     | 7.8                                     | -5                                               | 5.6                                         |
|          | Baker.....           | C 3501                 | 1889-1947                     | -19                                    | -17                                   | 33.8                           | 3                                                     | 6.4                                     | 15                                               | 4.3                                         |
|          | Baker.....           | A 3374                 | 1939-1947                     | -4                                     | -17                                   | 33.8                           | 3                                                     | 6.4                                     | 15                                               | 4.3                                         |
|          | Eugene.....          | C 366                  | 1890-1942*                    | 9                                      | -17                                   | 45.4                           | 23                                                    | 5.3                                     | 5                                                | 4.3                                         |
|          | Eugene.....          | A 368                  | 1942-1947                     | -10                                    | -17                                   | 44.7                           | 23                                                    | 5.3                                     | 5                                                | 4.3                                         |
|          | Medford.....         | C 1428*                | 1911-1929                     | -10                                    | -17                                   | 44.7                           | 23                                                    | 5.3                                     | 5                                                | 4.3                                         |

TABLE 1. WINTER CLIMATIC CONDITIONS<sup>a</sup>—(CONTINUED)

| COL. 1 | COL. 2               | COL. 3                       | COL. 4                        | COL. 5                                    | COL. 6                          | COL. 7                     | COL. 8                                                | COL. 9                                            | COL. 10                                                | COL. 11                                     |
|--------|----------------------|------------------------------|-------------------------------|-------------------------------------------|---------------------------------|----------------------------|-------------------------------------------------------|---------------------------------------------------|--------------------------------------------------------|---------------------------------------------|
| STATE  | STATION <sup>b</sup> | ELEVATION <sup>c</sup><br>FT | PERIOD OF RECORD <sup>d</sup> | LOWEST TEMP. ON RECORD <sup>e</sup><br>°F | AVERAGE ANNUAL MIN. TEMP.<br>°F | AVERAGE WINTER TEMP.<br>°F | DESIGN DRY-BULB TEMP. ON TAC BASIS <sup>f</sup><br>°F | WIND VELOCITY AT DESIGN TEMP. <sup>h</sup><br>MPH | DESIGN DRY-BULB TEMP. IN COMMON USE <sup>i</sup><br>°F | AVERAGE WIND VELOCITY DEC. JAN. FEB.<br>MPH |
| Ore.   | Medford              | A 1343                       | 1929-1947                     | -3                                        |                                 |                            | 23                                                    | 4.3                                               |                                                        | 7.3                                         |
|        | Portland             | C 98                         | 1874-1947                     | -2                                        | 18                              | 46.1                       |                                                       |                                                   | 10                                                     |                                             |
|        | Portland             | A 25                         | 1940-1947                     | 3                                         |                                 | 44.3                       | 22                                                    | 8.0                                               |                                                        | 3.9                                         |
|        | Roseburg             | A 523                        | 1877-1947                     | -6                                        | 19                              | 46.7                       |                                                       |                                                   | 10                                                     |                                             |
| Pa.    | Curwensville         | C 2219                       | 1943-1947                     | -10                                       |                                 | 33.7                       | 0                                                     | 13.5                                              |                                                        |                                             |
|        | Erie                 | C 771                        | 1873-1946                     | -16                                       | -3                              | 37.3                       |                                                       |                                                   | -5                                                     | 13.6                                        |
|        | Erie                 | A 736                        | 1935-1939*                    |                                           |                                 |                            | 6                                                     | 12.1                                              |                                                        |                                             |
|        | Harrisburg           | C 335*                       | 1888-1938*                    | -14                                       | 3                               | 39.9                       |                                                       |                                                   | 0                                                      | 7.6                                         |
|        | Harrisburg           | C 339                        | 1935-1939*                    |                                           |                                 |                            | 7                                                     | 9.0                                               |                                                        |                                             |
| Pa.    | Philadelphia         | C 200                        | 1871-1947                     | -11                                       | 6                               | 42.7                       |                                                       |                                                   | 0                                                      | 11.0                                        |
|        | Philadelphia         | A 18                         | 1940-1947                     | 1                                         |                                 | 41.4                       |                                                       |                                                   | 0                                                      | 11.6                                        |
|        | Pittsburgh           | C 929                        | 1875-1947                     | -20                                       | -2                              | 40.9                       |                                                       |                                                   | 0                                                      |                                             |
|        | Pittsburgh           | A 1294                       | 1935-1947                     | -16                                       |                                 | 38.7                       | 6                                                     | 12.1                                              | 0                                                      | 9.0                                         |
|        | Reading              | C 311                        | 1913-1947                     | -14                                       |                                 | 41.2                       |                                                       |                                                   | -5                                                     | 7.6                                         |
|        | Seranton             | C 877                        | 1901-1947                     | -19                                       |                                 | 37.7                       |                                                       |                                                   |                                                        |                                             |
|        | Sunbury              | A 448                        | 1935-1939*                    |                                           |                                 |                            | 7                                                     | 7.1                                               |                                                        |                                             |
| R. I.  | Block Island         | C 46                         | 1881-1947                     | -10                                       |                                 | 40.1                       |                                                       |                                                   | 0                                                      | 20.6                                        |
|        | Providence           | C 77                         | 1904-1947                     | -17                                       | 1                               | 37.5                       |                                                       |                                                   | 0                                                      | 12.1                                        |
| S. C.  | Charleston           | C 59                         | 1871-1947                     | 7                                         | 22                              | 57.4                       |                                                       |                                                   | 15                                                     | 10.5                                        |
|        | Charleston           | A 51                         | 1940-1947                     | 14                                        |                                 | 55.0                       | 26                                                    | 6.9                                               |                                                        |                                             |
|        | Columbia             | C 401                        | 1887-1947                     | -2                                        | 19                              | 54.4                       |                                                       |                                                   | 10                                                     | 8.0                                         |
|        | Columbia             | A 227                        | 1939-1947                     | 9                                         |                                 | 49.2                       |                                                       |                                                   | 10                                                     | 8.4                                         |
|        | Greenville           | C 1006*                      | Up to 1946                    | -5                                        |                                 | 28.2                       |                                                       |                                                   | -20                                                    | 10.7                                        |
| S. D.  | Huron                | C 1342                       | 1881-1938                     | -43                                       | -26                             | 28.2                       |                                                       |                                                   | -20                                                    | 8.0                                         |
|        | Huron                | A 1287                       | 1938-1947                     | -30                                       |                                 | 33.4                       |                                                       |                                                   | -20                                                    |                                             |
|        | Rapid City           | C 3309                       | 1887-1947                     | -34                                       | -21                             | 33.4                       |                                                       |                                                   |                                                        |                                             |
|        | Rapid City           | A 3220                       | 1939-1947                     | -27                                       |                                 |                            |                                                       |                                                   | 10                                                     | 7.7                                         |
| Tenn.  | Chattanooga          | C 932                        | 1879-1947                     | -10                                       | 9                               | 50.3                       |                                                       |                                                   |                                                        |                                             |
|        | Chattanooga          | A 675                        | 1940-1947                     | 6                                         |                                 | 47.8                       | 19                                                    | 6.2                                               | 0                                                      | 7.2                                         |
|        | Knoxville            | C 1024                       | 1871-1942                     | -16                                       | 2                               | 47.9                       |                                                       |                                                   | 0                                                      | 9.3                                         |
|        | Knoxville            | A 1007                       | 1942-1947                     | 1                                         |                                 | 46.8                       |                                                       |                                                   | 0                                                      |                                             |
|        | Memphis              | C 348                        | 1872-1941                     | -9                                        | 9                               | 51.1                       |                                                       |                                                   | 0                                                      | 9.8                                         |
|        | Memphis              | A 267                        | 1941-1947                     | 1                                         |                                 | 50.0                       | 19                                                    | 8.9                                               | 0                                                      |                                             |
|        | Nashville            | C 714                        | 1871-1947                     | -13                                       | 5                               | 48.5                       | 14                                                    | 7.3                                               |                                                        |                                             |
|        | Nashville            | A 610                        | 1939-1947                     | -15                                       |                                 | 53.9                       |                                                       |                                                   | 15                                                     | 10.1                                        |
| Texas. | Abilene              | C 1748                       | 1885-1944                     | -6                                        |                                 |                            | 20                                                    | 10.4                                              | -5                                                     |                                             |
|        | Abilene              | A 1756                       | 1940-1947                     | 9                                         |                                 |                            |                                                       |                                                   | -10                                                    | 12.1                                        |
|        | Amarillo             | C 3686                       | 1892-1941                     | -16                                       | 0                               | 45.2                       | 11                                                    | 12.9                                              |                                                        |                                             |
|        | Amarillo             | A 3595                       | 1941-1947                     | -7                                        |                                 |                            |                                                       |                                                   | 20                                                     | 8.3                                         |
|        | Austin               | C 625                        | 1897-1942                     | -1                                        |                                 | 58.4                       |                                                       |                                                   |                                                        |                                             |
|        | Brownsville          | C 140                        | 1922-1943                     | 12                                        | 29                              | 66.8                       |                                                       |                                                   | 30                                                     | 10.4                                        |
|        | Brownsville          | A 25                         | 1943-1947                     | 30                                        |                                 |                            |                                                       |                                                   | 20                                                     | 11.0                                        |
|        | Corpus Christi       | C 21                         | 1887-1942*                    | 11                                        |                                 | 63.7                       |                                                       |                                                   | 0                                                      | 10.6                                        |
|        | Corpus Christi       | A 45                         | 1943-1946*                    | 23                                        | 13                              | 55.6                       | 23                                                    | 8.8                                               |                                                        |                                             |
|        | Dallas               | C 732                        | 1913-1940                     | -3                                        |                                 |                            |                                                       |                                                   | 15                                                     | 8.0                                         |
|        | Dallas               | A 520                        | 1940-1947                     | 5                                         |                                 | 60.6                       |                                                       |                                                   | 10                                                     | 9.0                                         |
|        | Del Rio              | C 1020                       | 1905-1947                     | 12                                        | 16                              | 53.5                       |                                                       |                                                   | 10                                                     |                                             |
|        | El Paso              | C 3792                       | 1890-1942                     | -5                                        |                                 |                            | 26                                                    | 8.6                                               |                                                        |                                             |
|        | El Paso              | A 3958                       | 1939-1947                     | 11                                        |                                 |                            |                                                       |                                                   | 10                                                     | 10.5                                        |
|        | Fort Worth           | C 708                        | 1898-1939*                    | -8                                        | 12                              | 55.1                       |                                                       |                                                   |                                                        |                                             |
|        | Fort Worth           | A 728                        | 1940-1947                     | 4                                         |                                 | 61.7                       |                                                       |                                                   | 20                                                     | 11.2                                        |
|        | Galveston            | C 128                        | 1871-1947                     | 8                                         |                                 |                            |                                                       |                                                   | 20                                                     | 10.5                                        |
|        | Galveston            | A 9                          | 1939-1947                     | 14                                        |                                 |                            |                                                       |                                                   |                                                        |                                             |
|        | Houston              | C 198                        | 1888-1947                     | 5                                         | 22                              | 61.0                       |                                                       |                                                   | 15                                                     | 8.0                                         |
|        | Houston              | A 73                         | 1932-1947                     | 5                                         |                                 | 60.1                       | 33                                                    | 9.2                                               |                                                        |                                             |
|        | Palestine            | C 555                        | 1881-1947                     | -6                                        |                                 | 57.1                       |                                                       |                                                   | 20                                                     | 10.7                                        |
|        | Port Arthur          | C 64                         | 1917-1947                     | 11                                        |                                 | 61.2                       |                                                       |                                                   |                                                        |                                             |
|        | Port Arthur          | A 21                         | 1944-1947                     | 24                                        |                                 |                            |                                                       |                                                   | 20                                                     | 8.3                                         |
|        | San Antonio          | C 770                        | 1885-1941                     | 4                                         | 21                              | 60.6                       |                                                       |                                                   |                                                        |                                             |
|        | San Antonio          | A 800                        | 1942-1947                     | 17                                        |                                 |                            | 32                                                    | 7.6                                               |                                                        |                                             |
|        | Waco                 | C 513                        | 1931-1947                     | 7                                         |                                 |                            | 23                                                    | 8.5                                               |                                                        |                                             |
|        | Wink                 | A 2511                       | 1935-1939*                    | -17                                       |                                 |                            | -2                                                    | 7.7                                               |                                                        |                                             |
| Utah.  | Millford             | C 5085                       | 1935-1939*                    | -32                                       | -15                             | 36.3                       |                                                       |                                                   | -15                                                    | 9.0                                         |
|        | Modesto              | C 5472                       | 1901-1947                     | -20                                       | -2                              | 40.0                       |                                                       |                                                   | -10                                                    | 7.8                                         |
|        | Salt Lake City       | C 4254                       | 1874-1947                     | -30                                       |                                 | 38.3                       | 7                                                     | 7.4                                               |                                                        |                                             |
|        | Salt Lake City       | A 4254                       | 1928-1947                     | -29                                       | -17                             | 31.5                       |                                                       |                                                   | -10                                                    | 11.6                                        |
| Vt.    | Burlington           | C 409                        | 1884-1943                     | -23                                       |                                 |                            |                                                       |                                                   | 10                                                     | 14.0                                        |
|        | Burlington           | A 335                        | 1943-1944                     | -23                                       |                                 |                            |                                                       |                                                   | 5                                                      | 8.1                                         |
| Va.    | Cape Henry           | C 24                         | 1874-1947                     | -5                                        |                                 | 49.2                       |                                                       |                                                   |                                                        |                                             |
|        | Lynchburg            | C 644                        | 1874-1944                     | -7                                        | 8                               | 46.8                       |                                                       |                                                   |                                                        |                                             |
|        | Lynchburg            | A 951                        | 1944-1947                     | 7                                         |                                 |                            |                                                       |                                                   | 15                                                     | 12.1                                        |
|        | Norfolk              | C 91                         | 1871-1947                     | -3                                        | 15                              | 49.3                       |                                                       |                                                   | 15                                                     | 8.1                                         |
|        | Richmond             | C 180                        | 1897-1947                     | -12                                       | 10                              | 47.0                       |                                                       |                                                   |                                                        |                                             |
|        | Richmond             | A 172                        | 1929-1947                     |                                           |                                 |                            | 15                                                    | 7.1                                               |                                                        |                                             |
|        | Roanoke              | A 1194                       | 1935-1939*                    |                                           |                                 |                            | 21                                                    | 8.2                                               |                                                        |                                             |
| Wash.  | Ellensburg           | A 1731                       | 1935-1939*                    |                                           |                                 |                            | 1                                                     | 3.8                                               |                                                        |                                             |

TABLE 1. WINTER CLIMATIC CONDITIONS<sup>a</sup>—(CONTINUED)

| COL. 1 | COL. 2               | COL. 3                       | COL. 4                        | COL. 5                                    | COL. 6                          | COL. 7                     | COL. 8                                                | COL. 9                                            | COL. 10                                                | COL. 11                                     |
|--------|----------------------|------------------------------|-------------------------------|-------------------------------------------|---------------------------------|----------------------------|-------------------------------------------------------|---------------------------------------------------|--------------------------------------------------------|---------------------------------------------|
| STATE  | STATION <sup>b</sup> | ELEVATION <sup>c</sup><br>FT | PERIOD OF RECORD <sup>d</sup> | LOWEST TEMP. ON RECORD <sup>e</sup><br>°F | AVERAGE ANNUAL MIN. TEMP.<br>°F | AVERAGE WINTER TEMP.<br>°F | DESIGN DRY-BULB TEMP. ON TAC BASIS <sup>f</sup><br>°F | WIND VELOCITY AT DESIGN TEMP. <sup>h</sup><br>MPH | DESIGN DRY-BULB TEMP. IN COMMON USE <sup>i</sup><br>°F | AVERAGE WIND VELOCITY DEC. JAN. FEB.<br>MPH |
| Wash.  | North Head           | C 199                        | 1884-1947                     | 11                                        | 24                              | 46.4                       |                                                       |                                                   | 20                                                     | 16.1                                        |
|        | Seattle              | C 104                        | 1890-1947                     | 3                                         | 20                              | 46.3                       |                                                       |                                                   | 15                                                     | 9.8                                         |
|        | Seattle              | A 47                         | 1928-1947                     | 3                                         |                                 | 45.1                       | 24                                                    | 6.3                                               |                                                        |                                             |
|        | Spokane              | C 2030                       | 1931-1941                     | -30                                       | -5                              | 37.7                       |                                                       |                                                   | -15                                                    | 6.2                                         |
|        | Spokane              | A 1974                       | 1941-1947                     | -7                                        |                                 |                            |                                                       |                                                   |                                                        |                                             |
|        | Tacoma               | C 279                        | 1897-1947                     | -7                                        |                                 | 44.9                       | 4                                                     | 5.1                                               |                                                        |                                             |
|        | Tacoma               | A 110                        | 1883-1947                     | 7                                         |                                 | 45.4                       |                                                       |                                                   | 15                                                     | 8.0                                         |
|        | Yakima               | C 1160                       | 1938-1946                     | -24                                       |                                 | 39.8                       |                                                       |                                                   | 15                                                     | 8.9                                         |
|        | Yakima               | A 1066                       | 1944-1947                     | -4                                        |                                 |                            |                                                       |                                                   | -5                                                     | 4.1                                         |
| W. Va. | Elkins               | C 1989*                      | 1898-1944                     | -28                                       | -8                              | 39.4                       |                                                       |                                                   | -10                                                    | 6.2                                         |
|        | Parkersburg          | C 685                        | 1888-1947                     | -27                                       | -1                              | 42.0                       |                                                       |                                                   | -10                                                    | 7.2                                         |
| Wis.   | Green Bay            | C 598                        | 1886-1947                     | -36                                       | -18                             | 29.8                       |                                                       |                                                   | -20                                                    | 10.5                                        |
|        | La Crosse            | C 725                        | 1872-1947                     | -43                                       | -21                             | 31.7                       |                                                       |                                                   | -25                                                    | 9.3                                         |
|        | La Crosse            | A 677                        | 1943-1947                     | -28                                       |                                 | 30.5                       | -17                                                   | 6.9                                               |                                                        |                                             |
|        | Madison              | C 1008                       | 1888-1947                     | -29                                       |                                 | 31.4                       |                                                       |                                                   | -15                                                    | 10.1                                        |
|        | Madison              | A 584                        | 1935-1939*                    |                                           |                                 |                            |                                                       |                                                   |                                                        |                                             |
|        | Milwaukee            | C 744                        | 1870-1947                     | -25                                       | -12                             | 33.4                       | -8                                                    | 9.1                                               | -15                                                    | 12.1                                        |
|        | Milwaukee            | A 707                        | 1927-1947                     | -29                                       |                                 | 29.0                       | -6                                                    | 11.9                                              | -15                                                    |                                             |
| Wyo.   | Cheney               | C 6144                       | 1873-1935                     | -38                                       | -18                             | 33.6                       | -3                                                    | 11.1                                              | -15                                                    | 13.3                                        |
|        | Cheney               | A 6161                       | 1935-1947                     | -34                                       |                                 |                            |                                                       |                                                   | -18                                                    | 3.9                                         |
|        | Lander               | C 5448                       | 1891-1946                     | -40                                       | -12                             | 30.0                       |                                                       |                                                   |                                                        |                                             |
|        | Lander               | A 5568                       | 1946-1947                     | -14                                       |                                 |                            |                                                       |                                                   |                                                        |                                             |
|        | Rock Springs         | A 6746                       | 1932-1942                     | -33                                       |                                 | 30.1                       | -7                                                    | 9.1                                               |                                                        |                                             |

| PROV. OF CANADA | STATION <sup>b</sup> | ELEVATION <sup>c</sup><br>FT | PERIOD OF RECORD <sup>d</sup> | LOWEST TEMP. ON RECORD <sup>e</sup><br>°F | AVERAGE ANNUAL MIN. TEMP.<br>°F | WINTER DESIGN TEMP <sup>a</sup> |        |     |     | AVERAGE WIND VELOCITY <sup>o</sup><br>MPH |
|-----------------|----------------------|------------------------------|-------------------------------|-------------------------------------------|---------------------------------|---------------------------------|--------|-----|-----|-------------------------------------------|
|                 |                      |                              |                               |                                           |                                 | 1%                              | 2 1/2% | 5%  | 10% |                                           |
| Alta.           | Calgary              | A 3540*                      | 1921-1950                     | -46                                       | -31                             | -35                             | -29    | -25 | -16 | 10.1                                      |
|                 | Edmonton             | A 2218*                      | 1921-1950                     | -55                                       | -39                             | -39                             | -33    | -29 | -21 | 7.6                                       |
|                 | Grande Prairie       | A 2190*                      | 1942-1950                     | -62                                       | -47                             | -43                             | -39    | -34 | -27 | 7.9                                       |
|                 | Lethbridge           | A 3018*                      | 1921-1950                     | -45                                       | -32                             | -38                             | -32    | -28 | -19 | 15.0                                      |
|                 | Medicine Hat         | A 1216*                      | 1921-1950                     | -64                                       | -51                             | -48                             | -42    | -37 | -30 |                                           |
| B. C.           | Estevan Point        | A 2365*                      | 1921-1950                     | -49                                       | -34                             | -41                             | -35    | -31 | -22 | 9.0                                       |
|                 | Fort Nelson          | A 1230*                      | 1938-1950                     | -61                                       | -47                             | -42                             | -38    | -33 | -27 | 9.9                                       |
|                 | Prince George        | A 1121*                      | 1921-1950                     | -16                                       | -1                              | -14                             | -6     | -1  | 4   | 3.7                                       |
|                 | Prince Rupert        | A 2218*                      | 1921-1950                     | -58                                       | -42                             | -43                             | -32    | -25 | -16 | 7.2                                       |
|                 | Vancouver            | C 170*                       | 1921-1950                     | -3                                        | 12                              | 5                               | 8      | 12  | 18  | 8.0                                       |
| Man.            | Victoria             | C 228*                       | 1938-1950                     | 0                                         | 13                              | 8                               | 11     | 15  | 21  | 7.7                                       |
|                 | Brandon              | C 1200*                      | 1921-1950                     | -49                                       | -30                             | -20                             | -12    | -5  | 19  | 25                                        |
|                 | Churchill            | A 115*                       | 1932-1950                     | -50                                       | -43                             | -43                             | -42    | -40 | -37 | 14.7                                      |
|                 | The Pas              | A 894*                       | 1921-1950                     | -54                                       | -42                             | -43                             | -39    | -30 | -26 | 6.4                                       |
| N. B.           | Winnipeg             | A 788*                       | 1921-1950                     | -44                                       | -35                             | -33                             | -29    | -25 | -21 | 12.0                                      |
|                 | Fredericton          | C 164*                       | 1923-1950                     | -38                                       | -24                             | -9                              | -6     | -3  | 0   | 9.2                                       |
|                 | Moncton              | A 248*                       | 1921-1950                     | -36                                       | -23                             | -11                             | -8     | -5  | 0   | 14.9                                      |
| Nfld.           | Saint John           | C 119*                       | 1921-1950                     | -21                                       | -12                             | -6                              | -3     | 0   | 5   | 13.8                                      |
|                 | Corner Brook         | C 40*                        | 1937-1950                     | -25                                       | -12                             | -4                              | -1     | 2   | 6   |                                           |
|                 | Gander               | A 482*                       | 1938-1950                     | -31                                       | -14                             | -11                             | -8     | -3  | 0   | 17.2                                      |
|                 | Goose Bay            | A 144*                       | 1942-1950                     | -35                                       | -30                             | -29                             | -26    | -24 | -20 | 10.3                                      |
| N.W.T.          | St. John's           | A 463*                       | 1926-1950                     | -10                                       | -2                              | -1                              | 1      | 4   | 7   | 19.3                                      |
|                 | Aklavik              | C 30*                        | 1927-1950                     | -62                                       | -42                             | -50                             | -46    | -43 | -39 |                                           |
|                 | Fort Norman          | C 300*                       | 1925-1950                     | -65                                       | -54                             | -56                             | -48    | -43 | -35 |                                           |
|                 | Resolute             | A 68*                        | 1942-1950                     | -49                                       | -44                             | -51                             | -47    | -43 | -39 |                                           |
| N.S.            | Yellowknife          | C 56*                        | 1948-1950                     | -55                                       | -53                             | -45                             | -42    | -40 | -36 | 9.2                                       |
|                 | Halifax              | A 682*                       | 1942-1950                     | -60                                       | -51                             | -49                             | -47    | -45 | -41 |                                           |
|                 | Halifax              | C 83*                        | 1921-1950                     | -21                                       | -6                              | 0                               | 4      | 7   | 11  | 9.6                                       |
|                 | Sydney               | A 197*                       | 1944-1950                     | -11                                       | -9                              | -3                              | 2      | 5   | 9   | 12.4                                      |
| Ont.            | Yarmouth             | A 136*                       | 1921-1950                     | -23                                       | -9                              | -7                              | 1      | 4   | 8   | 13.1                                      |
|                 | Fort William         | A 644*                       | 1921-1950                     | -11                                       | 1                               | 4                               | 7      | 10  | 13  | 13.5                                      |
|                 | Hamilton             | C 303*                       | 1930-1950                     | -17                                       | -8                              | -4                              | 0      | 5   | 10  | 9.6                                       |
|                 | Kapuskasing          | A 752*                       | 1921-1950                     | -53                                       | -42                             | -34                             | -30    | -27 | -22 | 10.0                                      |
|                 | Kingston             | C 340*                       | 1921-1950                     | -31                                       | -17                             | -15                             | -11    | -6  | -1  | 10.8                                      |
|                 | Kitchener            | C 1100*                      | 1921-1950                     | -29                                       | -11                             | -8                              | -3     | 2   | 7   |                                           |
|                 | London               | A 912*                       | 1921-1950                     | -27                                       | -11                             | -5                              | -1     | 3   | 8   | 11.9                                      |

TABLE 1. WINTER CLIMATIC CONDITIONS<sup>a</sup>—(CONCLUDED)

| COL. 1<br>PROV.<br>OF<br>CAN-<br>ADA | COL. 2<br><br>STATION <sup>b</sup> | COL. 3<br><br>ELE-<br>VA-<br>TION <sup>c</sup><br><br>FT | COL. 4<br><br>PERIOD<br>OF<br>RECORD <sup>d</sup> | COL. 5<br>LOW-<br>EST<br>TEMP.<br>ON<br>REC.<br>ORD <sup>e</sup><br>°F | COL. 6<br>AVER-<br>AGE<br>AN-<br>NUAL<br>MIN.<br>TEMP. <sup>f</sup><br>°F | COL. 7   COL. 8   COL. 9   COL. 10<br>WINTER DESIGN TEMP. <sup>g</sup> |     |     |     | COL. 11<br>AVG.<br>WIND<br>VEL. <sup>h</sup><br>MPH |      |
|--------------------------------------|------------------------------------|----------------------------------------------------------|---------------------------------------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------|-----|-----|-----|-----------------------------------------------------|------|
|                                      |                                    |                                                          |                                                   |                                                                        |                                                                           | 1%   2½%   5%   10%                                                    |     |     |     |                                                     |      |
|                                      |                                    |                                                          |                                                   |                                                                        |                                                                           | °F                                                                     | °F  | °F  | °F  |                                                     |      |
| Ont....                              | North Bay.....                     | A                                                        | 1210°                                             | 1925-1950                                                              | -46                                                                       | -33                                                                    | -24 | -20 | -16 | -11                                                 | 11.3 |
|                                      | Ottawa.....                        | A                                                        | 339°                                              | 1921-1950                                                              | -38                                                                       | -26                                                                    | -18 | -15 | -11 | -7                                                  | 11.1 |
|                                      | Peterborough.....                  | C                                                        | 648°                                              | 1921-1950                                                              | -38                                                                       | -21                                                                    | -15 | -11 | -6  | -1                                                  |      |
|                                      | Sioux Lookout.....                 | A                                                        | 1227°                                             | 1931-1950                                                              | -50                                                                       | -39                                                                    | -38 | -33 | -29 | -24                                                 | 8.5  |
|                                      | Sudbury.....                       | C                                                        | 837°                                              | 1921-1950                                                              | -45                                                                       | -31                                                                    | -21 | -17 | -12 | -5                                                  |      |
|                                      | Timmins.....                       | C                                                        | 1100°                                             | 1921-1950                                                              | -55                                                                       | -34                                                                    | -30 | -26 | -22 | -17                                                 |      |
|                                      | Toronto.....                       | C                                                        | 379°                                              | 1921-1950                                                              | -22                                                                       | -7                                                                     | -4  | 0   | 5   | 10                                                  | 14.1 |
|                                      | Toronto.....                       | A                                                        | 578°                                              | 1938-1950                                                              | -24                                                                       | -13                                                                    | -9  | -4  | 1   | 6                                                   | 12.1 |
|                                      | Windsor.....                       | A                                                        | 637°                                              | 1921-1950                                                              | -10                                                                       | -2                                                                     | 0   | 3   | 7   | 11                                                  | 12.3 |
|                                      | Charlottetown.....                 | C                                                        | 74°                                               | 1921-1950                                                              | -23                                                                       | -11                                                                    | -6  | -3  | 0   | 4                                                   | 11.3 |
| P. E. I.<br>Que....                  | Arvida.....                        | C                                                        | 375°                                              | 1932-1950                                                              | -42                                                                       | -31                                                                    | -23 | -19 | -16 | -11                                                 | 8.2  |
|                                      | Knob Lake.....                     | A                                                        | 1605°                                             | 1948-1950                                                              | -59                                                                       | -48                                                                    | -44 | -40 | -34 | -30                                                 |      |
|                                      | Mont Joli.....                     | A                                                        | 150°                                              | 1943-1950                                                              | -28                                                                       | -14                                                                    | -11 | -8  | -3  | 3                                                   | 13.3 |
|                                      | Montreal.....                      | C                                                        | 187°                                              | 1921-1950                                                              | -29                                                                       | -16                                                                    | -12 | -9  | -6  | -2                                                  | 12.3 |
|                                      | Montreal.....                      | A                                                        | 98°                                               | 1942-1950                                                              | -28                                                                       | -20                                                                    | -14 | -11 | -8  | -4                                                  | 13.1 |
|                                      | Port Harrison.....                 | C                                                        | 66°                                               | 1942-1950                                                              | -49                                                                       | -42                                                                    | -43 | -39 | -35 | -31                                                 | 13.4 |
|                                      | Quebec City.....                   | C                                                        | 296°                                              | 1921-1950                                                              | -32                                                                       | -19                                                                    | -16 | -12 | -9  | -4                                                  | 12.4 |
|                                      | Seven Islands.....                 | A                                                        | 190°                                              | 1944-1950                                                              | -43                                                                       | -23                                                                    | -20 | -17 | -12 | -5                                                  |      |
|                                      | Sherbrooke.....                    | C                                                        | 620°                                              | 1921-1950                                                              | -39                                                                       | -24                                                                    | -15 | -12 | -9  | -5                                                  | 8.2  |
|                                      | Three Rivers.....                  | C                                                        | 50°                                               | 1921-1950                                                              | -43                                                                       | -24                                                                    | -17 | -13 | -10 | -5                                                  |      |
| Sask. .                              | Prince Albert.....                 | A                                                        | 1414°                                             | 1921-1950                                                              | -56                                                                       | -46                                                                    | -48 | -41 | -37 | -30                                                 | 4.9  |
|                                      | Regina.....                        | A                                                        | 1884°                                             | 1921-1950                                                              | -54                                                                       | -39                                                                    | -39 | -34 | -30 | -25                                                 | 12.1 |
|                                      | Saskatoon.....                     | A                                                        | 1645°                                             | 1921-1950                                                              | -54                                                                       | -41                                                                    | -45 | -37 | -33 | -26                                                 | 9.7  |
|                                      | Swift Current.....                 | A                                                        | 2877°                                             | 1921-1950                                                              | -54                                                                       | -34                                                                    | -39 | -33 | -29 | -24                                                 | 14.6 |
| Y. T. .                              | Dawson.....                        | C                                                        | 1062°                                             | 1921-1950                                                              | -73                                                                       | -54                                                                    | -62 | -56 | -50 | -39                                                 |      |
|                                      | Whitehorse.....                    | A                                                        | 2289°                                             | 1941-1950                                                              | -62                                                                       | -51                                                                    | -49 | -43 | -37 | -26                                                 | 8.7  |

<sup>a</sup> United States data compiled from U. S. Weather Bureau Records for years indicated, and Canadian data from the Climatological Atlas of Canada for years indicated.

<sup>b</sup> Col. 2. The stations followed by letter A are airport stations; all others are city office stations and are followed by letter C.

<sup>c</sup> Col. 3. The elevations marked c are ground elevations of the station. All other elevations given are the actual elevations of the thermometer bulb above mean sea level.

<sup>d</sup> Col. 4. The periods of record indicated apply only to the lowest temperature ever recorded shown in Col. 5, and generally extend from a summer month of the first year indicated through the spring months of the last year indicated. The periods marked by \* terminated in December of the year indicated.

<sup>e</sup> Average of readings of one lowest temperature obtained for each year for period of record. For Canada, in some cases, more than one location have been used.

<sup>f</sup> For period October to April, inclusive.

<sup>g</sup> It should be noted that Col. 8 in the United States section of the table applies only to airports, as these data for city stations are not available at this time. The temperature shown is the minimum hourly outdoor temperature which has been equalled or exceeded 97½ percent of the total hours in December, January and February for the period of record. It is pointed out that in most cases the airport stations are outside of the city and these data would apply primarily to rural areas.

<sup>h</sup> Col. 9 indicates the maximum wind velocity which occurred at temperatures the same as, and lower than, the temperatures shown in Col. 5.

<sup>i</sup> Col. 10 records design temperatures in use by A.S.H.A.E. Members as reported by Chapter Secretaries for the various stations. Where these were not available the design temperatures from an ACRMA publication and various other sources have been inserted.

<sup>j</sup> The wind velocities indicated in Col. 11 were furnished by the U. S. Weather Bureau and corrected through Feb. 1948.

<sup>k</sup> A bulletin prepared by A.S.H.A.E. and U. S. Weather Bureau for annual weather data of city of Detroit indicates 6 as design temperature based on Dec. to March, inclusive.

<sup>l</sup> Computed for Reading by Karl Shelley and O. F. Smith.

<sup>m</sup> The winter design temperatures for Canadian cities for bases of 1, 2½, 5 and 10 percent are the Fahrenheit temperature values at or below which 1, 2½, 5 and 10 percent of the January hourly outdoor temperatures occur, for the 10 years 1941 to 1950. The tabulated values are based on hourly temperature observations for some of the cities and upon the difference between the mean monthly temperature and the design temperature for the remainder of the cities listed.

<sup>n</sup> Most of the wind speeds are based on periods ending in 1947 which are somewhat shorter than the periods for the minimum temperatures. The three months, December, January and February were used.

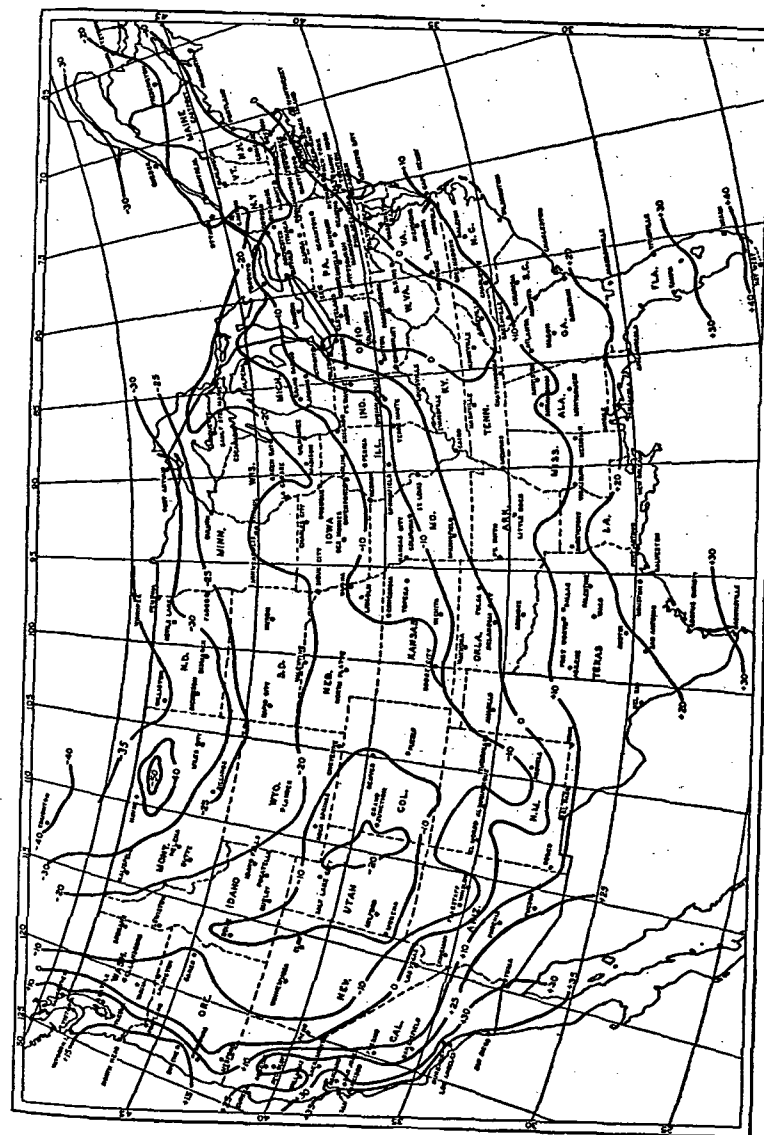


FIG. 1. ISOOTHERMS OF WINTER OUTDOOR DESIGN TEMPERATURE

tween the 0 F and 10 F isotherms would normally have a design temperature of 5 F although sharp changes in elevation must be taken into consideration in mountainous areas where large differences in climate may occur within relatively small distances. This map will be of considerable value in selecting design temperatures for cities and towns not listed in Table 1. The design temperatures in Column 10 of Table 1 are often used with a design wind velocity of 15 mph. However, Column 11 shows that the

average wind velocity from December through February is 15 mph or higher in only 7 of the cities listed and Column 9 shows that a wind velocity of 15 mph did not occur in any city listed for temperatures equal to or lower than those shown in Column 8 for the years 1935-1939. Consequently, it will often be desirable to modify the U values in Tables 6 to 9 and 15 to 19 of Chapter 9 to correspond to lower wind velocities. Correction factors for wind velocities can be found in Table 21 of Chapter 9.

Column 6 in Table 1 lists the average annual minimum temperature which is the average of readings of the one lowest temperature occurring for each year the weather station has been in existence. A comparison of the temperatures listed in Columns 6, 8, and 10 of Table 1 offers some guidance in selecting a suitable outdoor design temperature for particular cities. For the 63 cities in the United States having temperatures listed in all three columns the average annual minimums in Column 6 average 2.3 deg warmer than the design temperature in common use listed in Column 10 whereas the design temperatures in Column 8 average 11.0 deg warmer than those in Column 10. There are variations of 6 deg or more in either direction from these average differences, however, for a few cities in this group.

Designers are cautioned against attempting to compensate for internal vagrant heat sources in a structure, the heat generated by electrical equipment, the approximations that may exist in heat transmission factors and infiltration rates, and the safety factors used in selecting heating plant capacity by adjusting the design temperature difference between indoors and outdoors. These factors should be accounted for by more careful analysis of their existence and magnitude in computing the heating load that must be carried by the heating plant itself.

### INSIDE TEMPERATURES

The inside air temperature which must be maintained within a building is understood to be the dry-bulb temperature at the breathing line, 5 ft above the floor, or at the seating level, 30 in. above the floor, and not less than 3 ft from the outside walls. Inside air temperatures usually specified, vary in accordance with the intended use of the building. Table 2 presents values which conform to good practice.

The proper dry-bulb temperature to be maintained depends upon the relative humidity and air motion, as explained in Chapter 6. In other words, a person may feel warm or cool at the same dry-bulb temperature, depending on the relative humidity and air motion. The optimum winter *effective temperature* for sedentary persons, as determined at the A.S.H.V.E. Research Laboratory, is 67-68 ET.

As explained in Chapter 6 for so-called still air conditions, a relative humidity of approximately 50 percent is required to produce an effective temperature of 68 ET when the dry-bulb temperature is 72.5 F. However, even where provision is made for artificial humidification, the relative humidity is seldom maintained higher than 40 percent during the extremely cold weather, and where no provision is made for humidification, the relative humidity may be 20 percent or less. Consequently, in using the figures listed in Table 2, consideration should be given to the actual relative humidity to be maintained, if provision is to be made for humidification. If no humidification is to be provided, the higher temperatures

may not even produce comfort on cold days; if humidity is to be maintained at 50 percent, the lower temperatures will apply.

In rooms having large glass areas, when sun is not shining, or in rooms with walls having a high transmission coefficient, the lowered surface temperature will cause a feeling of coolness even though the air temperature in the room is at or above the temperatures indicated in the table. In rooms of this character, it is desirable to design for even higher temperatures than those listed, unless a compensating higher temperature surface is installed to offset the low temperature surfaces.

TABLE 2. WINTER INSIDE DRY-BULB TEMPERATURES USUALLY SPECIFIED\*

| TYPE OF BUILDING               | DEG F | TYPE OF BUILDING                        | DEG F |
|--------------------------------|-------|-----------------------------------------|-------|
| <b>SCHOOLS—</b>                |       | <b>THEATERS—</b>                        |       |
| Class rooms.....               | 70-72 | Seating space.....                      | 68-72 |
| Assembly rooms.....            | 68-72 | Lounge rooms.....                       | 68-72 |
| Gymnasiums.....                | 55-65 | Toilets.....                            | 68    |
| Toilets and baths.....         | 70    | <b>HOTELS—</b>                          |       |
| Wardrobe and locker rooms..... | 65-68 | Bedrooms and baths.....                 | 70    |
| Kitchens.....                  | 68    | Dining rooms.....                       | 70    |
| Dining and lunch rooms.....    | 65-70 | Kitchens and laundries.....             | 68    |
| Playrooms.....                 | 60-65 | Ballrooms.....                          | 65-68 |
| Natoriums.....                 | 75    | Toilets and service rooms.....          | 68    |
| <b>HOSPITALS—</b>              |       | <b>HOMES.....</b>                       | 70-72 |
| Private rooms.....             | 70-72 | <b>STORES.....</b>                      | 65-68 |
| Private rooms (surgical).....  | 70-80 | <b>PUBLIC BUILDINGS.....</b>            | 68-72 |
| Operating rooms.....           | 70-95 | WARM AIR BATHS.....                     | 120   |
| Wards.....                     | 68    | STEAM BATHS.....                        | 110   |
| Kitchens and laundries.....    | 68    | <b>FACTORIES AND MACHINE SHOPS.....</b> | 60-65 |
| Toilets.....                   | 68    | <b>FOUNDRIES AND BOILER SHOPS.....</b>  | 50-60 |
| Bathrooms.....                 | 70-80 | <b>PAINT SHOPS.....</b>                 | 80    |

\* The most comfortable dry-bulb temperature to be maintained depends on the relative humidity and air motion. These three factors considered together constitute what is termed the *effective temperature*. (See Chapter 6.) When relative humidity is not controlled separately, optimum dry-bulb temperature for comfort will be slightly higher than shown in Table 2.

The inside temperatures specified in Table 2 may be used for panel heated spaces as well as for spaces heated by warm air, radiators or convectors. It is true that warm panel surfaces tend to produce a comfortable environment at a lower room air temperature than when warm panels are not present, but field experience in the United States has indicated that actual reductions in air temperature are slight in operation.

**Temperature at Proper Level.** In making the actual heat loss computations, however, for the various rooms in a building it is often necessary to modify the temperatures given in Table 2 so that the air temperature at the proper level will be used. By *air temperature at the proper level* is meant, in the case of walls, the air temperature at the mean height between floor and ceiling; in the case of glass, the air temperature at the mean height of the glass; in the case of roof or ceiling, the air temperature at the mean height of the roof or ceiling above the floor of the heated room; and in the case of floors, the air temperature at the floor level.

**Temperature at Ceiling.** The air temperature at the ceiling is generally higher than at the breathing level due to stratification of air resulting from the tendency of the warmer or less dense air to rise. An allowance for this fact should be made in calculating ceiling heat losses, particularly in the case of high ceilings. However, the exact allowance to be made may be somewhat difficult to determine as it depends on many factors, including (1) the type of heating system, (2) ceiling height, and (3) the inside-outside temperature differential. The type of heating system is par-

ticularly important, as the temperature gradient from floor to breathing-level to ceiling may depend to a large extent on whether direct radiation, unit heaters or warm air is used, and in the latter case, whether the air is moved mechanically or by gravity. The temperature of the heating medium is also a factor.

It is impracticable to establish rigid rules for determining the temperature difference to use in all cases. However, for residences and structures having ceiling heights under 10 ft, the comparatively small temperature differential between the breathing level and ceiling generally may be

TABLE 3. APPROXIMATE TEMPERATURE DIFFERENTIALS BETWEEN BREATHING LEVEL AND CEILING, APPLICABLE TO CERTAIN TYPES OF HEATING SYSTEMS\*

| CEILING HEIGHT (Ft) | BREATHING LEVEL TEMPERATURE (5 FT ABOVE FLOOR) |      |      |      |      |      |      |      |      |      |
|---------------------|------------------------------------------------|------|------|------|------|------|------|------|------|------|
|                     | 60                                             | 65   | 70   | 72   | 74   | 76   | 78   | 80   | 85   | 90   |
| 10                  | 3.0                                            | 3.3  | 3.5  | 3.6  | 3.7  | 3.8  | 3.9  | 4.0  | 4.3  | 4.5  |
| 11                  | 3.6                                            | 3.9  | 4.2  | 4.3  | 4.4  | 4.6  | 4.7  | 4.8  | 5.1  | 5.4  |
| 12                  | 4.2                                            | 4.5  | 4.9  | 5.0  | 5.2  | 5.3  | 5.5  | 5.6  | 6.0  | 6.3  |
| 13                  | 4.8                                            | 5.2  | 5.6  | 5.8  | 5.9  | 6.1  | 6.2  | 6.4  | 6.8  | 7.2  |
| 14                  | 5.4                                            | 5.9  | 6.3  | 6.5  | 6.7  | 6.8  | 7.0  | 7.2  | 7.7  | 8.1  |
| 15                  | 6.0                                            | 6.5  | 7.0  | 7.2  | 7.4  | 7.6  | 7.8  | 8.0  | 8.5  | 9.0  |
| 16                  | 6.1                                            | 6.6  | 7.1  | 7.3  | 7.5  | 7.7  | 7.9  | 8.1  | 8.6  | 9.1  |
| 17                  | 6.2                                            | 6.7  | 7.2  | 7.4  | 7.6  | 7.8  | 8.0  | 8.2  | 8.7  | 9.2  |
| 18                  | 6.3                                            | 6.8  | 7.3  | 7.5  | 7.7  | 7.9  | 8.1  | 8.3  | 8.8  | 9.3  |
| 19                  | 6.4                                            | 6.9  | 7.4  | 7.6  | 7.8  | 8.0  | 8.2  | 8.4  | 8.9  | 9.4  |
| 20                  | 6.5                                            | 7.0  | 7.5  | 7.7  | 7.9  | 8.1  | 8.3  | 8.5  | 9.0  | 9.5  |
| 25                  | 7.0                                            | 7.5  | 8.0  | 8.2  | 8.4  | 8.6  | 8.8  | 9.0  | 9.5  | 10.0 |
| 30                  | 7.5                                            | 8.0  | 8.5  | 8.7  | 8.9  | 9.1  | 9.3  | 9.5  | 10.0 | 10.5 |
| 35                  | 8.0                                            | 8.5  | 9.0  | 9.2  | 9.4  | 9.6  | 9.8  | 10.0 | 10.5 | 11.0 |
| 40                  | 8.5                                            | 9.0  | 9.5  | 9.7  | 9.9  | 10.1 | 10.3 | 10.5 | 11.0 | 11.5 |
| 45                  | 9.0                                            | 9.5  | 10.0 | 10.2 | 10.4 | 10.6 | 10.8 | 11.0 | 11.5 | 12.0 |
| 50                  | 9.5                                            | 10.0 | 10.5 | 10.7 | 10.9 | 11.1 | 11.3 | 11.5 | 12.0 | 12.5 |

\* The figures in this table are based on an increase of 1 percent per foot of height above the breathing level (5 ft) up to 15 ft and  $\frac{1}{10}$  of one degree for each foot above 15 ft. This table is generally applicable to forced air types of heating systems. For direct radiation or gravity warm air, increase values 50 percent to 100 percent.

neglected without serious error. For higher ceilings, an allowance of approximately 1 percent per foot of height above the breathing level may be made for ceiling heights up to 15 ft and approximately  $\frac{1}{10}$  of 1 deg per foot of height above this level. The values in Table 3 are calculated on this basis. For direct radiation and gravity warm air systems, the allowance should be increased from 50 percent to 100 percent over those given in Table 3. These rules should, however, be used with considerable discretion, and they do not apply to some types of heating systems such as those using panel and baseboard radiation, where very low temperature differences between the floor and the ceiling may exist.

**Temperature at Floor Level.** According to tests at the University of Illinois,<sup>3, 4, 5, 6</sup> the temperature at the floor level ranged from about 2 to 6 deg below that at the breathing level, or somewhat greater than the difference between the breathing level and ceiling temperatures. Tests at the University of Wisconsin<sup>7</sup> indicated a somewhat smaller differential between the floor and breathing level temperatures. As a general rule, if the breathing level to ceiling temperature differential is neglected (as with ceiling heights under 10 ft), the breathing level to floor differential may also be neglected, as the two are somewhat compensating, especially where both floor and ceiling losses are calculated for the same space. In other cases, the 10 ft temperature differentials in Table 3 may be used in arriving at the floor heat loss, these differentials to be subtracted from the breathing level temperature.

### ATTIC TEMPERATURES

Frequently, it is necessary to estimate the attic temperature, and in such cases Equation 1 can be used for this purpose:

$$t_a = \frac{A_c U_c t_i + t_o (A_r U_r + A_w U_w + A_g U_g)}{A_c U_c + A_r U_r + A_w U_w + A_g U_g} \quad (1)$$

where

$t_a$  = attic temperature, Fahrenheit degrees.

$t_i$  = inside temperature near top floor ceiling, Fahrenheit degrees.

$t_o$  = outside temperature, Fahrenheit degrees.

$A_c$  = area of ceiling, square feet.

$A_r$  = area of roof, square feet.

$A_w$  = area of net vertical attic wall surface, square feet.

$A_g$  = area of attic glass, square feet.

$U_c$  = coefficient of transmission of ceiling, based on surface conductance of 2.20 (upper surface, see Chapter 9). 2.20 = reciprocal of one-half the air space resistance.

$U_r$  = coefficient of transmission of roof, based on surface conductance of 2.20 (lower surface, see Chapter 9).

$U_w$  = coefficient of transmission of vertical wall surface.

$U_g$  = coefficient of transmission of glass.

**Example 1.** Calculate the temperature in an unheated attic, assuming the following conditions:  $t_i = 70$ ;  $t_o = 10$ ;  $A_c = 1000$ ;  $A_r = 1200$ ;  $A_w = 100$ ;  $A_g = 10$ ;  $U_c = 0.50$ ;  $U_r = 0.40$ ;  $U_w = 0.30$ ;  $U_g = 1.13$ .

**Solution:** Substituting these values in Equation 1:

$$t_a = \frac{(1000 \times 0.40 \times 70) + 10[(1200 \times 0.50) + (100 \times 0.30) + (10 \times 1.13)]}{(1000 \times 0.40) + (1200 \times 0.50) + (100 \times 0.30) + (10 \times 1.13)}$$

$$t_a = \frac{34,413}{1041} = 33.1 \text{ F.}$$

Equation 1 neglects the effect of any interchange of air such as would take place through attic vents or louvers intended to preclude attic condensation. However, according to tests,<sup>8</sup> such venting of attics by means of small louvers or other small openings does not appreciably reduce the attic temperature and may be neglected without serious error.

Neither does this equation take into consideration such factors as heat exchange between chimney and attic or solar radiation to and from the roof. Because of these latter effects, actual attic temperatures are frequently higher than the calculated values using Equation 1. The attic temperature may be calculated in the usual manner by means of Equation 1, allowing the full value of the roof. The error resulting from this assumption will generally be considerably less than if the roof were neglected (as is sometimes the practice) and the attic temperature assumed to be the same as the outside temperature. When relatively large louvers are installed, as is customary in the southern states, the attic temperature is often assumed as the average between inside and outside.

For a shorter, approximate method of calculating heat losses through

attics, the combined ceiling and roof coefficient may be used, as described in Chapter 9.

### TEMPERATURES IN UNHEATED SPACES

The heat loss from heated rooms into unheated rooms or spaces must be based on the estimated or assumed temperature in such unheated spaces. This temperature will lie in the range between the inside and outside temperatures, depending on the relative areas of the surfaces adjacent to the heated room and those exposed to the outside. If the respective surface areas adjacent to the heated room and exposed to the outside are approximately the same, and if the coefficients of transmission are approximately equal, the temperature in the unheated space may be assumed to be the mean of the inside and outside design temperatures. If, however, the surface areas and coefficients are unequal, the temperature in the unheated space should be estimated by means of Equation 2.

$$t_u = \frac{t_i(A_1U_1 + A_2U_2 + A_3U_3 + \text{etc.}) + t_o(A_aU_a + A_bU_b + A_cU_c + \text{etc.})}{A_1U_1 + A_2U_2 + A_3U_3 + \text{etc.} + A_aU_a + A_bU_b + A_cU_c + \text{etc.}} \quad (2)$$

where

$t_u$  = temperature in unheated space, Fahrenheit degrees.

$t_i$  = inside design temperature of heated room, Fahrenheit degrees.

$t_o$  = outside design temperature, Fahrenheit degrees.

$A_1, A_2, A_3$ , etc. = areas of surface of unheated space adjacent to heated space, square feet.

$A_a, A_b, A_c$ , etc. = areas of surface of unheated space exposed to outside, square feet.

$U_1, U_2, U_3$ , etc. = coefficients of transmission of surfaces of  $A_1, A_2, A_3$ , etc.

$U_a, U_b, U_c$ , etc. = coefficients of transmission of surfaces  $A_a, A_b, A_c$ , etc.

**Example 2:** Calculate the temperature in an unheated space adjacent to a heated room having surface areas ( $A_1, A_2$ , and  $A_3$ ) in contact therewith of 100, 120, and 140 sq ft and coefficients ( $U_1, U_2$ , and  $U_3$ ) of 0.15, 0.20, and 0.25, respectively. The surface areas of the unheated space exposed to the outside ( $A_a$  and  $A_b$ ) are respectively 100 and 140 sq ft, and the corresponding coefficients are 0.10 and 0.30. The sixth surface is on the ground and is neglected in this example. Assume  $t_i = 70$  and  $t_o = -10$ .

**Solution:** Substituting in Equation 2:

$$t_u = \frac{70[(100 \times 0.15) + (120 \times 0.20) + (140 \times 0.25)] + -10[(100 \times 0.10) + (140 \times 0.30)]}{(100 \times 0.15) + (120 \times 0.20) + (140 \times 0.25) + (100 \times 0.10) + (140 \times 0.30)}$$

$$t_u = \frac{4660}{126} = 37 \text{ F.}$$

The temperatures in unheated spaces having large glass areas and having two or more surfaces exposed to the outside (such as sleeping porches and sun parlors), generally are assumed to be the same as outside.

### GROUND TEMPERATURES

Ground temperatures to be assumed for estimating basement heat losses usually will differ in the case of basement walls and floors, the temperatures under the floors generally being higher than those adjacent to walls. Factors affecting these temperatures will be discussed.

#### Temperatures Under Basement Floors

The temperature of the ground under basement floors<sup>9</sup> is affected by heat sources within the basement and is not influenced by atmospheric

conditions. In computing losses through basement floors, the ground temperatures may be assumed to be the same as water temperatures at depths of 30 to 60 ft given in Fig. 3, Chapter 35. Test observations indicate that heat losses through basement floors frequently are over-estimated.<sup>10</sup>

#### Temperatures Adjacent to Basement Walls

Ground temperatures near the surface and under open spaces vary with the climate, the season of the year and the depth below the surface. The nearer the surface (during the cold weather) the lower will be the ground temperature. Frost will penetrate to a depth of over 4 ft in some localities if not protected by snow. A thick blanket of snow will result in a higher ground temperature near the surface. Therefore, in localities where the ground is covered with a heavy blanket of snow throughout the

TABLE 4. BELOW GRADE HEAT LOSSES FOR BASEMENT WALLS AND FLOORS

| GROUND WATER TEMPERATURE <sup>a</sup> | BASEMENT FLOOR LOSS <sup>b</sup><br>Btu/Sq Ft | BELOW GRADE WALL LOSS <sup>b</sup><br>Btu/Sq Ft |
|---------------------------------------|-----------------------------------------------|-------------------------------------------------|
| 40                                    | 3.0                                           | 6.0                                             |
| 50                                    | 2.0                                           | 4.0                                             |
| 60                                    | 1.0                                           | 2.0                                             |

<sup>a</sup> See Fig. 3, Chapter 35.

<sup>b</sup> Based on basement temperature of 70 F and U of 0.10.

winter, the ground temperatures near the surface will be higher than when little or no snow is present.

Complete data on ground temperatures adjacent to buildings are not available, but since the recommended transmission coefficient for basement walls in contact with the soil is only 0.10, any reasonable, assumed ground temperature will not materially affect the calculated heat loss.

### BASEMENT TEMPERATURES AND HEAT LOSS

The allowance to be made for basement heat loss depends on whether the basement is to be heated or not.

If the basement is *heated* to a specified temperature, the heat loss should be calculated in the usual manner, based on the proper wall and floor coefficients (see Chapter 9) and the outside air and ground temperatures. Heat loss through windows and walls above grade should be based on outside temperatures and the proper air-to-air coefficients. Heat loss through basement walls below grade should be based on the floor and wall coefficients for surfaces in contact with the soil, and on the proper ground temperature.

The heat loss values for below grade basement walls and floors given in Table 4 are sufficiently precise for general practice.

If a basement is completely below grade and is *not heated*, the temperature in the basement normally will range between that in the rooms above and the ground temperature. Basement windows will, of course, lower the basement temperature when it is cold outside, and heat given off by the heating plant will increase the basement temperature. In any case, the exact basement temperature is indeterminate if the basement is not heated. In general, it is found that the transient heat from the heating plant warms the air near the basement ceiling sufficiently to make it un-



necessary to make an allowance for floor heat loss from rooms located over the basement.

The temperature in crawl spaces below floors will vary widely depending on the number and size of wall vents, the amount of warm piping present and type of piping insulation. It is necessary, therefore, to evaluate the conditions and to select an appropriate temperature by judgment.

### HEAT LOSSES FROM FLOOR SLABS

Two types of concrete floors used in basementless houses are (a) the unheated floor, relying for warmth on heat delivered above floor level by the heating system, and (b) the heated floor containing heated pipes or ducts that constitute a radiant slab or portion thereof for complete or partial heating of the house.

For type (a) the floor heat loss, economically considered, is of minor importance since it comprises generally about 10 percent of the total heat loss of the house. From the comfort standpoint, however, it may be most important, since houses with cold floors are not successfully heated. In this connection, it should be remembered that a well insulated floor does not assure comfort if down-drafts from windows or exposed walls create pools of chilly air over considerable areas of the floor. For this reason a floor of type (a) should not be used in a severe climate except with a heating system that delivers enough heat near the floor to counteract the down-drafts of the exterior walls and the heat transmission through the floor.

The results of some experiments<sup>10, 11</sup> with type (a) unheated floor slabs indicate that the heat loss from a concrete slab floor on grade is more nearly proportional to the perimeter than to the area of the floor, and that the heat loss can be estimated by means of the equation:

$$H_F = FP (t - t_o) \quad (3)$$

where

$H_F$  = heat loss of the floor, Btu per hour.

$P$  = perimeter or exposed edge of the floor, linear feet.

$F$  = heat loss coefficient, Btu per (hour) (linear foot of exposed edge) (degree difference in temperature between the inside air and the outside air). ( $F$  ranges between 0.81 for a floor with no edge insulation to 0.55 for a floor with edge insulation).

$t$  = inside air temperature, Fahrenheit.

$t_o$  = outside air temperature, Fahrenheit.

In most instances the values given in Table 5 for edge loss are of sufficient precision for use.<sup>12</sup> The insulation shown extending under the floor horizontally for 2 ft can also be located along the foundation wall with equal effectiveness if the insulation extends 24 in. below the floor level.

**Example 3:** Calculate the heat loss from the floor of a 12 ft x 15 ft room with two exposures. The floor is an unheated concrete slab which is insulated at the edge with 2 in. of insulation extending horizontally for a distance of 2 ft from the edge, and the house is located in an area with an outside design temperature of -15 F.

**Solution:** From Table 5 the heat loss per foot of exposed edge is 45 Btu per hr. The length of exposed edge is 12 ft + 15 ft = 27 ft, and the total edge loss 27 x 45 = 1215 Btu per hr.

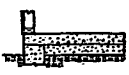
Floors of type (b) containing heating pipes or ducts, are now in common

use. The heat loss downward into the ground and outward through the edges of the floor slab is called the reverse loss.

The results<sup>13</sup> of an investigation in which a warm-air perimeter duct was embedded in four types of concrete floor slab and foundation constructions has verified the indication that Equation 3 can be used to calculate the reverse loss when warm-air perimeter heating ducts are used. To make the results of this application more usable, values corresponding to those shown in Table 5 for unheated floors are given in Table 6 for concrete floors with a warm-air perimeter duct.

The desirability of edge insulation is apparent. One inch of water-resistant material is the minimum thickness of edge insulation that should be used, but a 2-in. thickness is recommended.<sup>12, 14, 15</sup> The values of edge loss in Table 6 indicate that the reverse heat loss of heated slabs is likely to be about 20 percent of the total heat loss of many types of present day

TABLE 5. HEAT LOSS OF CONCRETE FLOORS AT OR NEAR GRADE LEVEL PER FOOT OF EXPOSED EDGE

| OUTDOOR DESIGN TEMPERATURE, F | HEAT LOSS PER FOOT OF EXPOSED EDGE, Btu/hr                                          |                                                                                     |                                                                                     |                                                                                     |
|-------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|                               | RECOMMENDED 2-IN. EDGE INSULATION                                                   | 1-IN. EDGE INSULATION                                                               | 1-IN. EDGE INSULATION                                                               | NO EDGE INSULATION*                                                                 |
|                               |  |  |  |  |
| -20 to -30                    | 50                                                                                  | 55                                                                                  | 60                                                                                  | 75                                                                                  |
| -10 to -20                    | 45                                                                                  | 50                                                                                  | 55                                                                                  | 65                                                                                  |
| 0 to -10                      | 40                                                                                  | 45                                                                                  | 50                                                                                  | 60                                                                                  |

\* This construction not recommended; shown for comparison only.

houses, and may exceed 20 per cent if only one inch of insulation is used at the edge of the floor.

The concrete floor slab is usually placed on a gravel fill 4 in. thick or more, both to insulate the floor from the earth and to retard the rise of ground water by capillarity. A waterproof membrane should be installed over the gravel fill. Obviously, it is important that such floors be laid several inches above grade, and that effective subsoil drainage be provided to avoid slabs soaked by rain or melting snow, and consequent excessive heat loss.

### TRANSMISSION HEAT LOSS

The basic formula for the loss of heat by transmission through any surface is given in Equation 4:

$$H_t = AU (t - t_o) \quad (4)$$

where

$H_t$  = heat loss transmitted through the wall, roof, ceiling, floor, or glass, Btu per hour.

$A$  = area of wall, glass, roof, ceiling, floor, or other exposed surface, square feet.



- $U$  = coefficient of transmission, air to air, Btu per (hour) (square foot) (Fahrenheit degree temperature difference) (Chapter 9).
- $t$  = inside temperature near surface involved (this may not necessarily be the so-called breathing line temperature), Fahrenheit degrees.
- $t_o$  = outside temperature, or temperature of adjacent unheated space or of the ground, Fahrenheit degrees.

**Example 4:** Calculate the transmission loss through an 8 in. brick wall having an area of 150 sq ft, if the inside temperature  $t$  is 70 F and the outside temperature  $t_o$  is -10 F.

**Solution:** The coefficient of transmission ( $U$ ) of a plain 8 in. brick wall is 0.50 (Chapter 9, Table 8). The area ( $A$ ) is 150 sq ft. Substituting in Equation 4:

$$H_t = 150 \times 0.50 \times [70 - (-10)] = 6000 \text{ Btu per hour.}$$

TABLE 6. FLOOR HEAT LOSS TO BE USED WHEN WARM-AIR PERIMETER HEATING DUCTS ARE EMBEDDED IN SLAB<sup>a</sup>  
Btu per (hour) (linear foot of heated edge)

| OUTDOOR DESIGN TEMPERATURE, F | EDGE INSULATION                                          |                                                              |                                                              |
|-------------------------------|----------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------|
|                               | 1-IN. VERTICAL EXTENDING DOWN 18 IN. BELOW FLOOR SURFACE | 1-IN. L-TYPE EXTENDING AT LEAST 12 IN. DEEP AND 12 IN. UNDER | 2-IN. L-TYPE EXTENDING AT LEAST 12 IN. DOWN AND 12 IN. UNDER |
| -20                           | 105                                                      | 100                                                          | 85                                                           |
| -10                           | 95                                                       | 90                                                           | 75                                                           |
| 0                             | 85                                                       | 80                                                           | 65                                                           |
| 10                            | 75                                                       | 70                                                           | 55                                                           |
| 20                            | 62                                                       | 57                                                           | 45                                                           |

<sup>a</sup> Factors include loss downward through inner area of slab.

### Transmission Loss Through Ceilings and Roofs

The transmission heat loss through top floor ceilings, attics, and roofs may be estimated by either of two methods:

- By substituting in Equation 4 the ceiling area  $A$ , the inside-outside temperature difference ( $t - t_o$ ) and the proper value of  $U$ :
  - Flat roofs.** Select the coefficient of transmission of the ceiling and roof from Tables 15 or 16, Chapter 9, or use appropriate coefficients in Equation 1 if side walls extend appreciably above the ceiling of the floor below.
  - Pitched roofs.** Select the combined roof and ceiling coefficient from Table 18, Chapter 9 or calculate the combined roof and ceiling coefficient by means of Equations 4 and 5, Chapter 9, where these formulas are applicable as explained in Chapter 9.
- By estimating the attic temperature (based on the inside and outside design temperatures) by means of Equation 1, and substituting for  $t_o$  in Equation 4, the value of  $t_o$  thus obtained, together with the ceiling area  $A$  and the ceiling coefficient  $U$ . This applies to *pitched roofs*. In the case of *flat roofs* it is not necessary to calculate the attic temperatures, as the ceiling-roof heat loss can be determined as suggested in paragraph 1a.

### INFILTRATION HEAT LOSS

The infiltration heat loss includes (1) the *sensible heat loss* or the heat required to warm the outside air entering by infiltration, and (2) the *latent heat loss* or the heat equivalent of any moisture which must be added.

### Heating Load

#### Sensible Heat Loss

The formula for the heat required to warm the outside air which enters a room by infiltration to the temperature of the room, is given in Equation 5:

$$H_s = 0.240 Qd (t - t_o) \quad (5)$$

where

$H_s$  = heat required to raise temperature of air leaking into building from  $t_o$  to  $t$ , Btu per hour.

0.240 = specific heat of air.

$Q$  = volume of outside air entering building, cubic feet per hour (see Chapter 11).

$d$  = density of air at temperature  $t_o$ , pounds per cubic foot.

It is sufficiently accurate to use  $d = 0.075$  in which case Equation 5 reduces to

$$H_s = 0.018 Q (t - t_o) \quad (5a)$$

The volume  $Q$  of outside air entering per hour depends on the wind velocity and direction, the width of crack or size of openings, the type of openings and other factors, as explained in Chapter 11. Where the crack method is used for estimating leakage, it is more convenient to express the air leakage heat loss in terms of the crack length:

$$H_s = B L (t - t_o) \quad (5b)$$

where

$B$  = air leakage per (hour) (foot of crack) (Chapter 11) for the wind velocity and type of windows or door crack involved, multiplied by 0.018.

$L$  = length of window or door crack to be taken into consideration, feet.

**Example 5:** What is the infiltration heat loss per hour through the crack of a 3 x 5 ft average, double-hung, non-weatherstripped, wood window, based on a wind velocity of 15 mph? Assume inside and outside temperatures to be 70 F and zero, respectively.

**Solution:** According to Table 2, Chapter 11, the air leakage through a window of this type (based on  $\frac{1}{8}$  in. crack and  $\frac{1}{4}$  in. clearance) is 39 cu ft per (ft of crack) (hour). Therefore,  $B = 39 \times 0.018 = 0.70$ . The length of crack  $L$  is  $(2 \times 5) + (3 \times 3)$ , or 19 ft;  $t = 70$  and  $t_o = 0$ . Substituting in Equation 5b,

$$H_s = 0.70 \times 19 \times (70 - 0) = 931 \text{ Btu per hour.}$$

#### Crack Length to be Used for Computations

For designers who prefer to use the crack method, the basis of calculation is as follows: The amount of crack used for computing the infiltration heat loss should be not less than half of the total length of crack in the outside walls of the room. For a building having no partitions, air entering through the cracks on the windward side must leave through the cracks on the leeward side. Therefore, take one-half the total crack for computing each side and end of the building. In a room with one exposed wall, take all the crack; with two exposed walls, take the wall having the

most crack; and with three or four exposed walls, take the wall having the most crack; but in no case take less than half the total crack.

In small residences the total infiltration loss of the house is generally considered to be equal to the sum of the infiltration losses of the various rooms. However, this is not necessarily accurate as at any given time infiltration will take place only on the windward side or sides and not on the leeward side. Therefore, for determining the total heat requirements of larger buildings it is more accurate to base the total infiltration loss on the wall having the most total crack, but in no case on less than half of the total crack in the building.

#### Number of Air Changes to be Used for Computations

Since a certain amount of judgment is required regarding quality of construction, weather conditions, use of room and other factors in estimating infiltration by any method, some designers base infiltration upon an estimated number of air changes rather than upon the length of window cracks. Table 4 of Chapter 11 indicates air changes commonly used, but should be taken only as a guide.

When calculating infiltration losses by the air change method, Equation 5a may be used by substituting for  $Q$  the volume of the room multiplied by the number of air changes obtained from Table 4, Chapter 11. For further discussion of the method see section on Air Change Method in Chapter 11.

#### Latent Heat Loss

When it is intended to add moisture to air leaking into a room in order to maintain proper winter comfort conditions, it is necessary to determine the heat required to evaporate the water vapor added. This heat may be calculated by the equation

$$H_1 = Qd(W_i - W_o)h_{fg} \quad (6)$$

where

$H_1$  = heat required to increase moisture content of air leaking into building from  $m_o$  to  $m_i$ , Btu per hour.

$Q$  = volume of outside air entering building, cubic feet per hour.

$d$  = density of air at temperature  $t_i$ , pounds per cubic foot.

$W_i$  = vapor density of inside air, pounds per pound of dry air.

$W_o$  = vapor density of outside air, pounds per pound of dry air.

$h_{fg}$  = latent heat of vapor at  $m_i$ , Btu per pound.

If the latent heat of vapor  $h_{fg}$  is assumed to be 1060 Btu per lb, Equation 6 reduces to:

$$H_1 = 79.5 Q (W_i - W_o) \quad (6a)$$

Equations 5a, 5b and 6a may also be used for determining the sensible and latent heat gains due to infiltration in cooling load computations.

#### SELECTION OF WIND VELOCITIES

The effect of wind on the heating requirements of any building should be given consideration for two reasons:

1. Wind movement increases the heat transmission of walls, glass, and roof, affecting poor walls to a much greater extent than good walls.

2. Wind increases materially the infiltration of cold air through the cracks around doors and windows, and even through the building materials themselves (see Tables 1 and 2, Chapter 11).

Theoretically, as a basis for design, the most unfavorable combination of temperature and wind velocity should be chosen. It is entirely possible that a building might require more heat on a windy day with a moderately low outside temperature, than on a quiet day with a much lower outside temperature. However, the combination of wind and temperature, which is the worst, would differ with different buildings, because wind velocity has a greater effect on buildings which have relatively high infiltration losses. It would be possible to compute the heating load for a building for several different combinations of temperature and wind velocity which records show to have occurred, and to select the worst combination, but designers generally do not feel that such a degree of refinement is justified.

Therefore, where Table 1 lists the maximum wind velocity occurring during the coldest 2½% of the winter hours for each locality, this value should be the basis for estimating infiltration losses. When using the air change method it will not be necessary to consider the wind velocities. Designers employing the crack method generally use values corresponding to a 15-mile wind. The effect of the wind velocity on the transmission coefficient can be evaluated from Table 21 of Chapter 9.

#### Exposure Factors

Many designers use empirical exposure factors to increase the calculated heat loss of rooms or spaces on the side or sides of the building exposed to the prevailing winds. However, the use of exposure factors is unnecessary when the GUIDE method of calculating heat losses is used. Therefore, exposure factors may be regarded as *factors of safety* for the rooms or spaces exposed to the prevailing winds, to allow for additional capacity for these rooms or spaces, or to *balance the radiation*, particularly in the case of multi-story buildings. Tall buildings may have severe infiltration heat losses, induced by their stack effect (see Chapter 11), which will require special consideration. Although the exposure allowance frequently is assumed to be 15 percent, the actual allowance to be made, if any, must to a large extent be a matter of experience and judgment of the designer, since there are at present no authentic test data available from which rules could be developed for the many conditions encountered in practice.

#### AUXILIARY HEAT SOURCES

The heat supplied by persons, lights, motors and machinery always should be ascertained in the case of theaters, assembly halls, and industrial plants, but allowances for such heat sources must be made only after careful consideration of all local conditions. In many cases, these heat sources should not affect the size of the heating plant at all, although they may have a marked effect on the operation and control of the system. In general, where audiences are present, the heating system must have sufficient capacity to bring the building to the stipulated inside temperature before the audience arrives. In industrial plants, quite a different condition exists, and heat sources, if always available during occupancy, may be substituted for a portion of the heating installation. In no case should the actual heating installation (exclusive of heat sources) be reduced below that required to maintain at least 40 F in the building.

## Electric Motors and Machinery

Motors and the machinery which they drive, if both are located in the room, convert all of the electrical energy supplied into heat. This heat is retained in the room if the product manufactured is not removed until its temperature is the same as the room temperature.

If power is transmitted to the machinery from the outside, then only the heat equivalent of the brake horsepower supplied is used. In some mills this is the chief source of heating, and it is frequently sufficient to overheat the building even in zero weather, thus requiring cooling by ventilation the year round. Table 7 shows the heat output equivalent

TABLE 7. HEAT EQUIVALENTS OF VARIOUS SOURCES\*

|                                                            |            |
|------------------------------------------------------------|------------|
| Machinery (Motor in room) = Motor Hp/efficiency x 2544     | Btu/hr.    |
| Machinery (Motor outside room) = Motor Hp x 2544           | Btu/hr.    |
| Electric Lights = Kilowatts x 3413                         | Btu/hr.    |
| Gas (Producer = 150) (Manufactured = 535) (Natural = 1000) | Btu/cu ft. |

\* Additional values are given in Chapter 13, Table 26.

of various sources of heat in a factory. For information concerning the heat supplied by persons, refer to data given in Chapter 6, and also Table 25, Chapter 13. For appliances see Table 26, Chapter 13.

## INTERMITTENTLY HEATED BUILDINGS

In the case of intermittently heated buildings additional heat is required for raising the temperature of the air, the building materials and the material contents of the building to the specified inside temperature. The rate at which this additional heat must be supplied depends upon the heat capacity of the structure and its material contents, and upon the time in which these are to be heated.<sup>15</sup>

This additional heat may be computed and allowed for as conditions require, but inasmuch as the heating system proportioned for taking care of the heat losses will usually have a capacity about 100 percent greater than that required for average winter weather, and inasmuch as most buildings may either be continuously heated or have more time allowed for heating up during the few minimum temperature days, no allowance usually is made, except in the size of boilers or furnaces. For churches, auditoriums and other intermittently heated buildings, additional capacity should be provided.

## RESIDENCE HEAT LOSS PROBLEMS

The following *Examples 6 and 7* will illustrate the procedure for calculating the heat loss of a residence, uninsulated and insulated, in accordance with the recommendations given in this chapter.

*Example 6:* Calculate the heat loss of the residence shown in Fig. 2 located in the vicinity of Chicago. From Table 1, design outdoor conditions are -10 F and 12 mph wind velocity. Inside temperature from Table 2 is assumed to be 70 F. The attic is unheated. Assume ground temperature to be 50 F (see Fig. 3, Chapter 35) under basement and garage floors and 32 F adjoining basement walls. Estimate infiltration losses by the air change method. No wall, ceiling or roof insulation is to be considered in this problem, but all first and second floor windows, except in the garage,

## Heating Load

TABLE 8. HEAT LOSS CALCULATION SHEET FOR UNINSULATED RESIDENCE (Fig. 2)

| A                              | B                                                                                                | C                                                                                  | D                                                           | E                                                      | F                                                          | G                     |
|--------------------------------|--------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------|--------------------------------------------------------|------------------------------------------------------------|-----------------------|
| ROOM OR SPACE                  | PART OF STRUCTURE OR INFILTRATION AIR CHANGES                                                    | NET AREA OR AIR VOLUME                                                             | COEFFICIENT                                                 | TEMP. DIFF.*                                           | HEAT LOSS (Btu per hour)                                   | TOTALS (Btu per hour) |
| Bedroom A and Closet           | Walls<br>Glass<br>Ceiling<br>Infiltration (3/4)*                                                 | 238 sq ft<br>40 sq ft<br>252 sq ft<br>1510 cfb <sup>b</sup>                        | 0.28<br>0.45<br>0.69<br>0.018*                              | 80<br>80<br>39.8 <sup>d</sup><br>80                    | 5330<br>1440<br>9910<br>2180                               | 15,880                |
| Bedroom B and Closet           | Walls<br>Glass<br>Ceiling<br>Infiltration (3/4)*                                                 | 156 sq ft<br>40 sq ft<br>170 sq ft<br>1020 cfb <sup>b</sup>                        | 0.28<br>0.45<br>0.69<br>0.018*                              | 80<br>80<br>39.8 <sup>d</sup><br>80                    | 3490<br>1440<br>4660<br>1470                               | 11,060                |
| Bedroom C and Closet           | Walls<br>Glass<br>Ceiling<br>Infiltration (3/4)*                                                 | 114 sq ft<br>27 sq ft<br>129 sq ft<br>874 cfb <sup>b</sup>                         | 0.28<br>0.45<br>0.69<br>0.018*                              | 80<br>80<br>39.8 <sup>d</sup><br>80                    | 2580<br>970<br>3540<br>1280                                | 8,330                 |
| Bedroom D and Closet           | Walls<br>Glass<br>Ceiling<br>Floor over garage<br>Infiltration (3/4)*                            | 118 sq ft<br>20 sq ft<br>110 sq ft<br>110 sq ft<br>680 cfb <sup>b</sup>            | 0.28<br>0.45<br>0.69<br>0.25<br>0.018*                      | 80<br>80<br>39.8 <sup>d</sup><br>35 <sup>e</sup><br>80 | 2650<br>720<br>3020<br>960 <sup>p</sup><br>950             | 8,300                 |
| Bathroom 1                     | Walls<br>Glass<br>Ceiling<br>Infiltration (1)*                                                   | 30 sq ft<br>14 sq ft<br>55 sq ft<br>440 cfb <sup>b</sup>                           | 0.28<br>0.45<br>0.69<br>0.018*                              | 80<br>80<br>39.8 <sup>d</sup><br>80                    | 670<br>500<br>1510<br>630                                  | 3,310                 |
| Bathroom 2                     | Walls<br>Glass<br>Ceiling<br>Floor over garage<br>Infiltration (1)*                              | 79 sq ft<br>9 sq ft<br>35 sq ft<br>35 sq ft<br>280 cfb <sup>b</sup>                | 0.28<br>0.45<br>0.69<br>0.25<br>0.018*                      | 80<br>80<br>39.8 <sup>d</sup><br>35 <sup>e</sup><br>80 | 1640<br>320<br>990<br>310 <sup>p</sup><br>400              | 3,630                 |
| Living Room                    | Walls<br>Walls (adjoining garage)<br>Glass<br>Floor<br>Infiltration (1 1/4) <sup>b</sup>         | 267 sq ft<br>94 sq ft<br>50 sq ft<br>294 sq ft<br>3745 cfb <sup>b</sup>            | 0.28<br>0.39 <sup>f</sup><br>0.45<br>0.45<br>0.018*         | 80<br>35 <sup>e</sup><br>80<br>80<br>80                | 5980<br>1280 <sup>p</sup><br>1800                          | 14,460                |
| Dining Room                    | Walls<br>Glass (doors)<br>Glass (windows)<br>Floor<br>Infiltration (1 1/4) <sup>i</sup>          | 166 sq ft<br>35 sq ft<br>20 sq ft<br>168 sq ft<br>2140 cfb <sup>b</sup>            | 0.28<br>0.85<br>0.45<br>0.45<br>0.018*                      | 80<br>80<br>80<br>80<br>80                             | 3720<br>2380<br>720                                        | 9,900                 |
| Kitchen and Entrance to Garage | Walls<br>Walls (adjoining garage)<br>Glass<br>Door<br>Floor<br>Infiltration (1 1/4) <sup>j</sup> | 96 sq ft<br>51 sq ft<br>18 sq ft<br>17 sq ft<br>125 sq ft<br>1595 cfb <sup>b</sup> | 0.28<br>0.39 <sup>f</sup><br>0.45<br>0.51<br>0.45<br>0.018* | 80<br>35 <sup>e</sup><br>80<br>35<br>80                | 2150<br>700 <sup>p</sup><br>650<br>300                     | 6,100                 |
| Lavette and Vestibule          | Walls<br>Walls (adjoining garage)<br>Glass<br>Door<br>Floor<br>Infiltration (1 1/4) <sup>k</sup> | 82 sq ft<br>85 sq ft<br>9 sq ft<br>19 sq ft<br>30 sq ft<br>333 cfb <sup>b</sup>    | 0.28<br>0.39 <sup>f</sup><br>0.45<br>0.51<br>0.45<br>0.018* | 80<br>35 <sup>e</sup><br>80<br>320<br>80               | 1840<br>1160 <sup>p</sup><br>320<br>780                    | 4,650                 |
| Entrance Hall                  | Walls<br>Door<br>Ceiling<br>Infiltration (2) <sup>l</sup>                                        | 39 sq ft<br>21 sq ft<br>87 sq ft<br>1110 cfb <sup>b</sup>                          | 0.28<br>0.38<br>0.69<br>0.018*                              | 80<br>80<br>39.8 <sup>d</sup><br>80                    | 870<br>840<br>2390<br>1600                                 | 5,500                 |
| Garage                         | Walls<br>Glass<br>Doors<br>Infiltration (1 1/4) <sup>m</sup><br>Floor<br>Gain adjoining rooms    | 167 sq ft<br>53 sq ft<br>44 sq ft<br>2360 cfb <sup>b</sup><br>29 ft <sup>a</sup>   | 0.28<br>1.13<br>0.51<br>0.018*<br>0.81                      | 45 <sup>e</sup><br>45<br>45<br>45<br>45                | 2110<br>2700<br>1010<br>1910<br>1060<br>-4410 <sup>p</sup> | 4,380                 |
| Recreation Room <sup>n</sup>   | Walls<br>Glass<br>Floor<br>Infiltration (1) <sup>a</sup>                                         | 220 sq ft<br>8 sq ft<br>287 sq ft<br>2010 cfb <sup>b</sup>                         | 0.10<br>1.13<br>0.10<br>0.018*                              | 38<br>80<br>20<br>80                                   | 840<br>720<br>570<br>2890                                  | 5,020                 |
| TOTAL                          |                                                                                                  |                                                                                    |                                                             |                                                        | 100,500                                                    |                       |

## NOTES FOR TABLE 8.

- <sup>a</sup> The inside-outside temperature difference is 70 - (-10) or 80 F except where otherwise noted.
- <sup>b</sup> Volume of infiltration, cfh = (no. air changes) x (floor or ceiling area) x (ceiling height).
- <sup>c</sup> From Equation 5a.
- <sup>d</sup> The ceiling heat losses are calculated by estimating the attic temperature and then calculating the loss through the ceiling using the proper temperature difference. This unheated attic is not ventilated during winter months. The attic temperature is estimated from Equation 1 to be 30.2 F when the outside temperature is -10 F and room temperature is 70 F. The temperature difference is then 70 - 30.2 or 39.8 deg. For the insulated residence, attic temperature becomes 4.6 F and temperature difference 70 - 4.6 = 65.4 deg.
- <sup>e</sup> Temperature in garage assumed to be 35 F.
- <sup>f</sup> Coefficient for wall adjoining garage calculated on basis of metal lath and plaster on both sides of studs (U = 0.39).
- <sup>g</sup> One half of value from Table 4, Chapter 11, for storm windows or weatherstripping.
- <sup>h</sup> Exposed on two sides, weatherstripped windows offset by fire-place. Use 1 1/4.
- <sup>i</sup> Window on one side weatherstripped but double-doors are hard to close tightly. Hence, conservative value of 1 1/2.
- <sup>j</sup> Assuming kitchen vent, door to vestibule usually open, allow full table value of 1 1/4.
- <sup>k</sup> One-half value in Table 4, Chapter 11, increased to 1 1/4 by nearby outside door in vestibule.
- <sup>l</sup> Full value in Table 4, Chapter 11, to allow for frequent opening of outside door.
- <sup>m</sup> Two sides exposed, large doors but large volume. Use value 1 1/4 as given in Table 4, Chapter 11.
- <sup>n</sup> Two small unweatherstripped windows in protected location, but fireplace, indicate 1 change.
- <sup>o</sup> Heat losses from these rooms into garage are heat gains for garage.
- <sup>p</sup> Neglect heat loss to basement, as losses from boiler, piping, etc., will probably keep basement near, if not above, 70 F.
- <sup>q</sup> Upstairs hall ceiling figures with downstairs. Heat should be provided downstairs for both.
- <sup>r</sup> Linear feet of exposed edge.

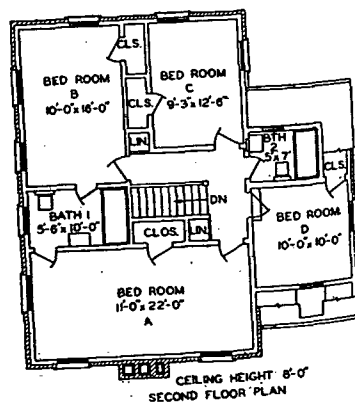
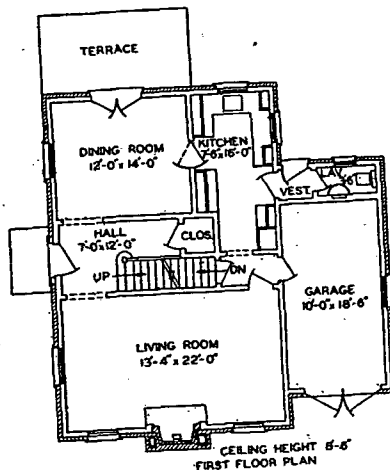
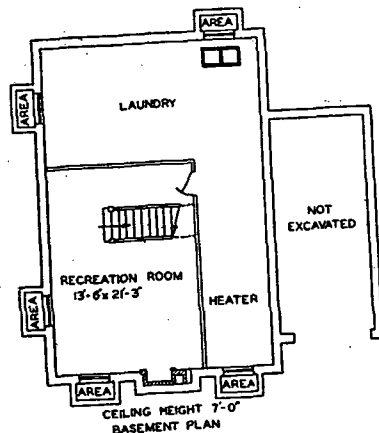


FIG. 2. FLOOR PLANS OF RESIDENCE

## Heating Load

TABLE 9. SUMMARY OF HEAT LOSSES OF UNINSULATED RESIDENCE (Btu Per Hour)

| ROOM OR SPACE                 | WALLS              | CEILING AND ROOF   | FLOOR | GLASS AND DOOR | INFILTRATION | TOTALS  |
|-------------------------------|--------------------|--------------------|-------|----------------|--------------|---------|
| Bedroom A                     | 5330               | 6910               | ...   | 1440           | 2180         | 15,860  |
| Bedroom B                     | 3490               | 4660               | ...   | 1440           | 1470         | 11,060  |
| Bedroom C                     | 2560               | 3540               | ...   | 970            | 1260         | 8,330   |
| Bedroom D                     | 2650               | 3020               | 960   | 720            | 950          | 8,300   |
| Bathroom 1                    | 670                | 1510               | ...   | 500            | 630          | 3,310   |
| Bathroom 2                    | 1640               | 960                | 310   | 320            | 400          | 3,630   |
| Living Room                   | 7260               | ...                | ...   | 1800           | 5400         | 14,460  |
| Dining Room                   | 3720               | ...                | ...   | 3100           | 3080         | 9,900   |
| Kitchen                       | 2850               | ...                | ...   | 950            | 2300         | 6,100   |
| Lavette                       | 3000               | ...                | ...   | 1100           | 550          | 4,650   |
| Entrance Hall                 | 870                | 2390               | ...   | 640            | 1600         | 5,500   |
| Garage                        | -1030 <sup>a</sup> | -1270 <sup>b</sup> | 1060  | 3710           | 1910         | 4,380   |
| Recreation                    | 840                | ...                | 570   | 720            | 2890         | 5,020   |
| Design Totals                 | 33,850             | 21,720             | 2,900 | 17,410         | 24,620       | 100,500 |
| Operating Totals <sup>c</sup> | 33,850             | 21,720             | 2,900 | 17,410         | 12,310       | 88,190  |
| Percentages <sup>d</sup>      | 38.4               | 24.6               | 3.3   | 19.7           | 14.0         | 100.0   |

<sup>a</sup> Wall heat loss of 2110 Btuh minus wall heat gains of 1280, 700 and 1160 Btuh. Heat gains of 960 and 0 Btuh. <sup>c</sup> Based on 1/4 computed infiltration. <sup>d</sup> Based on operating totals.

are to have storm sash. The building is constructed as follows (heat transmission coefficients U are parentheses):

**Walls:** Brick veneer, building paper, wood sheathing, studding, metal lath and plaster (0.28). Walls of dormer over garage, same except wood siding in place of brick veneer (0.26).

**Attic Walls:** Brick veneer, building paper, wood sheathing on studding (0.42).

**Basement Walls:** 10 in. concrete (0.10).

**Roof:** Asphalt shingles on wood sheathing on rafters (0.53).

**Ceiling (Second floor):** Metal lath and plaster (0.69).

**Windows:** Double-hung wood windows averaging 70 percent glass (0.45; from Chapter 9, Table 20, Section D, the U value for wood windows with storm sash is 0.53 x application factor; by interpolation this factor is 0.85). Steel casement sash in garage and basement (1.13; from Chapter 9, Table 20, U is 1.13 for all glass and the application factor is 1.00). French doors in dining room 50 percent glass, no storm doors (0.85; from Chapter 9, Table 20, U is 1.13 for all glass; by interpolation the application factor is 0.75).

**Floor (Bedroom D):** Maple finish flooring on yellow pine sub-flooring; metal lath and plaster ceiling below (0.25).

**Floor (Basement and Garage):** 4 in. stone concrete on 3 in. cinder concrete (0.10).

**Solution:** The calculations for this problem are given in Table 8, and a summary

TABLE 10. SUMMARY OF HEAT LOSSES OF INSULATED RESIDENCE (Btu Per Hour)

| ROOM OR SPACE                 | WALLS             | CEILING AND ROOF  | FLOOR | GLASS AND DOOR | INFILTRATION | TOTALS |
|-------------------------------|-------------------|-------------------|-------|----------------|--------------|--------|
| Bedroom A                     | 2480              | 2460              | ...   | 1440           | 2180         | 8,560  |
| Bedroom B                     | 1620              | 1660              | ...   | 1440           | 1470         | 6,190  |
| Bedroom C                     | 1190              | 1260              | ...   | 970            | 1260         | 4,680  |
| Bedroom D                     | 1230              | 1080              | 690   | 720            | 950          | 4,670  |
| Bathroom 1                    | 310               | 540               | ...   | 500            | 630          | 1,980  |
| Bathroom 2                    | 760               | 250               | 220   | 320            | 400          | 1,950  |
| Living Room                   | 3370              | ...               | ...   | 1800           | 5400         | 10,570 |
| Dining Room                   | 1730              | ...               | ...   | 3100           | 3080         | 7,910  |
| Kitchen                       | 1320              | ...               | ...   | 950            | 2300         | 4,570  |
| Lavette                       | 1380              | ...               | ...   | 1100           | 550          | 3,040  |
| Entrance Hall                 | 410               | 850               | ...   | 640            | 1600         | 3,500  |
| Garage                        | -470 <sup>a</sup> | -910 <sup>b</sup> | 1060  | 3710           | 1910         | 5,300  |
| Recreation                    | 840               | ...               | 570   | 720            | 2890         | 5,020  |
| Design Totals                 | 16,180            | 7,190             | 2,540 | 17,410         | 24,620       | 67,940 |
| Operating Totals <sup>c</sup> | 16,180            | 7,190             | 2,540 | 17,410         | 12,310       | 55,630 |
| Percentages <sup>d</sup>      | 29.1              | 12.9              | 4.6   | 31.3           | 22.1         | 100.0  |

<sup>a</sup> Wall heat loss of 980 Btuh minus wall heat gains of 590, 320 and 540 Btuh. <sup>b</sup> Heat gains 690 and 220 Btuh. <sup>c</sup> Based on 1/4 computed infiltration. <sup>d</sup> Based on operating totals.

of the results in Table 9. The values in column F of Table 8 were obtained by multiplying together the figures in columns C, D, and E. The heat losses are calculated to the nearest 10 Btu. See reference notes for Table 7 for further explanation of data.

Attention is called to the summary of heat losses (Table 9) for the uninsulated residence. As storm windows are used in this instance the glass and door transmission heat losses of 19.8 percent are relatively small. The infiltration losses of 14.0 percent are also comparatively small because the storm windows are equivalent to weatherstripping. In this problem, the wall, ceiling and floor transmission losses comprise 66.2 percent of the total.

**Example 7:** Calculate the heat loss of residence shown in Fig. 2 based on the same conditions as in *Example 6* but having construction improved or insulated to obtain coefficients as follows:

Walls, 0.13; Walls of Dormer over Garage, 0.12; Attic Walls, 0.28; Walls Adjoining Garage, 0.18; Basement Walls (Recreation Room), 0.10.

Roof, 0.53.

Ceiling (Second Floor), 0.15.

Windows (Same as in *Example 6*).

Floor (Bedroom D), 0.18.

**Solution:** The procedure for calculating the heat losses is similar to that for *Example 6*. A summary of the results is given in Table 10.

## REFERENCES

- <sup>1</sup> ARI Application Engineering Standards for Air Conditioning for Comfort, 1947 (Air-Conditioning and Refrigeration Institute).
- <sup>2</sup> An Analysis of Winter Temperatures for One Hundred and Twenty Cities, by Clark M. Humphreys (Carnegie Institute of Technology Bulletin 1939).
- <sup>3</sup> Investigation of Oil-Fired Forced Air Furnace Systems in the Research Residence, by A. P. Kratz and S. Konzo (University of Illinois Engineering Experiment Station Bulletin No. 318).
- <sup>4</sup> Performance of a Hot-Water Heating System in the I=B=R Research Home at the University of Illinois, by A. P. Kratz, W. S. Harris, M. K. Fahnestock, and R. J. Martin (University of Illinois Engineering Experiment Station Bulletin No. 349).
- <sup>5</sup> A Study of Radiant Baseboard Heating in the I=B=R Research Home, by A. P. Kratz and W. S. Harris (University of Illinois Engineering Experiment Station Bulletin No. 359).
- <sup>6</sup> Performance of a One-Pipe Steam System in the I=B=R Research Home, by W. S. Harris (University of Illinois Engineering Experiment Station Bulletin No. 383).
- <sup>7</sup> A.S.H.V.E. RESEARCH REPORT No. 1011—Tests of Three Heating Systems in an Industrial Type of Building, by G. L. Larson, D. W. Nelson, and John James (A.S.H.V.E. TRANSACTIONS, Vol. 41, 1935, p. 185).
- <sup>8</sup> Methods of Moisture Control and Their Application to Building Construction, by F. B. Rowley, A. B. Algren and C. E. Lund (University of Minnesota, Engineering Experiment Station Bulletin No. 17).
- <sup>9</sup> A.S.H.V.E. RESEARCH REPORT No. 1213—Heat Loss Through Basement Walls and Floors, by F. C. Houghten, S. I. Taimuty, Carl Gutberlet and C. J. Brown (A.S.H.V.E. TRANSACTIONS, Vol. 48, 1942, p. 369).
- <sup>10</sup> Measurements of Heat Losses from Slab Floor, by R. S. Dill, W. C. Robinson and H. E. Robinson (U. S. Department of Commerce, National Bureau of Standards, Building Materials and Structures Report BMS 103).
- <sup>11</sup> Temperature and Heat Loss Characteristics of Concrete Floors Laid on the Ground, by H. D. Bareither, A. N. Flemming and B. E. Alberty (University of Illinois, Small Homes Council Technical Report).
- <sup>12</sup> Concrete Floors for Basementless Houses (University of Illinois, Small Homes Council Circular No. F 4.3).
- <sup>13</sup> Warm-Air Perimeter Heating, Part III—Heat Losses from Floor Slab, by J. R. Jamieson, R. W. Reese and S. Konzo. (ASHVE TRANSACTIONS, Vol. 58, 1952, p. 217).
- <sup>14</sup> Warm-Air Perimeter Heating—Manual 4, National Warm Air Heating and Air Conditioning Association.
- <sup>15</sup> Heat Requirement Tables for Intermittently Heated Buildings (Engineering Experiment Station Bulletin No. 60, A. and M. College of Texas, College Station, Texas) contains a set of tables applicable to either intermittent heating or cooling. Further information may be found in a paper, A Method of Compiling Tables for Intermittent Heating, by Elmer G. Smith (A.S.H.V.E. JOURNAL SECTION, Heating, Piping and Air Conditioning, June 1942, p. 386).
- <sup>16</sup> Slab-on-Ground Construction for Residences, (Publication No. 385, Building Research Advisory Board, National Research Council).

## CHAPTER 13

## COOLING LOAD

Cooling Load Calculations; Design Conditions; Instantaneous Heat Load; Solar Radiation; Periodic Heat Flow; Tables for Calculating Solar Heat Gain Through Walls, Roofs and Glass; Instantaneous Heat Gain vs. Cooling Loads; Load from Interior Partitions, Ceiling and Floors; Load from Outside Air, Ventilation and Infiltration; Effect of Outside Air on Load; Heat Sources Within Conditioned Space; Moisture Transfer Heat Load; Miscellaneous Heat Loads; Apparatus Dew Point and Required Air Quantity Through Conditioning Equipment; Minimum Entering Air Temperature; Example Cooling Load Calculation

THE variables affecting cooling-load calculations are numerous, often difficult to define precisely, and always intricately inter-related. Most of the components of the cooling load vary in magnitude over a wide range during a 24-hour period, and as the cyclic changes in load components are not usually in phase with each other, careful analysis is required to establish the resultant maximum cooling load for a building or zone. A zoned system must often handle peak loads in different zones at different hours.

Economic considerations must be of particular influence in the selection of equipment for cooling season operation in comfort air conditioning, and this fact, coupled with present inadequacies in available data and knowledge of the air-conditioning art, places a premium on the experienced judgment essential to successful design or practice. Variations in the weather, building occupancy, and other factors affecting load, necessitate carefully coordinated controls to regulate simultaneously the components and the equipment in order to maintain the desired room conditions.

The calculation procedures presented in this chapter deal with the various instantaneous rates of heat gain, both sensible and latent, in a conditioned space. There may be an appreciable difference between the *net instantaneous rate of heat gain* and the *total cooling load* at any instant. This difference is caused by the storage and subsequent release of heat by the structure and its contents. This thermal-storage effect may be quite important in determining an economical cooling equipment capacity. The lack of any adequate means of treating this storage quantitatively in its entirety for a complete structure, must be recognized in judging the procedures and data presented for calculating individual components of the net rate of instantaneous heat gain.

Solar heating calculations involve the same principles as cooling load calculations. Many of the data on solar radiation given in this chapter can be used in calculations for solar heating.

## COOLING LOAD CALCULATIONS

Summer cooling load calculations, whether for industrial or comfort applications, require consideration of the following factors:

A. *Design Conditions:* (1) indoor conditions; (2) outdoor conditions; (3) ventilation rate.

B. *Instantaneous Heat Load, Sensible and Latent:* (1) load from solar radiation,

sky radiation and from outdoor-indoor temperature differential for glass areas and exterior, walls and roofs, modified by periodic heat flow or lag factors depending on the type of structure; (2) load due to heat gain through interior partitions, ceilings and floors; (3) load due to ventilation, either natural or mechanical; (4) load due to heat sources within the conditioned space such as people, lights, power equipment, and appliances; (5) load due to moisture transfer through permeable building materials; (6) miscellaneous heat sources.

#### C. Determination of Air Quantity and Apparatus Dew Point.

These factors will be discussed in turn. The material presented leads to an illustrative procedure for a cooling-load calculation, and a numerical example is given to demonstrate the calculations involved.

### DESIGN CONDITIONS

#### Indoor Conditions

Indoor air conditions for human health and comfort have been and continue to be the subject of much discussion and research.

The effective temperature index, explained in Chapter 6 is probably the best available source of design criteria for comfort air conditioning systems for buildings or enclosures in which the air and inside surface

TABLE 1. DESIGN ROOM CONDITIONS USUALLY SPECIFIED FOR SUMMER AVERAGE PEAK LOAD IN COMFORT AIR CONDITIONING<sup>a</sup>

| TYPE OF INSTALLATION           | DRY-BULB TEMP | WET-BULB TEMP <sup>b</sup> | RELATIVE HUMIDITY PER CENT | GRAINS PER LB <sup>b</sup> | EFFECTIVE TEMP <sup>c</sup> |
|--------------------------------|---------------|----------------------------|----------------------------|----------------------------|-----------------------------|
| 1. Ample Capacity.....         | 78            | 65                         | 50                         | 72.7                       | 72.2                        |
| 2. Practical Application.....  | 80            | 67                         | 51                         | 78.5                       | 74.0                        |
| 3. Occupancy—15 to 40 min..... | 82            | 68                         | 49                         | 80.0                       | 75.3                        |

<sup>a</sup> Values in Table 1 are for peak load conditions. It is general practice to operate a system at approximately 76 F and 50 percent relative humidity at other than peak load.

<sup>b</sup> Psychrometric data for standard barometric pressure.

<sup>c</sup> Fig. 10, Chapter 6, air movement 15 to 25 fpm.

temperatures remain substantially equal; a condition that can safely be assumed for most ordinary comfort air conditioning installations. Other sources of design specifications are to be found in the requirements of codes and ordinances, and in the varied long-term experiences of manufacturers, contractors, and engineering specialists.

Past experience, cumulative over many years, indicates that indoor design conditions for which summer air-conditioning equipment is selected, should not exceed a temperature of 80 F or a relative humidity of 50 percent for the average job in the United States. If these conditions are exceeded, complaints of discomfort may be expected, especially with continuous occupancy. For very brief occupancy only, a slightly higher peak-load design temperature may be employed. In regard to the lower limit of humidity, complaints are not encountered for store installations operated down to 35 percent relative humidity or, for office jobs, somewhat lower. These observations apply to normal commercial practice in this country only; for extremes, such as tropical or very hot regions, it is regarded as more practicable to design for a peak-load outdoor-indoor temperature difference of about 15 to 20 F.

Table 1 offers typical design conditions for average requirements encountered. The values in line 1 would also apply in general for localities having a summer outdoor design temperature of 90 F or less; and the 15 to 40 min occupancy values, or even somewhat higher dry-bulb tem-

peratures, would indicate acceptable conditions for very hot localities. Table 1 is to be used with good judgment, for there is no universal rule which may be applied to indoor design conditions.

Guarantees of conditions to be maintained for summer operation are based upon a definite set of load conditions. At other than the guarantee load, the conditions produced by a system are determined by the balance of imposed load and equipment capacity, and by the method adopted for regulating the system operation. Complete specifications of indoor design conditions would include part-load and overload operation, particularly from the viewpoint of economy.

In the field of industrial air conditioning, indoor design conditions are established by the requirements of goods and processes, in addition to the comfort and efficiency of the workers. Many typical indoor design conditions for products in industrial air conditioning are given in Chapter 45.

The load calculations for either comfort or industrial air conditioning are usually made in accordance with a guarantee. In comfort applications, for example, this is frequently 80 F and 51 percent relative humidity or 78 F and 50 percent relative humidity. The system is normally operated at 75 or 76 F and approximately 50 percent relative humidity at all times as long as the equipment has capacity to maintain these conditions. During very hot weather, the room temperature will rise above the control point and the equipment will operate continuously. Normally, industrial jobs are operated at design conditions at all times if the optimum conditions are selected for the benefit of the product.

The indoor design conditions suggested have had reference to conditions to be maintained at the level of occupancy. For extremely high ceilings in public or industrial buildings, only the zone from 10 to 15 ft above the floor may be cooled to the full extent. The air temperature at the ceiling would be much higher, and this should be kept in mind when calculating the convective portion of the roof heat gain. A reduction of outdoor-to-indoor air temperature differential may be assumed in such instances; radiation from the inner roof surface is not diminished.

#### Outdoor Conditions

Summer climatic conditions and suggested design wet-bulb and dry-bulb temperatures are given in Table 2 for various locations in the United States. The highest temperature ever recorded is for the period of record shown. In some cases it should be noted that this period of record is comparatively short, and higher temperatures may be expected. In making comparisons for other localities than those shown in Table 2, due consideration must be given to elevation.

Column 6 of Table 2 indicates the design dry-bulb temperature suggested by the A.S.H.A.E. Technical Advisory Committee on Weather Design Conditions. This temperature is the maximum hourly outdoor temperature which has been equalled or exceeded 2½ percent of the total hours of June, July, August and September for the period of record, in this case the 5-year period 1935-1939, and should not be confused with the period of record given in Column 4 which applies only to highest temperature ever recorded. Since all of these data (Column 4) are based on airport records, they are not necessarily applicable to cities.

The data given in Columns 7 and 8 were obtained from local A.S.H.A.E. Chapter Secretaries, and represent the design temperatures in local use. Where such information was not available, it was taken from a publication of the A.R.I.<sup>1</sup> and from various other sources.



The Technical Advisory Committee on Weather Design Conditions has suggested that wet-bulb design temperature be taken as that wet-bulb temperature which has been equalled or exceeded in 5 percent of the hours during months of the period of record. While not available for the 1956 edition of *THE GUIDE*, due to the tremendous task of compiling these data, it is hoped that they will be available for some stations for future editions.

The wind velocity to be used in design should be that wind velocity which accompanies the design temperatures in each instance, but since these data are not available, the average summer wind velocities for the period of record were taken from U. S. Weather Bureau records revised to 1948. It is pointed out that this is not necessarily the velocity which coincides with the design temperatures, but it may serve as a guide to the designer.

Other weather data, such as *daily range of temperature*, are useful particularly when making cooling load calculations for an early morning peak on an east exposure. Daily range of temperature is the difference between the average of the daily maximum dry-bulb temperatures and the average of the daily minimum temperatures. This range is highest in semi-arid or desert regions and at high elevations, and lowest near the oceans or very large lakes. The daily range of temperature (Fahrenheit degrees) in July for the principal areas of the United States can be approximated from the following tabulation:

|                        |          |                                           |          |
|------------------------|----------|-------------------------------------------|----------|
| East Sea Shore.....    | 12 to 18 | East of Mississippi River.....            | 19 to 24 |
| Gulf Sea Shore.....    | 12 to 18 | Mississippi River to Rocky Mountains..... | 24 to 33 |
| Great Lakes Shore..... | 18 to 21 | Rocky Mountain Area.....                  | 33 to 42 |
| West Sea Shore.....    | 15 to 20 | West Coastal States.....                  | 20 to 36 |

### Ventilation Rate

The introduction of outside air is necessary for the ventilation of conditioned spaces. Chapter 6 suggests *minimum* outdoor-air requirements for representative applications; but it is to be emphasized that minimum requirements are not necessarily *adequate* requirements for all psychological attitudes and physiological responses. Where maximum economy in space and load are essential, as in submarines or other restricted spaces, as little as 1 cfm of outside air per person has been found to be sufficient provided that satisfactory ventilation is simultaneously obtained by an adequate decontamination of recirculated air.<sup>2</sup>

Local codes and ordinances frequently specify ventilation requirements for public places and for industrial installations. For operating rooms, minimum requirements for safe practice are given in a *National Board of Fire Underwriters' pamphlet*.<sup>3</sup> This pamphlet does not require 100 percent outside air in operating rooms, although 100 percent outside air is normally used and recommended.

Recommended and minimum ventilation rates for the most common applications are summarized in Table 3. For further general applications, a basis of estimating the cfm per person may be taken as:

|                            |                |            |
|----------------------------|----------------|------------|
| 1. People not smoking..... | 7½ Recommended | 5 Minimum  |
| 2. People smoking.....     | 40 Recommended | 25 Minimum |

The cooling load due to the introduction of outside air for ventilation is determined once the indoor and outdoor design conditions are fixed. Calculations will be discussed subsequently.

### Cooling Load

TABLE 2. SUMMER CLIMATIC CONDITIONS\*  
Suggested Design Wet-Bulb and Dry-Bulb Temperatures

| COL. 1<br>STATE | COL. 2<br>STATION <sup>b</sup> | COL. 3<br>ELEVATION <sup>c</sup><br>Ft | COL. 4<br>PERIOD<br>OF<br>RECORD <sup>d</sup> | COL. 5<br>HIGHEST<br>TEMP.<br>EVER<br>RECORDED <sup>e</sup><br>°F | COL. 6<br>DESIGN<br>DRY-BULB<br>TEMP. ON<br>T.A.C. 24%<br>BASIS <sup>f</sup><br>°F | COL. 7<br>DESIGN<br>DRY-BULB<br>TEMP. IN<br>COMMON<br>USE <sup>g</sup><br>°F | COL. 8<br>DESIGN<br>WET-BULB<br>TEMP. IN<br>COMMON<br>USE <sup>h</sup><br>°F | COL. 9<br>AVERAGE<br>SUMMER<br>WIND<br>VELOCITY <sup>i</sup><br>MPH |
|-----------------|--------------------------------|----------------------------------------|-----------------------------------------------|-------------------------------------------------------------------|------------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------|---------------------------------------------------------------------|
| Ala.            | Anniston.....CO                | 733                                    | 1893-1947                                     |                                                                   |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Birmingham.....CO              | 711                                    | 1893-1945                                     | 105                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Mobile.....AP                  | 615                                    | 1939-1947                                     | 107                                                               |                                                                                    | 95                                                                           | 78                                                                           |                                                                     |
|                 | Mobile.....CO                  | 143                                    | 1872-1947                                     | 103                                                               | 94                                                                                 | 95                                                                           | 78                                                                           | 5.4                                                                 |
|                 | Montgomery.....AP              | 219                                    | 1940-1947                                     | 103                                                               |                                                                                    | 95                                                                           | 80                                                                           | 8.0                                                                 |
|                 | Montgomery.....CO              | 293                                    | 1872-1947                                     | 107                                                               | 92                                                                                 |                                                                              |                                                                              |                                                                     |
| Ariz.           | Flagstaff.....CO               | 6957                                   | 1935-1939                                     | 103                                                               |                                                                                    | 95                                                                           | 78                                                                           |                                                                     |
|                 | Kingman.....AP                 | 3473                                   | 1899-1947                                     | 93                                                                |                                                                                    | 90                                                                           | 65                                                                           |                                                                     |
|                 | Phoenix.....CO                 | 1122                                   | 1895-1947                                     | 107                                                               | 99                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | Tucson.....AP                  | 1112                                   | 1933-1947                                     | 118                                                               |                                                                                    | 105                                                                          | 76                                                                           |                                                                     |
|                 | Winslow.....CO                 | 2561                                   | 1935-1939                                     | 117                                                               | 107                                                                                |                                                                              |                                                                              | 6.0                                                                 |
|                 | Winslow.....AP                 | 4853                                   | Up to 1946                                    | 112                                                               | 102                                                                                | 105                                                                          | 72                                                                           |                                                                     |
| Ark.            | Yuma.....CO                    | 4899                                   | 1937-1947                                     | 107                                                               | 95                                                                                 | 100                                                                          | 70                                                                           |                                                                     |
|                 | Fort Smith.....CO              | 146                                    | 1876-1946                                     | 120                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Fort Smith.....AP              | 345                                    | 1882-1945                                     | 113                                                               |                                                                                    | 110                                                                          | 78                                                                           |                                                                     |
|                 | Little Rock.....CO             | 463                                    | 1845-1947                                     | 107                                                               |                                                                                    | 95                                                                           | 76                                                                           | 6.1                                                                 |
| Calif.          | Little Rock.....AP             | 451                                    | 1879-1942 <sup>d</sup>                        | 107                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Bakersfield.....AP             | 282                                    | 1942-1947                                     | 110                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Burbank.....AP                 | 499                                    | 1937-1945                                     | 107                                                               | 97                                                                                 | 95                                                                           | 78                                                                           | 6.2                                                                 |
|                 | Dayton.....AP                  | 740                                    | 1931-1947 <sup>d</sup>                        | 113                                                               | 104                                                                                | 105                                                                          |                                                                              |                                                                     |
|                 | Eureka.....AP                  | 1925                                   | 1935-1939                                     | 113                                                               | 94                                                                                 |                                                                              | 70                                                                           |                                                                     |
|                 | Fresno.....CO                  | 132                                    | 1886-1947                                     | 85                                                                | 104                                                                                |                                                                              |                                                                              |                                                                     |
|                 | Fresno.....AP                  | 387                                    | 1887-1939                                     | 115                                                               |                                                                                    | 90                                                                           | 65                                                                           |                                                                     |
|                 | Los Angeles.....CO             | 534                                    | 1877-1947                                     | 111                                                               | 103                                                                                | 105                                                                          | 74                                                                           | 7.9                                                                 |
|                 | Oakland.....AP                 | 21                                     | 1929-1947                                     | 109                                                               |                                                                                    | 90                                                                           | 70                                                                           |                                                                     |
|                 | Red Bluff.....CO               | 305 <sup>c</sup>                       | 1877-1934                                     | 102                                                               | 80                                                                                 | 85                                                                           | 65                                                                           | 5.8                                                                 |
|                 | Red Bluff.....AP               | 346                                    | 1944-1947                                     | 115                                                               |                                                                                    | 100                                                                          | 70                                                                           |                                                                     |
|                 | Redding.....AP                 | 579                                    | 1935-1939                                     | 112                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Sacramento.....CO              | 116                                    | 1877-1947                                     | 114                                                               | 101                                                                                |                                                                              |                                                                              |                                                                     |
|                 | Sacramento.....AP              | 22                                     | 1938-1947                                     | 108                                                               |                                                                                    | 100                                                                          | 72                                                                           | 7.9                                                                 |
|                 | San Diego.....CO               | 90                                     | 1871-1940                                     | 110                                                               |                                                                                    | 85                                                                           | 68                                                                           |                                                                     |
|                 | San Diego.....AP               | 34                                     | 1939-1947                                     | 106                                                               | 79                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | San Francisco.....CO           | 164                                    | 1875-1947                                     | 101                                                               |                                                                                    | 85                                                                           | 65                                                                           | 10.7                                                                |
|                 | San Jose.....AP                | 100                                    | Up to 1946                                    | 106                                                               |                                                                                    | 85                                                                           | 70                                                                           |                                                                     |
| Colo.           | Williams.....AP                | 124                                    | 1935-1939                                     | 116                                                               |                                                                                    | 91                                                                           |                                                                              |                                                                     |
|                 | Denver.....CO                  | 5398                                   | 1871-1947                                     | 105                                                               | 103                                                                                |                                                                              |                                                                              |                                                                     |
|                 | Denver.....AP                  | 5379                                   | 1934-1947                                     | 104                                                               |                                                                                    | 95                                                                           | 64                                                                           | 6.9                                                                 |
|                 | Durango.....CO                 | 6558                                   | Up to 1946                                    | 99                                                                | 93                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | Grand Junction.....CO          | 4587 <sup>c</sup>                      | Up to 1946                                    | 105                                                               |                                                                                    | 95                                                                           | 65                                                                           |                                                                     |
|                 | Pueblo.....CO                  | 4770                                   | 1839-1938                                     | 104                                                               |                                                                                    | 95                                                                           | 65                                                                           | 6.3                                                                 |
| Conn.           | Pueblo.....AP                  | 4810                                   | 1939-1947                                     | 104                                                               |                                                                                    | 95                                                                           | 65                                                                           |                                                                     |
|                 | Hartford.....CO                | 229                                    | 1905-1940 <sup>d</sup>                        | 101                                                               | 95                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | Hartford.....AP                | 20                                     | 1940-1947                                     | 98                                                                |                                                                                    | 83                                                                           | 76                                                                           |                                                                     |
| D. C.           | New Haven.....CO               | 180                                    | 1872-1947                                     | 101                                                               | 88                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | New Haven.....AP               | 17                                     | 1943-1947                                     | 94                                                                |                                                                                    | 95                                                                           | 76                                                                           | 7.4                                                                 |
| Fla.            | Washington.....CO              | 128                                    | 1871-1947                                     | 106                                                               | 84                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | Washington.....AP              | 23                                     | 1935-1939                                     | 106                                                               |                                                                                    | 95                                                                           | 78                                                                           | 5.9                                                                 |
|                 | Apalachicola.....CO            | 20                                     | 1922-1947                                     | 102                                                               | 92                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | Jacksonville.....CO            | 104                                    | 1871-1947                                     | 104                                                               |                                                                                    | 95                                                                           | 80                                                                           |                                                                     |
|                 | Jacksonville.....AP            | 29                                     | 1938-1947                                     | 105                                                               |                                                                                    | 95                                                                           | 78                                                                           | 8.4                                                                 |
|                 | Key West.....CO                | 23                                     | 1871-1947                                     | 100                                                               | 94                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | Key West.....AP                | 48                                     | 1939-1947                                     | 95                                                                |                                                                                    | 98                                                                           | 78                                                                           |                                                                     |
|                 | Miami.....CO                   | 253                                    | 1896-1947                                     | 98                                                                |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Miami.....AP                   | 13                                     | 1940-1947                                     | 100                                                               | 89                                                                                 | 91                                                                           | 79                                                                           | 8.7                                                                 |
|                 | Pensacola.....CO               | 67                                     | 1879-1947                                     | 103                                                               |                                                                                    | 95                                                                           | 78                                                                           |                                                                     |
|                 | Pensacola.....AP               | 113                                    | 1943-1947                                     | 105                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Tampa.....CO                   | 111                                    | 1890-1940                                     | 98                                                                |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Tampa.....AP                   | 12                                     | 1941-1946 <sup>d</sup>                        | 98                                                                |                                                                                    | 95                                                                           | 78                                                                           | 7.4                                                                 |
| Ga.             | Titusville.....AP              | 52                                     | 1935-1939                                     | 98                                                                |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Atlanta.....AP                 | 1020                                   | 1935-1939                                     | 102                                                               | 90                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | Augusta.....CO                 | 195                                    | 1871-1946                                     | 106                                                               | 93                                                                                 | 95                                                                           | 78                                                                           | 7.9                                                                 |
|                 | Augusta.....AP                 | 424                                    | 1939-1947                                     | 105                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Macon.....CO                   | 408                                    | 1899-1947                                     | 105                                                               |                                                                                    | 95                                                                           | 78                                                                           |                                                                     |
|                 | Macon.....AP                   | 432                                    | 1939-1947                                     | 102                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Savannah.....CO                | 115                                    | 1871-1945 <sup>d</sup>                        | 105                                                               |                                                                                    | 95                                                                           | 78                                                                           |                                                                     |
|                 | Savannah.....AP                | 56                                     | 1939-1947                                     | 105                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
| Idaho.          | Boise.....CO                   | 2818                                   | 1864-1939                                     | 112                                                               | 93                                                                                 | 95                                                                           | 78                                                                           | 8.0                                                                 |
|                 | Burley.....AP                  | 2849                                   | 1939-1947                                     | 109                                                               |                                                                                    | 95                                                                           | 65                                                                           | 5.8                                                                 |
|                 | Idaho Falls.....AP             | 4150                                   | 1935-1939                                     | 104                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Lewiston.....CO                | 4744                                   | 1935-1939                                     | 100                                                               | 88                                                                                 |                                                                              |                                                                              |                                                                     |
|                 | Pocatello.....CO               | 763                                    | 1900-1944 <sup>d</sup>                        | 117                                                               |                                                                                    |                                                                              |                                                                              |                                                                     |
|                 | Pocatello.....AP               | 4522                                   | 1899-1947                                     | 105                                                               |                                                                                    | 95                                                                           | 65                                                                           |                                                                     |
| Ill.            | Cairo.....CO                   | 4467                                   | 1938-1947                                     | 103                                                               | 92                                                                                 | 95                                                                           | 65                                                                           |                                                                     |
|                 | Chicago.....CO                 | 601                                    | Up to 1946                                    | 106                                                               |                                                                                    | 98                                                                           | 78                                                                           |                                                                     |
|                 | Chicago.....AP                 | 615                                    | 1935-1939                                     | 107                                                               |                                                                                    | 95                                                                           | 75                                                                           | 9.5                                                                 |
|                 | Moline.....AP                  | 594                                    | 1932-1947                                     | 106                                                               | 94                                                                                 | 96                                                                           | 76                                                                           |                                                                     |



TABLE 2. SUMMER CLIMATIC CONDITIONS\* (CONTINUED)  
Suggested Design Wet-Bulb and Dry-Bulb Temperatures

| COL. 1<br>STATE | COL. 2<br>STATION <sup>b</sup> | COL. 3<br>ELEVATION <sup>c</sup><br>FT | COL. 4<br>PERIOD<br>OF RECORD <sup>d</sup> | COL. 5<br>HIGHEST<br>TEMP.<br>EVER<br>RECORDED <sup>d</sup><br>°F | COL. 6<br>DESIGN<br>DRY-BULB<br>TEMP. ON<br>T.A.C. 24%<br>BASIS <sup>e</sup><br>°F | COL. 7<br>DESIGN<br>DRY-BULB<br>TEMP. IN<br>COMMON<br>USE <sup>f</sup><br>°F | COL. 8<br>DESIGN<br>WET-BULB<br>TEMP. IN<br>COMMON<br>USE <sup>f</sup><br>°F | COL. 9<br>AVERAGE<br>SUMMER<br>WIND<br>VELOCITY <sup>g</sup><br>MPH |
|-----------------|--------------------------------|----------------------------------------|--------------------------------------------|-------------------------------------------------------------------|------------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------|---------------------------------------------------------------------|
| Ill.            | Peoria.....AP                  | 660                                    | 1935-1939                                  | 111                                                               | 94                                                                                 | 96                                                                           | 76                                                                           | 8.2                                                                 |
|                 | Springfield.....CO             | 603                                    | 1879-1947                                  | 110                                                               | 98                                                                                 | 98                                                                           | 77                                                                           | ...                                                                 |
|                 | Springfield.....CO             | 608                                    | 1930-1947                                  | 109                                                               | 96                                                                                 | 96                                                                           | 78                                                                           | 7.0                                                                 |
| Ind.            | Evansville.....CO              | 484                                    | 1897-1940                                  | 108                                                               | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | Fort Wayne.....CO              | 585                                    | 1911-1941 <sup>d</sup>                     | 106                                                               | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | Helmer.....AP                  | 970                                    | 1935-1939                                  | 107                                                               | 89                                                                                 | 95                                                                           | 76                                                                           | 8.9                                                                 |
|                 | Indianapolis.....CO            | 816                                    | 1871-1946                                  | 106                                                               | ...                                                                                | 95                                                                           | 76                                                                           | ...                                                                 |
|                 | Indianapolis.....CO            | 800                                    | 1932-1946                                  | 107                                                               | 91                                                                                 | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Terre Haute.....CO             | 1146                                   | 1893-1946                                  | 110                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
| Iowa            | Terre Haute.....AP             | 589                                    | 1941-1946                                  | 103                                                               | ...                                                                                | 95                                                                           | 78                                                                           | 8.8                                                                 |
|                 | Davenport.....CO               | 648                                    | 1872-1947                                  | 111                                                               | 95                                                                                 | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Des Moines.....CO              | 979                                    | 1935-1939                                  | 110                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Dubuque.....CO                 | 740                                    | 1874-1947                                  | 113                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Keokuk.....CO                  | 637                                    | 1873-1946                                  | 111                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Sioux City.....CO              | 1063 <sup>e</sup>                      | 1889-1944 <sup>d</sup>                     | 111                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Sioux City.....AP              | 1098                                   | 1940-1946                                  | 108                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
| Kans.           | Sioux City.....CO              | 1425                                   | 1885-1947                                  | 116                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Concordia.....CO               | 2515                                   | 1874-1942 <sup>d</sup>                     | 109                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Dodge City.....AP              | 2599                                   | 1942-1947                                  | 109                                                               | ...                                                                                | 100                                                                          | 78                                                                           | ...                                                                 |
|                 | Topeka.....CO                  | 991                                    | 1887-1947                                  | 114                                                               | ...                                                                                | 100                                                                          | 78                                                                           | ...                                                                 |
|                 | Topeka.....AP                  | 883                                    | 1946-1947                                  | 108                                                               | ...                                                                                | 100                                                                          | 75                                                                           | 11.8                                                                |
|                 | Wichita.....CO                 | 1497                                   | 1888-1939                                  | 114                                                               | ...                                                                                | 95                                                                           | 78                                                                           | 7.2                                                                 |
|                 | Wichita.....CO                 | 1423                                   | 1939-1947                                  | 109                                                               | 100                                                                                | 95                                                                           | 78                                                                           | 6.9                                                                 |
| Ky.             | Louisville.....CO              | 563                                    | 1871-1947                                  | 107                                                               | ...                                                                                | 95                                                                           | 80                                                                           | 7.0                                                                 |
|                 | Louisville.....CO              | 544                                    | 1937-1947                                  | 103                                                               | 93                                                                                 | 95                                                                           | 80                                                                           | 8.7                                                                 |
| La.             | New Orleans.....AP             | 85                                     | 1874-1947                                  | 102                                                               | ...                                                                                | 95                                                                           | 78                                                                           | 7.4                                                                 |
|                 | New Orleans.....AP             | 8                                      | 1937-1947                                  | 100                                                               | 93                                                                                 | 95                                                                           | 78                                                                           | 12.5                                                                |
|                 | Shreveport.....AP              | 179                                    | 1935-1939                                  | 109                                                               | 98                                                                                 | 100                                                                          | 78                                                                           | ...                                                                 |
| Maine.          | Eastport.....CO                | 100                                    | 1873-1947                                  | 93                                                                | ...                                                                                | 90                                                                           | 70                                                                           | ...                                                                 |
|                 | Portland.....CO                | 185                                    | 1885-1940                                  | 103                                                               | ...                                                                                | 90                                                                           | 73                                                                           | ...                                                                 |
|                 | Portland.....AP                | 65                                     | 1940-1947                                  | 99                                                                | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
| Md.             | Baltimore.....CO               | 114                                    | 1871-1947                                  | 107                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Baltimore.....AP               | 43                                     | 1935-1939                                  | 105                                                               | 91                                                                                 | 92                                                                           | 75                                                                           | ...                                                                 |
| Mass.           | Boston.....CO                  | 356                                    | 1870-1935                                  | 104                                                               | ...                                                                                | 92                                                                           | 75                                                                           | ...                                                                 |
|                 | Boston.....AP                  | 45                                     | 1935-1947                                  | 101                                                               | 87                                                                                 | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | Nantucket.....CO               | 45                                     | 1886-1947                                  | 92                                                                | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
| Mich.           | Nantucket.....AP               | 48                                     | 1946-1947                                  | 82                                                                | ...                                                                                | 95                                                                           | 75                                                                           | 9.5                                                                 |
|                 | Alpena.....CO                  | 615                                    | 1874-1946                                  | 104                                                               | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | Detroit.....CO                 | 1000                                   | 1873-1933                                  | 104                                                               | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | Detroit.....AP                 | 632                                    | 1934-1947                                  | 105                                                               | 89                                                                                 | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | Lansing.....CO                 | 861                                    | 1910-1947                                  | 102                                                               | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | Lansing.....AP                 | 863                                    | 1940-1947                                  | 98                                                                | ...                                                                                | 93                                                                           | 73                                                                           | ...                                                                 |
| Minn.           | Marquette.....CO               | 721                                    | 1874-1947                                  | 108                                                               | ...                                                                                | 93                                                                           | 73                                                                           | ...                                                                 |
|                 | Duluth.....CO                  | 1133                                   | 1874-1947                                  | 106                                                               | ...                                                                                | 93                                                                           | 73                                                                           | ...                                                                 |
|                 | Duluth.....AP                  | 1413                                   | 1941-1947                                  | 95                                                                | ...                                                                                | 95                                                                           | 75                                                                           | 10.2                                                                |
|                 | Minneapolis.....CO             | 945                                    | 1890-1947                                  | 108                                                               | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | Minneapolis.....AP             | 873                                    | 1938-1947                                  | 104                                                               | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | St. Paul.....CO                | 951                                    | 1871-1933                                  | 104                                                               | ...                                                                                | 95                                                                           | 75                                                                           | ...                                                                 |
|                 | St. Paul.....AP                | 708                                    | 1937-1947                                  | 104                                                               | 91                                                                                 | 95                                                                           | 79                                                                           | 4.6                                                                 |
| Miss.           | Meridian.....CO                | 410                                    | 1889-1947                                  | 105                                                               | ...                                                                                | 95                                                                           | 78                                                                           | 6.4                                                                 |
|                 | Meridian.....AP                | 298                                    | 1939-1947                                  | 105                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Vicksburg.....CO               | 316                                    | 1874-1947                                  | 104                                                               | ...                                                                                | 100                                                                          | 78                                                                           | ...                                                                 |
|                 | Vicksburg.....AP               | 266                                    | 1941-1947                                  | 104                                                               | ...                                                                                | 100                                                                          | 78                                                                           | ...                                                                 |
| Mo.             | Columbia.....CO                | 739                                    | 1839-1947                                  | 111                                                               | ...                                                                                | 100                                                                          | 78                                                                           | 9.1                                                                 |
|                 | Columbia.....AP                | 787                                    | 1939-1947                                  | 102                                                               | ...                                                                                | 100                                                                          | 78                                                                           | 9.6                                                                 |
|                 | Kansas City.....CO             | 780                                    | 1935-1939                                  | 112                                                               | 101                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | St. Louis.....CO               | 646                                    | 1871-1947                                  | 110                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | St. Louis.....AP               | 597                                    | 1930-1947                                  | 111                                                               | 97                                                                                 | ...                                                                          | ...                                                                          | 8.7                                                                 |
| Mont.           | Springfield.....AP             | 1270                                   | 1935-1939                                  | 105                                                               | 96                                                                                 | ...                                                                          | 66                                                                           | ...                                                                 |
|                 | Billings.....AP                | 3584                                   | 1935-1947                                  | 106                                                               | 92                                                                                 | 90                                                                           | 66                                                                           | ...                                                                 |
|                 | Butte.....AP                   | 5538                                   | 1931-1947                                  | 100                                                               | 85                                                                                 | 70                                                                           | ...                                                                          | ...                                                                 |
|                 | Havre.....CO                   | 2498                                   | 1880-1947                                  | 108                                                               | ...                                                                                | 95                                                                           | 67                                                                           | 8.1                                                                 |
|                 | Helena.....CO                  | 4175                                   | 1880-1940                                  | 103                                                               | ...                                                                                | 95                                                                           | 65                                                                           | ...                                                                 |
|                 | Kaliapell.....CO               | 3004                                   | 1897-1947                                  | 101                                                               | ...                                                                                | 95                                                                           | 65                                                                           | ...                                                                 |
|                 | Miles City.....AP              | 2629                                   | 1935-1939                                  | 108                                                               | 97                                                                                 | 95                                                                           | 78                                                                           | 9.7                                                                 |
| Nebr.           | Lincoln.....CO                 | 1189                                   | 1887-1947                                  | 115                                                               | ...                                                                                | 95                                                                           | 78                                                                           | 8.1                                                                 |
|                 | Lincoln.....AP                 | 1183                                   | 1933-1947                                  | 115                                                               | 101                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | North Platte.....CO            | 2815                                   | 1874-1947                                  | 109                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | North Platte.....AP            | 2788                                   | 1935-1939                                  | 109                                                               | 98                                                                                 | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Omaha.....CO                   | 1219                                   | 1873-1935 <sup>d</sup>                     | 111                                                               | ...                                                                                | 95                                                                           | 78                                                                           | 8.9                                                                 |
|                 | Omaha.....AP                   | 1009                                   | 1935-1947                                  | 114                                                               | 98                                                                                 | 95                                                                           | 78                                                                           | ...                                                                 |
|                 | Valentine.....CO               | 2627                                   | 1889-1947                                  | 110                                                               | ...                                                                                | 95                                                                           | 78                                                                           | ...                                                                 |
| Nev.            | Elko.....AP                    | 5079                                   | 1935-1939                                  | 102                                                               | ...                                                                                | 115                                                                          | 75                                                                           | 7.3                                                                 |
|                 | Las Vegas.....AP               | 1882                                   | 1937-1947                                  | 117                                                               | 108                                                                                | 95                                                                           | 65                                                                           | ...                                                                 |
|                 | Reno.....CO                    | 4588                                   | 1905-1942                                  | 106                                                               | ...                                                                                | 95                                                                           | 65                                                                           | ...                                                                 |
|                 | Reno.....AP                    | 4417                                   | 1940-1947                                  | 105                                                               | 93                                                                                 | 95                                                                           | 65                                                                           | 4.9                                                                 |
| N. H.           | Winnemucca.....CO              | 4293                                   | 1871-1947                                  | 108                                                               | ...                                                                                | 90                                                                           | 73                                                                           | ...                                                                 |
|                 | Concord.....CO                 | 343                                    | 1871-1941 <sup>d</sup>                     | 102                                                               | ...                                                                                | ...                                                                          | ...                                                                          | ...                                                                 |
|                 | Concord.....AP                 | 359                                    | 1941-1947                                  | 99                                                                | ...                                                                                | ...                                                                          | ...                                                                          | ...                                                                 |

TABLE 2. SUMMER CLIMATIC CONDITIONS\* (CONTINUED)  
Suggested Design Wet-Bulb and Dry-Bulb Temperatures

| COL. 1 | COL. 2               | COL. 3                 | COL. 4                        | COL. 5                                   | COL. 6                                                 | COL. 7                                           | COL. 8                                           | COL. 9                                    |
|--------|----------------------|------------------------|-------------------------------|------------------------------------------|--------------------------------------------------------|--------------------------------------------------|--------------------------------------------------|-------------------------------------------|
| STATE  | STATION <sup>b</sup> | ELEVATION <sup>c</sup> | PERIOD OF RECORD <sup>d</sup> | HIGHEST TEMP. EVER RECORDED <sup>d</sup> | DESIGN DRY-BULB TEMP. ON T.A.C. 24% BASIS <sup>e</sup> | DESIGN DRY-BULB TEMP. IN COMMON USE <sup>f</sup> | DESIGN WET-BULB TEMP. IN COMMON USE <sup>f</sup> | AVERAGE SUMMER WIND VELOCITY <sup>g</sup> |
|        |                      | FT                     |                               | °F                                       | °F                                                     | °F                                               | °F                                               | MPH                                       |
| N. J.  | Atlantic City.....CO | 45                     | 1874-1947                     | 104                                      | .....                                                  | 95                                               | 78                                               | .....                                     |
|        | Camden.....AP        | 20                     | 1935-1939                     | 105                                      | 91                                                     | .....                                            | .....                                            | .....                                     |
|        | Newark.....AP        | 15                     | 1931-1947                     | 104                                      | 89                                                     | 95                                               | 75                                               | .....                                     |
| N. M.  | Trenton.....CO       | 144                    | 1860-1946                     | 106                                      | .....                                                  | 95                                               | 78                                               | 8.8                                       |
|        | Albuquerque.....CO   | 5022                   | 1931-1933 <sup>d</sup>        | 99                                       | .....                                                  | 95                                               | 70                                               | 7.8                                       |
|        | Albuquerque.....AP   | 5319                   | 1933-1947                     | 101                                      | 93                                                     | .....                                            | .....                                            | .....                                     |
|        | El Morro.....AP      | 7120                   | 1935-1939                     | 92                                       | 84                                                     | .....                                            | .....                                            | .....                                     |
|        | Rodeo.....AP         | 4116                   | 1935-1939                     | 104                                      | 97                                                     | .....                                            | .....                                            | .....                                     |
|        | Roswell.....CO       | 3643                   | 1905-1947 <sup>d</sup>        | 107                                      | .....                                                  | 95                                               | 70                                               | .....                                     |
| N. Y.  | Tucumcari.....AP     | 4054                   | 1935-1939                     | 107                                      | 97                                                     | .....                                            | 75                                               | .....                                     |
|        | Albany.....CO        | 114                    | 1874-1947                     | 104                                      | .....                                                  | 93                                               | 75                                               | 7.5                                       |
|        | Albany.....AP        | 280                    | 1938-1947                     | 99                                       | 88                                                     | .....                                            | .....                                            | .....                                     |
|        | Binghamton.....CO    | 915                    | 1891-1946                     | 103                                      | .....                                                  | 95                                               | 75                                               | .....                                     |
|        | Binghamton.....AP    | 836                    | 1942-1947                     | 97                                       | .....                                                  | .....                                            | .....                                            | .....                                     |
|        | Buffalo.....CO       | 726                    | 1935-1939                     | 95                                       | 86                                                     | 93                                               | 73                                               | 12.1                                      |
|        | Canton.....CO        | 458                    | 1906-1947                     | 99                                       | .....                                                  | 90                                               | 73                                               | 8.2                                       |
|        | Elmira.....AP        | 948                    | 1935-1939                     | 98                                       | 88                                                     | .....                                            | .....                                            | .....                                     |
|        | New York.....CO      | 425                    | 1871-1947                     | 102                                      | .....                                                  | 95                                               | 75                                               | 12.5                                      |
|        | Oswego.....CO        | 363                    | 1871-1947                     | 100                                      | .....                                                  | 93                                               | 73                                               | .....                                     |
|        | Rochester.....CO     | 609                    | 1872-1947                     | 102                                      | .....                                                  | 95                                               | 76                                               | .....                                     |
|        | Rochester.....AP     | 560                    | 1935-1939                     | 98                                       | 89                                                     | .....                                            | .....                                            | .....                                     |
|        | Syracuse.....CO      | 465                    | 1902-1940                     | 102                                      | .....                                                  | 93                                               | 75                                               | .....                                     |
| N. C.  | Syracuse.....AP      | 404                    | 1940-1947                     | 97                                       | 88                                                     | .....                                            | .....                                            | .....                                     |
|        | Asheville.....CO     | 2280                   | 1902-1947                     | 99                                       | .....                                                  | 93                                               | 75                                               | 5.6                                       |
|        | Charlotte.....CO     | 809                    | 1876-1947                     | 103                                      | .....                                                  | 95                                               | 78                                               | .....                                     |
|        | Charlotte.....AP     | 757                    | 1939-1947                     | 103                                      | 93                                                     | .....                                            | .....                                            | .....                                     |
|        | Greensboro.....AP    | 896                    | 1928-1947                     | 101                                      | 91                                                     | 95                                               | 78                                               | .....                                     |
|        | Raleigh.....CO       | 405                    | 1887-1947                     | 104                                      | .....                                                  | 95                                               | 78                                               | 6.3                                       |
|        | Raleigh.....AP       | 446                    | 1944-1947                     | 102                                      | 93                                                     | .....                                            | .....                                            | .....                                     |
| N. D.  | Willington.....CO    | 78                     | 1871-1947                     | 103                                      | .....                                                  | 95                                               | 78                                               | 8.4                                       |
|        | Bismarck.....CO      | 1675                   | 1875-1940                     | 114                                      | .....                                                  | 95                                               | 73                                               | 9.5                                       |
|        | Bismarck.....AP      | 1655                   | 1940-1947                     | 109                                      | 96                                                     | .....                                            | .....                                            | .....                                     |
|        | Devils Lake.....CO   | 1481                   | 1904-1947                     | 112                                      | .....                                                  | 95                                               | 70                                               | .....                                     |
|        | Dickinson.....AP     | 2599                   | 1935-1939                     | 112                                      | 94                                                     | .....                                            | .....                                            | .....                                     |
|        | Fargo.....AP         | 900                    | 1935-1939                     | 115                                      | 93                                                     | 95                                               | 75                                               | .....                                     |
|        | Pembina.....AP       | 830                    | 1935-1939                     | 109                                      | 92                                                     | .....                                            | .....                                            | .....                                     |
| Ohio   | Williston.....CO     | 1919                   | 1879-1947                     | 110                                      | .....                                                  | 95                                               | 73                                               | .....                                     |
|        | Akron.....AP         | 104                    | 1935-1939                     | 101                                      | 88                                                     | 95                                               | 75                                               | .....                                     |
|        | Cincinnati.....CO    | 772                    | 1870-1947                     | 108                                      | .....                                                  | 95                                               | 78                                               | 5.6                                       |
|        | Cincinnati.....AP    | 488                    | 1931-1947                     | 108                                      | 94                                                     | .....                                            | .....                                            | .....                                     |
|        | Cleveland.....CO     | 669                    | 1871-1946                     | 100                                      | .....                                                  | 95                                               | 76                                               | 11.1                                      |
|        | Cleveland.....AP     | 813                    | 1930-1946                     | 107                                      | 90                                                     | .....                                            | .....                                            | .....                                     |
|        | Columbus.....CO      | 812                    | 1878-1946                     | 106                                      | .....                                                  | 95                                               | 76                                               | .....                                     |
|        | Columbus.....AP      | 820                    | 1939-1947                     | 100                                      | 90                                                     | .....                                            | .....                                            | .....                                     |
|        | Dayton.....CO        | 1086                   | 1883-1943 <sup>d</sup>        | 108                                      | .....                                                  | 95                                               | 78                                               | .....                                     |
|        | Dayton.....AP        | 1002                   | 1940-1947                     | 99                                       | .....                                                  | .....                                            | .....                                            | .....                                     |
|        | Sandusky.....CO      | 608                    | 1878-1946                     | 105                                      | .....                                                  | 95                                               | 75                                               | .....                                     |
|        | Toledo.....CO        | 668                    | 1871-1947                     | 105                                      | .....                                                  | 95                                               | 76                                               | .....                                     |
| Okla.  | Toledo.....AP        | 626                    | 1940-1947                     | 100                                      | 91                                                     | .....                                            | .....                                            | .....                                     |
|        | Ardmore.....AP       | 762                    | 1935-1939                     | 110                                      | 99                                                     | .....                                            | .....                                            | .....                                     |
|        | Oklahoma City.....CO | 1264                   | 1890-1947                     | 113                                      | .....                                                  | 101                                              | 77                                               | 9.8                                       |
|        | Oklahoma City.....AP | 1311                   | 1939-1947                     | 109                                      | 99                                                     | .....                                            | .....                                            | .....                                     |
|        | Tulsa.....AP         | 686                    | 1932-1947                     | 109                                      | 100                                                    | 101                                              | 77                                               | .....                                     |
| Ore.   | Waynoka.....AP       | 1529                   | 1935-1939                     | 115                                      | 103                                                    | .....                                            | .....                                            | .....                                     |
|        | Arlington.....AP     | 881                    | 1935-1939                     | 111                                      | 95                                                     | .....                                            | .....                                            | .....                                     |
|        | Baker.....CO         | 3501                   | 1889-1947                     | 104                                      | .....                                                  | 90                                               | 68                                               | .....                                     |
|        | Baker.....AP         | 3374                   | 1939-1947                     | 103                                      | 90                                                     | .....                                            | .....                                            | .....                                     |
|        | Eugene.....CO        | 366                    | 1890-1942                     | 104                                      | .....                                                  | 90                                               | 68                                               | .....                                     |
|        | Eugene.....AP        | 368                    | 1942-1947                     | 105                                      | 88                                                     | .....                                            | .....                                            | .....                                     |
|        | Medford.....CO       | 1428                   | 1911-1929                     | 110                                      | .....                                                  | 95                                               | 70                                               | .....                                     |
|        | Medford.....AP       | 1343                   | 1929-1947                     | 115                                      | 95                                                     | .....                                            | .....                                            | .....                                     |
|        | Portland.....CO      | 98                     | 1874-1947                     | 107                                      | .....                                                  | 90                                               | 68                                               | 6.5                                       |
|        | Portland.....AP      | 25                     | 1940-1947                     | 105                                      | 87                                                     | .....                                            | .....                                            | .....                                     |
| Pa.    | Roseburg.....CO      | 523                    | 1877-1947                     | 109                                      | .....                                                  | 90                                               | 66                                               | .....                                     |
|        | Curwensville.....AP  | 2219                   | 1943-1947                     | 90                                       | 82                                                     | .....                                            | .....                                            | .....                                     |
|        | Erie.....CO          | 771                    | 1873-1946                     | 98                                       | .....                                                  | 93                                               | 75                                               | .....                                     |
|        | Erie.....AP          | 736                    | 1935-1939                     | 96                                       | 85                                                     | 95                                               | 75                                               | .....                                     |
|        | Harrisburg.....AP    | 339                    | 1935-1939                     | 103                                      | 91                                                     | .....                                            | .....                                            | .....                                     |
|        | Philadelphia.....CO  | 200                    | 1871-1947                     | 106                                      | .....                                                  | 95                                               | 78                                               | 9.7                                       |
|        | Philadelphia.....AP  | 18                     | 1940-1947                     | 100                                      | .....                                                  | .....                                            | .....                                            | .....                                     |
|        | Pittsburgh.....CO    | 929                    | 1875-1947                     | 103                                      | .....                                                  | 95                                               | 75                                               | 8.9                                       |
|        | Pittsburgh.....AP    | 1294                   | 1935-1947                     | 102                                      | 88                                                     | .....                                            | .....                                            | .....                                     |
|        | Reading.....CO       | 311                    | 1913-1947                     | 105                                      | .....                                                  | 95                                               | 75                                               | .....                                     |
|        | Scranton.....CO      | 877                    | 1901-1947                     | 103                                      | .....                                                  | 95                                               | 75                                               | .....                                     |
| R. I.  | Sunbury.....AP       | 448                    | 1935-1939                     | 101                                      | 89                                                     | .....                                            | .....                                            | .....                                     |
| S. C.  | Block Island.....CO  | 46                     | 1881-1947                     | 93                                       | .....                                                  | 95                                               | 75                                               | .....                                     |
|        | Providence.....CO    | 7                      | 1790-1947                     | 100                                      | .....                                                  | 93                                               | 75                                               | 9.5                                       |
|        | Charleston.....CO    | 59                     | 1871-1947                     | 104                                      | .....                                                  | 95                                               | 78                                               | 9.8                                       |
|        | Charleston.....AP    | 51                     | 1940-1947                     | 103                                      | 91                                                     | .....                                            | .....                                            | .....                                     |

TABLE 2. SUMMER CLIMATIC CONDITIONS\* (CONTINUED)  
Suggested Design Wet-Bulb and Dry-Bulb Temperatures

| COL. 1 | COL. 2                | COL. 3                            | COL. 4                           | COL. 5                                                  | COL. 6                                                                  | COL. 7                                                             | COL. 8                                                             | COL. 9                                                    |
|--------|-----------------------|-----------------------------------|----------------------------------|---------------------------------------------------------|-------------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|-----------------------------------------------------------|
| STATE  | STATION <sup>b</sup>  | ELE-<br>VATION <sup>c</sup><br>Ft | PERIOD OF<br>RECORD <sup>d</sup> | HIGHEST<br>TEMP.<br>EVER<br>RECORDED <sup>e</sup><br>°F | DESIGN<br>DRY-BULB<br>TEMP. ON<br>T.A.C. 2%<br>BASIS <sup>f</sup><br>°F | DESIGN<br>DRY-BULB<br>TEMP. IN<br>COMMON<br>USE <sup>g</sup><br>°F | DESIGN<br>WET-BULB<br>TEMP. IN<br>COMMON<br>USE <sup>h</sup><br>°F | AVERAGE<br>SUMMER<br>WIND<br>VELOCITY <sup>i</sup><br>MPH |
| S. C.  | Columbia.....CO       | 401                               | 1887-1947                        | 106                                                     | ...                                                                     | 95                                                                 | 75                                                                 | ...                                                       |
| S. D.  | Columbia.....AP       | 227                               | 1939-1947 <sup>d</sup>           | 104                                                     | ...                                                                     | 95                                                                 | 75                                                                 | 10.3                                                      |
|        | Huron.....CO          | 1342                              | 1881-1935 <sup>d</sup>           | 111                                                     | ...                                                                     | 95                                                                 | 75                                                                 | 7.9                                                       |
|        | Huron.....AP          | 1287                              | 1938-1947                        | 110                                                     | ...                                                                     | 95                                                                 | 76                                                                 | 5.6                                                       |
|        | Rapid City.....CO     | 3309                              | 1888-1947                        | 106                                                     | ...                                                                     | 95                                                                 | 75                                                                 | 5.7                                                       |
| Tenn.  | Chattanooga.....CO    | 952                               | 1879-1947                        | 103                                                     | ...                                                                     | 94                                                                 | 75                                                                 | 7.3                                                       |
|        | Chattanooga.....AP    | 675                               | 1940-1947 <sup>d</sup>           | 105                                                     | ...                                                                     | 95                                                                 | 75                                                                 | ...                                                       |
|        | Knoxville.....CO      | 1024                              | 1871-1942 <sup>d</sup>           | 104                                                     | ...                                                                     | 94                                                                 | 78                                                                 | ...                                                       |
|        | Knoxville.....AP      | 1007                              | 1942-1947                        | 102                                                     | ...                                                                     | 95                                                                 | 78                                                                 | ...                                                       |
|        | Memphis.....CO        | 348                               | 1872-1941                        | 103                                                     | ...                                                                     | 96                                                                 | 78                                                                 | ...                                                       |
|        | Memphis.....AP        | 267                               | 1941-1947                        | 105                                                     | ...                                                                     | 95                                                                 | 78                                                                 | ...                                                       |
|        | Nashville.....CO      | 714                               | 1871-1947                        | 106                                                     | ...                                                                     | 95                                                                 | 78                                                                 | ...                                                       |
|        | Nashville.....AP      | 610                               | 1939-1947                        | 104                                                     | ...                                                                     | 95                                                                 | 78                                                                 | ...                                                       |
| Texas  | Abilene.....CO        | 1748                              | 1885-1944 <sup>d</sup>           | 111                                                     | ...                                                                     | 100                                                                | 74                                                                 | ...                                                       |
|        | Abilene.....AP        | 1756                              | 1940-1947                        | 109                                                     | ...                                                                     | 97                                                                 | 72                                                                 | 11.8                                                      |
|        | Amarillo.....CO       | 3686                              | 1892-1941                        | 107                                                     | ...                                                                     | 100                                                                | 72                                                                 | ...                                                       |
|        | Amarillo.....AP       | 3595                              | 1941-1947                        | 106                                                     | ...                                                                     | 96                                                                 | 78                                                                 | ...                                                       |
|        | Austin.....CO         | 625                               | 1897-1942                        | 109                                                     | ...                                                                     | 100                                                                | 78                                                                 | ...                                                       |
|        | Austin.....AP         | 625                               | 1942-1947                        | 104                                                     | ...                                                                     | 100                                                                | 80                                                                 | 7.0                                                       |
|        | Brownsville.....CO    | 140                               | 1922-1943 <sup>d</sup>           | 102                                                     | ...                                                                     | 100                                                                | 80                                                                 | ...                                                       |
|        | Brownsville.....AP    | 25                                | 1943-1947                        | 100                                                     | ...                                                                     | 95                                                                 | 80                                                                 | ...                                                       |
|        | Corpus Christi.....CO | 21                                | 1887-1942                        | 105                                                     | ...                                                                     | 95                                                                 | 78                                                                 | 9.3                                                       |
|        | Corpus Christi.....AP | 45                                | 1943-1946                        | 101                                                     | ...                                                                     | 100                                                                | 78                                                                 | ...                                                       |
|        | Dallas.....CO         | 732                               | 1913-1940                        | 110                                                     | ...                                                                     | 99                                                                 | 78                                                                 | 8.4                                                       |
|        | Dallas.....AP         | 520                               | 1940-1947                        | 109                                                     | ...                                                                     | 100                                                                | 78                                                                 | ...                                                       |
|        | Del Rio.....CO        | 1020                              | 1905-1947                        | 111                                                     | ...                                                                     | 100                                                                | 69                                                                 | ...                                                       |
|        | El Paso.....CO        | 3792                              | 1887-1942                        | 106                                                     | ...                                                                     | 97                                                                 | 100                                                                | ...                                                       |
|        | El Paso.....AP        | 3956                              | 1939-1947                        | 108                                                     | ...                                                                     | 100                                                                | 78                                                                 | 9.5                                                       |
|        | Fort Worth.....CO     | 708                               | 1898-1939                        | 112                                                     | ...                                                                     | 95                                                                 | 80                                                                 | 8.7                                                       |
|        | Fort Worth.....AP     | 728                               | 1940-1947                        | 110                                                     | ...                                                                     | 95                                                                 | 80                                                                 | ...                                                       |
|        | Galveston.....CO      | 128                               | 1871-1947                        | 101                                                     | ...                                                                     | 95                                                                 | 80                                                                 | ...                                                       |
|        | Galveston.....AP      | 9                                 | 1939-1947                        | 101                                                     | ...                                                                     | 95                                                                 | 80                                                                 | ...                                                       |
|        | Houston.....CO        | 198                               | 1888-1947                        | 108                                                     | ...                                                                     | 93                                                                 | 78                                                                 | ...                                                       |
|        | Houston.....AP        | 73                                | 1932-1947                        | 105                                                     | ...                                                                     | 100                                                                | 78                                                                 | ...                                                       |
|        | Palestine.....CO      | 555                               | 1891-1947                        | 102                                                     | ...                                                                     | 95                                                                 | 79                                                                 | ...                                                       |
|        | Port Arthur.....CO    | 64                                | 1917-1947                        | 98                                                      | ...                                                                     | 100                                                                | 78                                                                 | 7.8                                                       |
|        | Port Arthur.....AP    | 21                                | 1944-1947                        | 101                                                     | ...                                                                     | 95                                                                 | 78                                                                 | ...                                                       |
|        | San Antonio.....CO    | 770                               | 1885-1941 <sup>d</sup>           | 107                                                     | ...                                                                     | 98                                                                 | 78                                                                 | ...                                                       |
|        | San Antonio.....AP    | 800                               | 1942-1947                        | 104                                                     | ...                                                                     | 98                                                                 | 78                                                                 | ...                                                       |
|        | Waco.....CO           | 513                               | 1931-1947                        | 111                                                     | ...                                                                     | 98                                                                 | 78                                                                 | ...                                                       |
|        | Wink.....CO           | 2811                              | 1935-1939                        | 110                                                     | ...                                                                     | 99                                                                 | 78                                                                 | ...                                                       |
| Utah   | Milford.....AP        | 5095                              | 1935-1939                        | 103                                                     | ...                                                                     | 94                                                                 | 65                                                                 | 9.8                                                       |
|        | Modena.....CO         | 5472                              | 1901-1947                        | 101                                                     | ...                                                                     | 95                                                                 | 65                                                                 | ...                                                       |
|        | Salt Lake City.....CO | 4346                              | 1874-1947                        | 105                                                     | ...                                                                     | 95                                                                 | 73                                                                 | 8.5                                                       |
|        | Salt Lake City.....AP | 4254                              | 1928-1947                        | 106                                                     | ...                                                                     | 90                                                                 | 73                                                                 | ...                                                       |
| Vt.    | Burlington.....CO     | 409                               | 1884-1943 <sup>d</sup>           | 100                                                     | ...                                                                     | 90                                                                 | 73                                                                 | ...                                                       |
|        | Burlington.....AP     | 335                               | 1943-1947                        | 101                                                     | ...                                                                     | 95                                                                 | 78                                                                 | ...                                                       |
| Va.    | Cape Henry.....CO     | 24                                | 1874-1947                        | 104                                                     | ...                                                                     | 95                                                                 | 75                                                                 | ...                                                       |
|        | Lynchburg.....CO      | 644                               | 1874-1944                        | 106                                                     | ...                                                                     | 95                                                                 | 75                                                                 | 10.1                                                      |
|        | Lynchburg.....AP      | 951                               | 1944-1947                        | 100                                                     | ...                                                                     | 95                                                                 | 78                                                                 | 6.4                                                       |
|        | Norfolk.....CO        | 91                                | 1871-1947                        | 105                                                     | ...                                                                     | 95                                                                 | 78                                                                 | ...                                                       |
|        | Richmond.....CO       | 180                               | 1897-1947                        | 107                                                     | ...                                                                     | 92                                                                 | 76                                                                 | ...                                                       |
|        | Richmond.....AP       | 172                               | 1929-1947                        | 104                                                     | ...                                                                     | 90                                                                 | 76                                                                 | ...                                                       |
|        | Roanoke.....AP        | 1194                              | 1935-1939                        | 103                                                     | ...                                                                     | 90                                                                 | 76                                                                 | ...                                                       |
| Wash.  | Ellensburg.....AP     | 1731                              | 1935-1939                        | 105                                                     | ...                                                                     | 90                                                                 | 85                                                                 | 65                                                        |
|        | North Bend.....CO     | 199                               | 1884-1947                        | 97                                                      | ...                                                                     | 85                                                                 | 65                                                                 | 1.7                                                       |
|        | Seattle.....CO        | 104                               | 1890-1947                        | 100                                                     | ...                                                                     | 81                                                                 | 65                                                                 | 6.6                                                       |
|        | Seattle.....AP        | 47                                | 1928-1947                        | 99                                                      | ...                                                                     | 93                                                                 | 65                                                                 | ...                                                       |
|        | Spokane.....CO        | 2030                              | 1881-1941 <sup>d</sup>           | 99                                                      | ...                                                                     | 92                                                                 | 64                                                                 | ...                                                       |
|        | Spokane.....AP        | 1974                              | 1941-1947                        | 104                                                     | ...                                                                     | 85                                                                 | 64                                                                 | ...                                                       |
|        | Tacoma.....CO         | 279                               | 1897-1947                        | 98                                                      | ...                                                                     | 95                                                                 | 65                                                                 | ...                                                       |
|        | Tacoma.....AP         | 110                               | 1883-1947                        | 88                                                      | ...                                                                     | 95                                                                 | 65                                                                 | ...                                                       |
|        | Tacoma Island.....CO  | 1160                              | 1928-1946                        | 110                                                     | ...                                                                     | 95                                                                 | 65                                                                 | ...                                                       |
|        | Yakima.....AP         | 1066                              | 1944-1947                        | 103                                                     | ...                                                                     | 95                                                                 | 75                                                                 | 5.3                                                       |
| W. Va. | Parkersburg.....CO    | 685                               | 1888-1947                        | 106                                                     | ...                                                                     | 95                                                                 | 75                                                                 | 9.3                                                       |
| Wis.   | Green Bay.....CO      | 598                               | 1888-1947                        | 104                                                     | ...                                                                     | 95                                                                 | 75                                                                 | 6.4                                                       |
|        | La Crosse.....CO      | 725                               | 1872-1947                        | 106                                                     | ...                                                                     | 91                                                                 | 75                                                                 | 7.9                                                       |
|        | La Crosse.....AP      | 677                               | 1943-1947                        | 98                                                      | ...                                                                     | 95                                                                 | 75                                                                 | ...                                                       |
|        | Madison.....CO        | 1008                              | 1888-1947                        | 107                                                     | ...                                                                     | 89                                                                 | 75                                                                 | 9.8                                                       |
|        | Madison.....AP        | 884                               | 1935-1939                        | 106                                                     | ...                                                                     | 95                                                                 | 75                                                                 | ...                                                       |
|        | Milwaukee.....CO      | 744                               | 1870-1947                        | 105                                                     | ...                                                                     | 87                                                                 | 65                                                                 | 9.3                                                       |
|        | Milwaukee.....AP      | 707                               | 1927-1947                        | 106                                                     | ...                                                                     | 95                                                                 | 65                                                                 | ...                                                       |
| Wyo.   | Cheyenne.....CO       | 6144                              | 1873-1935                        | 100                                                     | ...                                                                     | 89                                                                 | 65                                                                 | ...                                                       |
|        | Cheyenne.....AP       | 6161                              | 1935-1947                        | 100                                                     | ...                                                                     | 95                                                                 | 65                                                                 | ...                                                       |
|        | Lander.....CO         | 5448                              | 1891-1946                        | 102                                                     | ...                                                                     | 97                                                                 | 65                                                                 | ...                                                       |
|        | Lander.....AP         | 5568                              | 1936-1947                        | 97                                                      | ...                                                                     | 87                                                                 | 65                                                                 | ...                                                       |
|        | Rock Springs.....AP   | 6746                              | 1932-1942                        | 98                                                      | ...                                                                     | 87                                                                 | 65                                                                 | ...                                                       |

TABLE 2. SUMMER CLIMATIC CONDITIONS\* (CONCLUDED)  
Suggested Design Wet-Bulb and Dry-Bulb Temperatures

| COL. 1                         | COL. 2                  | COL. 3                      | COL. 4                           | COL. 5                                             | COL. 6              | COL. 7  | COL. 8  | COL. 9   | COL. 10                                           | COL. 11                                           | COL. 12                                                       |
|--------------------------------|-------------------------|-----------------------------|----------------------------------|----------------------------------------------------|---------------------|---------|---------|----------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------------------|
| PROV. OF CAN. ADA <sup>j</sup> | STATION <sup>b</sup>    | ELE-<br>VATION <sup>c</sup> | PERIOD OF<br>RECORD <sup>d</sup> | HIGHEST<br>TEMP.<br>ON<br>RE-<br>CORD <sup>e</sup> | Summer Design Temp. |         |         |          | TEMP. IN<br>COM-<br>MON<br>USE <sup>f</sup><br>°F | TEMP. IN<br>COM-<br>MON<br>USE <sup>f</sup><br>°F | AVG. SUM-<br>MER<br>WIND<br>VELO-<br>CITY <sup>g</sup><br>MPH |
|                                |                         |                             |                                  |                                                    | 1%<br>F             | 2%<br>F | 5%<br>F | 10%<br>F |                                                   |                                                   |                                                               |
| Alta.                          | Calgary.....AP          | 3540°                       | 1921-1950                        | 97                                                 | 86                  | 83      | 80      | 77       | 90                                                | 66                                                | 9.7                                                           |
|                                | Edmonton.....AP         | 2219°                       | 1921-1950                        | 99                                                 | 87                  | 83      | 80      | 77       | 90                                                | 68                                                | 8.9                                                           |
|                                | Medicine hat.....AP     | 2365°                       | 1921-1950                        | 106                                                | 92                  | 89      | 86      | 82       | 90                                                | 65                                                | 9.1                                                           |
| B.C.                           | Vancouver.....AP        | 22°                         | 1938-1950                        | 87                                                 | 80                  | 77      | 75      | 72       | 80                                                | 67                                                | 7.8                                                           |
| Man.                           | Winnipeg.....AP         | 786°                        | 1921-1950                        | 103                                                | 89                  | 86      | 84      | 81       | 90                                                | 71                                                | 11.5                                                          |
| N.B.                           | Fredericton.....CO      | 184°                        | 1921-1950                        | 102                                                | 89                  | 87      | 84      | 81       | 90                                                | 75                                                | ...                                                           |
|                                | Saint John.....CO       | 119°                        | 1921-1950                        | 93                                                 | 80                  | 77      | 75      | 72       | 75                                                | 72                                                | 7.9                                                           |
| N.S.                           | Halifax.....CO          | 83°                         | 1921-1950                        | 94                                                 | 80                  | 78      | 76      | 73       | 90                                                | 75                                                | 6.6                                                           |
|                                | Sydney.....AP           | 197°                        | 1921-1950                        | 95                                                 | 85                  | 83      | 80      | 75       | 75                                                | 75                                                | 9.9                                                           |
| Ont.                           | Fort William.....AP     | 644°                        | 1921-1950                        | 104                                                | 86                  | 82      | 79      | 76       | 76                                                | 76                                                | 8.4                                                           |
|                                | North Bay.....AP        | 1210°                       | 1925-1950                        | 99                                                 | 83                  | 80      | 77      | 74       | 74                                                | 74                                                | 9.6                                                           |
|                                | Ottawa.....AP           | 339°                        | 1921-1950                        | 102                                                | 89                  | 86      | 84      | 81       | 90                                                | 75                                                | 8.9                                                           |
|                                | Sault Ste. Marie.....CO | 635°                        | 1921-1950                        | 99                                                 | 83                  | 80      | 77      | 74       | 93                                                | 75                                                | ...                                                           |
|                                | Toronto.....CO          | 379°                        | 1921-1950                        | 105                                                | 88                  | 86      | 83      | 81       | 93                                                | 75                                                | 8.1                                                           |
|                                | Toronto.....AP          | 578°                        | 1938-1950                        | 101                                                | 90                  | 87      | 84      | 81       | 94                                                | 74                                                | 8.7                                                           |
| P.E.I.                         | Charlottetown.....CO    | 74°                         | 1921-1950                        | 98                                                 | 82                  | 79      | 77      | 74       | 90                                                | 75                                                | 9.9                                                           |
| Que.                           | Montreal.....CO         | 187°                        | 1921-1950                        | 97                                                 | 87                  | 84      | 82      | 79       | 90                                                | 75                                                | 9.5                                                           |
|                                | Montreal.....AP         | 98°                         | 1942-1950                        | 96                                                 | 88                  | 85      | 83      | 80       | 90                                                | 75                                                | 9.0                                                           |
|                                | Quebec.....CO           | 296°                        | 1921-1950                        | 96                                                 | 85                  | 82      | 80      | 77       | 90                                                | 75                                                | 12.4                                                          |
| Sask.                          | Regina.....AP           | 1884°                       | 1921-1950                        | 111                                                | 91                  | 88      | 85      | 81       | 90                                                | 71                                                | 10.7                                                          |
|                                | Saskatoon.....AP        | 1645°                       | 1921-1950                        | 104                                                | 92                  | 89      | 86      | 81       | 90                                                | 70                                                | 10.7                                                          |

## Notes for Table 2

- \* Data compiled from U. S. Weather Bureau Data and various other sources.
- <sup>b</sup> Column 2. The station designation AP or CO indicates airport or city office station, respectively.
- <sup>c</sup> Column 3. The elevations marked c are ground elevations of the station. All other elevations given are the actual elevations of the thermometer bulb above mean sea level, corrected to 1948.
- <sup>d</sup> The periods of record indicated apply only to the highest temperature ever recorded shown in Column 5, and do not necessarily include all of the summer months of the first year indicated. The last year indicated includes July or August, except those marked d which terminate prior to July of that year.
- <sup>e</sup> It should be noted that Column 6 in the United States section of the table applies only to airports, as these data for city stations are not available at this time. The temperature shown is the maximum hourly outdoor temperature which has been equalled or exceeded 24 percent of the total hours of June, July, August and September for the 5-year period 1935-1939 inclusive. It is pointed out that in most cases the airport stations are outside of the city, and that these data would apply primarily to rural areas.
- <sup>f</sup> Columns 7 and 8 in the United States section and Columns 9 and 10 in the Canadian section of the table record wet and dry-bulb temperatures in use by A.S.H.A.E. members as reported by Chapter secretaries for various stations. Where such values were not available, the design temperatures published by API or obtained from various other sources have been inserted.
- <sup>g</sup> The average wind velocities in Column 9 in the United States section were furnished by the U. S. Weather Bureau, corrected to 1948. In general these velocities are averages for the months of June through September.
- <sup>h</sup> The bulletin published by the A.S.H.A.E. for the annual weather data of Detroit indicates 73 F as the design wet-bulb temperature which has been equalled or exceeded 5 percent of the hours for period 1935-39.
- <sup>i</sup> Blank spaces indicate data not available.
- <sup>j</sup> The data for Canada were compiled by D. W. Boyd and Morley Thomas from the records of the Meteorological Division, National Research Council of Canada.
- <sup>k</sup> The highest temperature ever recorded in the Canadian section of the table is for the 30 year period, 1921-1950, where available. In some cases the stations have been relocated and in a few instances some year, are missing.
- <sup>l</sup> In the Canadian section of the table, the summer design dry-bulb temperatures for the basis of 1, 2, 5 and 10 percent are the Fahrenheit temperature values at or above which these percentages of all the July hourly outdoor temperatures occur, for the years 1941-1950 inclusive.
- <sup>m</sup> Most of the wind speeds are based on the periods ending in 1947 which are somewhat shorter than the periods for the highest temperatures. The three months June, July and August were used.

## INSTANTANEOUS HEAT LOAD

The total cooling load is frequently divided for convenience into two components, *sensible heat* and *latent heat*. While this subdivision is not imperative, past practice has found it convenient.

A gain of *sensible heat* is considered to occur when there is a direct addi-

tion of heat to the enclosure by any one or all of the mechanisms of conduction, convection, and radiation. A gain of *latent heat* is considered to occur when there is an addition of water vapor to the air of the enclosure. For example, when the humidity in an enclosure is increased by water vapor emitted by human occupants, or by water vapor resulting from a process such as cooking, the heat required to vaporize the water does *not* come from the air. Maintenance of a constant humidity ratio in a sealed enclosure requires the condensation of water vapor in the cooling apparatus at a rate equal to its rate of addition within the enclosure. The rate of heat removal from this condensing vapor would be substantially equal to the product of the rate of condensation and the latent heat of condensation; this product, expressed in Btu per hour, would be called a *latent heat load*.

As a further example, the infiltration of outdoor air with a high dry-bulb temperature and a high humidity ratio, and the corresponding escape of room air at a lower dry-bulb temperature and a lower humidity ratio, would increase both the *sensible heat load* and the *latent heat load*.

### SOLAR RADIATION

#### Magnitude of Solar Radiation

If a plane surface were set perpendicular to the sun's rays (*i.e.*, for *normal incidence*) outside the earth's atmosphere, it would receive solar radiation of about 420 Btu per (hr) (sq ft). A similarly oriented surface, at the surface of the earth, would receive considerably less solar energy because a large part of the radiation is scattered in passing through the air, moisture, smoke, and dust which comprise the earth's atmosphere, and also, because some of the atmospheric constituents, notably water vapor, ozone, and carbon dioxide, absorb solar radiation. The intensity of solar radiation varies with wave length, reaching a peak at about 0.5 microns (a micron equals 1/1000 of a millimeter) and, for practical purposes, is confined to the radiation spectrum between 0.3 and 2.3 microns. The effects of scattering and absorption vary with the wave length, but to make an exact analysis of these phenomena is impracticable in air-conditioning estimates. The important principle to remember is that the total radiation  $I_t$ , received by a surface at the earth, is the sum of  $I_D$  and  $I_d$ , where

$I_D = K I_{Dn}$  = the *direct* or *beamed* solar radiation, Btu per (hour) (square foot of receiving surface).

$I_{Dn}$  = the direct solar radiation normal to the sun's rays, Btu per (hour) (square foot of receiving surface).

$I_d$  = the *sky* or *diffuse* solar radiation, Btu per (hour) (square foot of receiving surface). This comes principally from the atmosphere itself as a consequence of scattering. Vertical surfaces also receive solar radiation by reflection of direct and diffuse radiation from the ground and other objects. Such radiation is usually diffuse. The diffuse radiation strikes at all angles.

$I_t$  = total incident solar radiation, Btu per (hour) (square foot of receiving surface).

$K$  = cosine of the angle of incidence,  $\theta$ . For a vertical surface,  $\theta$  is defined in Fig. 1.

Standardized, practical-purpose values of the *direct* solar radiation  $I_{Dn}$  incident upon a plane *perpendicular* to the sun's rays at the earth's surface,

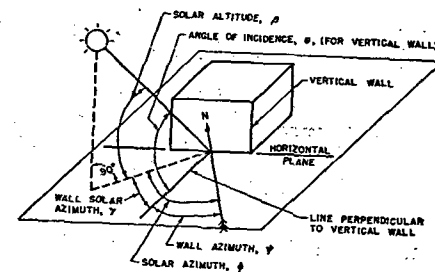


FIG. 1. DEFINITION OF SOLAR ANGLES

have been proposed by Moon.<sup>4</sup> Table 4 gives these values. They are representative of a *clear* summer day at sea-level elevation, and are nearly identical with values derived from suggested design sol-air temperatures for Lincoln, Nebraska.<sup>5</sup> Values typical of a humid industrial area derived from sol-air data for New York City<sup>6</sup> are also given in Table 4. Day-to-day changes in the amount of dust and water vapor in the atmosphere cause large differences in solar intensity values observed on cloudless days at a given locality. For example, it has been observed in Cleveland that

TABLE 3. OUTDOOR AIR REQUIREMENTS

| APPLICATION                               | SMOKING      | CFM PER PERSON <sup>b</sup> |                      | CFM PER SQ <sup>b</sup> FT OF FLOOR |
|-------------------------------------------|--------------|-----------------------------|----------------------|-------------------------------------|
|                                           |              | Recommended                 | Minimum <sup>c</sup> | Minimum <sup>c</sup>                |
| Apartment Average                         | Some         | 20                          | 10                   | ...                                 |
| DeLuxe                                    | Some         | 20                          | 10                   | ...                                 |
| Banking Space                             | Occasional   | 10                          | 7½                   | ...                                 |
| Barber Shops                              | Occasional   | 15                          | 10                   | ...                                 |
| Beauty Parlors                            | Occasional   | 10                          | 7½                   | ...                                 |
| Brokers' Board Rooms                      | Very Heavy   | 50                          | 20                   | ...                                 |
| Cocktail Bars                             | Very Heavy   | 40                          | 25                   | ...                                 |
| Corridors (Supply or Exhaust)             | None         | 7½                          | 5                    | 0.25                                |
| Department Stores                         | None         | 50                          | 30                   | 0.05                                |
| Directors' Rooms                          | Extensive    | 10                          | 7½                   | ...                                 |
| Drug Stores <sup>d</sup>                  | Considerable | 10                          | 7½                   | 0.10                                |
| Factories <sup>d, e</sup>                 | None         | 7½                          | 5                    | ...                                 |
| Five and Ten Cent Stores                  | None         | 10                          | 7½                   | ...                                 |
| Funeral Parlors                           | None         | 10                          | 7½                   | 1.0                                 |
| Garages <sup>d</sup>                      | None         | ...                         | ...                  | ...                                 |
| Hospitals Operating Rooms <sup>f, g</sup> | None         | 30                          | 25                   | 2.0                                 |
| Private Rooms                             | None         | 20                          | 10                   | 0.33                                |
| Wards                                     | None         | 30                          | 25                   | 0.33                                |
| Hotel Rooms                               | Heavy        | ...                         | ...                  | 4.0                                 |
| Kitchens Restaurant                       | Some         | 20                          | 15                   | 2.0                                 |
| Residence                                 | Some         | ...                         | ...                  | ...                                 |
| Laboratories <sup>h</sup>                 | Very Heavy   | 50                          | 30                   | 1.25                                |
| Meeting Rooms                             | Some         | 15                          | 10                   | ...                                 |
| Offices General                           | Private      | 25                          | 15                   | 0.25                                |
| Private                                   | Private      | 30                          | 25                   | 0.25                                |
| Restaurant Cafeteria <sup>i</sup>         | Considerable | 12                          | 10                   | ...                                 |
| Dining Room <sup>j</sup>                  | Considerable | 15                          | 12                   | 2.0                                 |
| School Rooms <sup>k</sup>                 | None         | 10                          | 7½                   | ...                                 |
| Shop, Retail                              | None         | 7½                          | 5                    | ...                                 |
| Theater <sup>l</sup>                      | None         | 15                          | 10                   | ...                                 |
| Theater                                   | Some         | ...                         | ...                  | ...                                 |
| Toilets <sup>d</sup> (Exhaust)            | Some         | ...                         | ...                  | ...                                 |

<sup>a</sup> Taken from present-day practice. <sup>b</sup> This is contaminant-free air. <sup>c</sup> When minimum is used, take the larger of the two. <sup>d</sup> See local codes which may govern. <sup>e</sup> May be governed by exhaust. <sup>f</sup> May be governed by special sources of contamination or local codes. <sup>g</sup> All outside air recommended to overcome explosion hazard of anesthetics. See National Board of Fire Underwriters' pamphlet No. 56.

TABLE 4. Values of  $I_{Dn}$ , DIRECT SOLAR RADIATION RECEIVED AT NORMAL INCIDENCE AT THE EARTH'S SURFACE, AND VALUES OF  $I_a$ , DIFFUSE OR SKY SOLAR RADIATION, RECEIVED BY VARIOUSLY ORIENTED SURFACES

| BTU PER (HOUR) (SQUARE FOOT)              |                                                 |                                            |    |    |    |        |                                                 |                                            |    |    |    |        |  |
|-------------------------------------------|-------------------------------------------------|--------------------------------------------|----|----|----|--------|-------------------------------------------------|--------------------------------------------|----|----|----|--------|--|
| SOLAR<br>ALTITUDE<br>$\beta$ ,<br>DEGREES | FOR CLEAR ATMOSPHERES                           |                                            |    |    |    |        | FOR INDUSTRIAL ATMOSPHERES                      |                                            |    |    |    |        |  |
|                                           | DIRECT <sup>a</sup><br>NORMAL<br>RADI-<br>ATION | DIFFUSE OR SKY<br>RADIATION <sup>b,c</sup> |    |    |    |        | DIRECT <sup>a</sup><br>NORMAL<br>RADI-<br>ATION | DIFFUSE OR SKY<br>RADIATION <sup>b,c</sup> |    |    |    |        |  |
|                                           |                                                 | N                                          | E  | S  | W  | HORIZ. |                                                 | N                                          | E  | S  | W  | HORIZ. |  |
|                                           |                                                 |                                            |    |    |    |        |                                                 |                                            |    |    |    |        |  |
| AM →<br>↓                                 |                                                 |                                            |    |    |    |        |                                                 |                                            |    |    |    |        |  |
| 5                                         | 67                                              | 6                                          | 11 | 4  | 4  | 7      | 34                                              | 4                                          | 11 | 5  | 3  | 9      |  |
| 10                                        | 123                                             | 11                                         | 20 | 8  | 7  | 14     | 58                                              | 8                                          | 22 | 9  | 7  | 18     |  |
| 15                                        | 186                                             | 14                                         | 27 | 11 | 10 | 19     | 80                                              | 11                                         | 28 | 13 | 9  | 24     |  |
| 20                                        | 197                                             | 15                                         | 32 | 13 | 12 | 23     | 103                                             | 13                                         | 36 | 17 | 12 | 31     |  |
| 25                                        | 218                                             | 16                                         | 35 | 15 | 13 | 26     | 121                                             | 16                                         | 43 | 21 | 16 | 38     |  |
| 30                                        | 235                                             | 17                                         | 36 | 17 | 15 | 28     | 136                                             | 18                                         | 47 | 24 | 18 | 44     |  |
| 35                                        | 248                                             | 17                                         | 36 | 19 | 16 | 30     | 148                                             | 19                                         | 50 | 27 | 21 | 48     |  |
| 40                                        | 258                                             | 18                                         | 36 | 21 | 17 | 31     | 158                                             | 20                                         | 50 | 30 | 23 | 52     |  |
| 45                                        | 266                                             | 19                                         | 35 | 23 | 18 | 32     | 165                                             | 21                                         | 49 | 31 | 25 | 55     |  |
| 50                                        | 273                                             | 19                                         | 33 | 25 | 19 | 33     | 172                                             | 22                                         | 47 | 34 | 27 | 58     |  |
| 60                                        | 283                                             | 21                                         | 28 | 27 | 21 | 34     | 181                                             | 22                                         | 41 | 37 | 30 | 63     |  |
| 70                                        | 289                                             | 22                                         | 23 | 29 | 23 | 35     | 188                                             | 23                                         | 34 | 41 | 34 | 69     |  |
| 80                                        | 292                                             | —                                          | —  | —  | —  | —      | 195                                             | —                                          | —  | —  | —  | —      |  |
| 90                                        | 294                                             | —                                          | —  | —  | —  | —      | 200                                             | —                                          | —  | —  | —  | —      |  |
| PM →                                      |                                                 | N                                          | W  | S  | E  | HORIZ. |                                                 | N                                          | W  | S  | E  | HORIZ. |  |

<sup>a</sup> Moon's<sup>1</sup> proposed standard for sea level, 20 mm precipitable water vapor, 300 dust particles per cu cm, 2.8 mm Hg partial pressure of ozone.

<sup>b</sup> For 40 deg north latitude on about August 1.

<sup>c</sup> Based on observations by ASHAE Laboratory at Cleveland on cloudless days during which the observed normal incidence values closely approximated the normal incidence values tabulated.

<sup>d</sup> Derived from recommended design sol-air temperatures<sup>4</sup> for New York City for a horizontal surface with absorptivity of 1.0.

values of the order of those given for industrial atmospheres are usually associated with dry-bulb and wet-bulb temperatures near the design values of 95 F and 75 F (67 F dew-point). On the other hand, values approaching or exceeding those for a clear atmosphere are often encountered during Cleveland summers, but with dew-point and maximum dry-bulb temperatures 10 to 15 deg lower. Considerable judgment, therefore, is required in selecting solar intensity values for design purposes.

Data regarding the irradiation of vertical and horizontal surfaces by diffuse or sky radiation are few. Suggested design values for a 40-deg latitude on August 1 (18 deg declination, north) are given in Table 4 for the two types of atmospheres. These are based upon observations made on cloudless days in Cleveland over a period of several summers. Since less extensive data were available for industrial atmospheres, there is more uncertainty regarding these values. In both instances, the values include an unknown amount of ground reflection, which may be expected to vary with location. It should be noted that clouds which do not obscure the sun tend to increase diffuse radiation values. Nearby buildings may reduce diffuse irradiation by partial shading.

#### Calculation Tables

The irradiation of a surface by the sun is the product of  $I_{Dn}$ , the direct normal radiation (see Table 4), and the cosine  $K$  of the incident angle,  $\theta$ . For horizontal surfaces, the cosine  $K$  equals the sine of the solar altitude.

TABLE 5. VALUES OF  $K$ , THE COSINE OF THE INCIDENT ANGLE, FOR VARIOUSLY ORIENTED WALLS AND A HORIZONTAL SURFACE  
Computed for 18 Deg Declination, North (August 1)

| LATITUDE     | SUN TIME      |      | COSINE K OF THE INCIDENT ANGLE |       |       |       |       |    |        |
|--------------|---------------|------|--------------------------------|-------|-------|-------|-------|----|--------|
|              | AM →          | PM → | N                              | NE    | E     | SE    | S     | SW | HORIZ. |
|              |               |      |                                |       |       |       |       |    |        |
| 30 Deg NORTH | 6 a.m. 6 p.m. |      | 0.267                          | 0.862 | 0.952 | 0.484 |       |    |        |
|              | 7 5           |      | 0.144                          | 0.752 | 0.919 | 0.548 |       |    | 0.156  |
|              | 8 4           |      | 0.030                          | 0.604 | 0.824 | 0.561 |       |    | 0.387  |
|              | 9 3           |      |                                | 0.427 | 0.672 | 0.524 | 0.068 |    | 0.566  |
|              | 10 2          |      |                                |       |       |       |       |    | 0.737  |
|              | 11 1          |      | 0.234                          | 0.478 | 0.438 | 0.144 |       |    | 0.866  |
|              | 12            |      | 0.039                          | 0.246 | 0.310 | 0.192 |       |    | 0.951  |
|              |               |      |                                | 0.000 | 0.147 | 0.208 | 0.147 |    | 0.978  |
| 40 Deg NORTH | 5 a.m. 7 p.m. |      | 0.406                          | 0.924 | 0.914 | 0.358 |       |    | 0.009  |
|              | 6 6           |      | 0.237                          | 0.840 | 0.951 | 0.505 |       |    | 0.199  |
|              | 7 5           |      | 0.079                          | 0.705 | 0.919 | 0.594 |       |    | 0.391  |
|              | 8 4           |      |                                | 0.533 | 0.824 | 0.631 | 0.069 |    | 0.566  |
|              | 9 3           |      |                                |       |       |       |       |    |        |
|              | 10 2          |      | 0.337                          | 0.673 | 0.614 | 0.196 |       |    | 0.713  |
|              | 11 1          |      | 0.129                          | 0.475 | 0.542 | 0.292 |       |    | 0.829  |
|              | 12            |      |                                | 0.246 | 0.424 | 0.354 | 0.075 |    | 0.903  |
|              |               |      |                                | 0.000 | 0.265 | 0.375 | 0.265 |    | 0.927  |
| 50 Deg NORTH | 5 a.m. 7 p.m. |      | 0.385                          | 0.922 | 0.920 | 0.378 |       |    | 0.078  |
|              | 6 6           |      | 0.199                          | 0.813 | 0.951 | 0.532 |       |    | 0.233  |
|              | 7 5           |      | 0.010                          | 0.656 | 0.918 | 0.643 |       |    | 0.399  |
|              | 8 4           |      |                                | 0.465 | 0.824 | 0.700 | 0.166 |    | 0.645  |
|              | 9 3           |      |                                |       |       |       |       |    |        |
|              | 10 2          |      | 0.252                          | 0.673 | 0.699 | 0.316 |       |    | 0.669  |
|              | 11 1          |      | 0.030                          | 0.475 | 0.642 | 0.433 |       |    | 0.766  |
|              | 12            |      |                                | 0.247 | 0.532 | 0.505 | 0.183 |    | 0.829  |
|              |               |      |                                | 0.000 | 0.375 | 0.530 | 0.375 |    | 0.848  |
|              | PM →          |      | N                              | NW    | W     | SW    | S     | SE | HORIZ. |

For vertical walls,  $K$  is a function of the solar altitude  $\beta$  and the wall solar azimuth  $\gamma$ , thus

$$K = \cos \theta = \cos \beta \cos \gamma \quad (1)$$

These three angles are defined in Fig. 1. Values of  $K$  are given in Table 5 and values of  $\beta$  and  $\gamma$  are given in Table 6 for 18 deg north declination (August 1).

To compute  $K$  values for orientations other than those given in Table 5, third angle  $\phi$ , the solar azimuth, is required. In this discussion,  $\phi$  will be measured east from south in the morning, and west from south in the afternoon. Hence,  $\phi$  values are equal to 90 deg minus the  $\gamma$  values for an east or west facing wall, except when Table 6 shows the south walls to be in the shade. In this case  $\phi$  equals  $90 + \gamma$ , that is,  $\phi$  is greater than 90 deg.

The wall azimuth  $\psi$  is the angle, measured east from south to the perpendicular to the wall for walls which have an easterly component, and west from south for those having a westerly component. For example,  $\psi$  for a wall facing northeast is 135 deg.

The wall solar azimuth  $\gamma$  may be found according to the following schedule:

For walls facing east of south:

$$\gamma = \phi - \psi \text{ a.m.}$$

$$\gamma = \phi + \psi \text{ p.m.}$$

For walls facing west of south:

$$\gamma = \phi + \psi \text{ a.m.}$$

$$\gamma = \phi - \psi \text{ p.m.}$$

Treat negative values of  $\gamma$  as if they were positive. If  $\gamma$  is greater than 90 deg, the wall is in the shade.

TABLE 6. VALUES OF THE WALL SOLAR AZIMUTH,  $\gamma$ , FOR VARIOUSLY ORIENTED WALLS AND SOLAR ALTITUDE  
Computed for 18 Deg Declination, North (August 1)

| LATITUDE     | SUN TIME |        | SOLAR ALTITUDE $\beta$ DEGREES | AZIMUTH ANGLE $\gamma$ , DEGREES |       |    |    |       |       |  |
|--------------|----------|--------|--------------------------------|----------------------------------|-------|----|----|-------|-------|--|
|              | AM →     |        |                                | N                                | NE    | E  | SE | S     | SW    |  |
| 80 DEG NORTH | 6 a.m.   | 6 p.m. | 9.0                            | 74                               | 29    | 16 | 61 |       |       |  |
|              | 7        | 5      | 21.5                           | 81                               | 36    | 9  | 54 |       |       |  |
|              | 8        | 4      | 34.5                           | 88                               | 43    | 2  | 47 | shade |       |  |
|              | 9        | 3      | 47.5                           | shade                            | 51    | 6  | 39 | 84    |       |  |
|              | 10       | 2      | 60.0                           |                                  | 62    | 17 | 28 | 73    |       |  |
|              | 11       | 1      | 72.0                           |                                  | 83    | 38 | 7  | 52    | shade |  |
|              | 12       |        | 78.0                           |                                  | shade | 90 | 45 | 0     | 45    |  |
| 40 DEG NORTH | 5 a.m.   | 7 p.m. | 0.5                            | 66                               | 21    | 24 | 69 |       |       |  |
|              | 6        | 6      | 11.5                           | 76                               | 31    | 14 | 59 |       |       |  |
|              | 7        | 5      | 23.0                           | 86                               | 40    | 5  | 50 | shade |       |  |
|              | 8        | 4      | 34.5                           | shade                            | 50    | 5  | 40 | 85    |       |  |
|              | 9        | 3      | 45.5                           |                                  | 61    | 16 | 29 | 74    | shade |  |
|              | 10       | 2      | 56.0                           |                                  | 76    | 31 | 14 | 59    | 80    |  |
|              | 11       | 1      | 64.5                           |                                  | shade | 55 | 10 | 35    | 45    |  |
| 50 DEG NORTH | 5 a.m.   | 7 p.m. | 4.5                            | 67                               | 22    | 23 | 68 |       |       |  |
|              | 6        | 6      | 13.5                           | 78                               | 33    | 12 | 57 |       |       |  |
|              | 7        | 5      | 23.5                           | 90                               | 45    | 0  | 45 | 90    |       |  |
|              | 8        | 4      | 33.0                           | shade                            | 57    | 12 | 33 | 78    |       |  |
|              | 9        | 3      | 42.0                           |                                  | 70    | 25 | 20 | 65    | shade |  |
|              | 10       | 2      | 50.0                           |                                  | 87    | 42 | 3  | 48    | 71    |  |
|              | 11       | 1      | 56.0                           |                                  | shade | 64 | 19 | 28    | 45    |  |
|              | 12       |        | 58.0                           |                                  |       | 90 | 45 | 0     |       |  |
|              | PM →     |        |                                | N                                | NW    | W  | SW | S     | SE    |  |

Values of  $K$  for other seasons and latitudes may be found in the literature,<sup>7</sup> or may be computed from data given in *Hydrographic Office Bulletin* No. 214, Tables of Computed Altitude and Azimuth<sup>8</sup> and the Ephemeris of the Sun.<sup>9</sup> Table 7 shows the variation of solar declination during the months ordinarily requiring cooling.

**Example 1:** Find the solar azimuth  $\phi$  at 6:30 p.m. at 40 deg north latitude on August 1st.

**Solution:** From Table 6 in the column of  $\gamma$  for a wall facing west  $\phi$  for 6:00 p.m. is 90 + 14 = 104 deg, and at 7:00 p.m. is 90 + 24 = 114 deg. By interpolation,  $\phi$  for 6:30 p.m. is 109 deg west of south (at 5:30 a.m.  $\phi$  would be 109 deg east of south.)

**Example 2:** Find  $K$  for a wall facing 18 deg east of south at 10:00 a.m. on August 1 at 50 deg north latitude.

**Solution:** The wall azimuth is 18 deg. The solar azimuth is 48 deg east (Table 6). The wall solar azimuth is 48 - 18 or 30 deg. From Table 6,  $\beta$  is 50 deg. Then

$$K = \cos \beta \cos \gamma = \cos 50 \times \cos 30 = 0.643 \times 0.866 = 0.557.$$

TABLE 7. APPROXIMATE SOLAR DECLINATIONS IN DEGREES

| DATE     | DECLINATION | DATE    | DECLINATION | DATE     | DECLINATION |
|----------|-------------|---------|-------------|----------|-------------|
| April 1  | 4.5         | June 1  | 22.0        | Aug. 1   | 18.0        |
| April 15 | 10.0        | June 15 | 23.5        | Aug. 15  | 14.0        |
| May 1    | 15.0        | July 1  | 23.0        | Sept. 1  | 8.5         |
| May 15   | 19.0        | July 15 | 21.5        | Sept. 15 | 3.0         |

**Example 3:** Find  $K$  for the wall in *Example 2* at 3:00 p.m.

**Solution:** The solar azimuth is 65 deg west. The wall solar azimuth is therefore 65 + 18 = 83 deg. The angle  $\beta$  is 42 deg.

$$K = \cos 42 \times \cos 83 = 0.743 \times 0.122 = 0.091.$$

**Example 4:** Find the total solar irradiation for the wall for the conditions of *Example 2*.

**Solution:** Use clear atmosphere solar intensities. At 50 deg altitude, the direct normal radiation is 273 Btu per (hr) (sq ft). Then,

$$I_D = K \times I_{Dn} = 0.557 \times 273 = 152.0 \text{ Btu per (hr) (sq ft).}$$

By linear interpolation, the diffuse irradiation is

$$I_d = 25 + \frac{1}{3} (33 - 25) = 26.6 \text{ Btu per (hr) (sq ft).}$$

The total solar irradiation is

$$I_t = 152.0 + 26.6 = 178.6 \text{ Btu per (hr) (sq ft).}$$

### PERIODIC HEAT FLOW THROUGH WALLS AND ROOFS

The calculation of heat flow, through a structural section of a building exposed to the weather, requires consideration of the diurnal cycles of solar irradiation and air temperature. These cycles and other factors lead to a periodic variation in the instantaneous rate of heat flow into the weather surface, and a related periodic variation in the rate of heat flow into the air conditioned space. Because of heat capacity and other factors, these heat flow cycles are, in general, out of time phase and unequal in amplitude.

In order to calculate the rate of heat entry into the weather surface of a building, it is necessary to know:

1. The intensity of direct solar radiation striking the surface.
2. The absorptivity (or reflectivity) of the surface for direct solar radiation.
3. The intensity of diffuse or sky solar radiation striking the surface.
4. The absorptivity (or reflectivity) of the surface for diffuse or sky solar radiation.
5. The rate at which the surface emits radiation to the sky and other surroundings.
6. The rate at which the surface absorbs the low temperature radiation emitted by the sky and other surroundings by virtue of their temperatures and radiating characteristics.
7. The temperature of the surrounding air.
8. The temperature of the outer building surface.
9. The unit convective conductance for heat transfer between the air and the building surface.

### The Sol-Air Temperature

The complex interrelationship of the above factors can be considerably simplified through the use of the sol-air temperature concept. The sol-air temperature  $t_a$  is the temperature of the outdoor air, which, in the absence of all radiation exchanges, would give the same rate of heat entry into the surface as would exist with the actual combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with the outdoor air.

The sol-air temperature data<sup>5, 6, 10</sup> as developed by Mackey and Wright for an industrial atmosphere were used as a basis for preparing Table 8 showing summer design sol-air temperatures. Sol-air temperatures may also be estimated from experimental observation of surface temperatures

TABLE 8. SUMMER DESIGN SOL-AIR TEMPERATURES USED FOR TABLES 9 AND 10

| MEAN SUN TIME                                | SOL-AIR TEMPERATURE $t_o$ FAHRENHEIT DEGREES |        |       |       |       |       |       |             |
|----------------------------------------------|----------------------------------------------|--------|-------|-------|-------|-------|-------|-------------|
|                                              | Any Sur. face <sup>a</sup>                   | Horis. | North | East  |       | South |       | West        |
| Ratio <sup>b</sup> : $\frac{\alpha}{f_{co}}$ | 0                                            | 0.225  | 0     | 0.225 | 0.125 | 0.225 | 0.125 | 0.225 0.125 |
| 12 Midnight                                  | 77                                           | 77     | 77    | 77    | 77    | 77    | 77    | 77          |
| 1 AM                                         | 76                                           | 76     | 76    | 76    | 76    | 76    | 76    | 76          |
| 2                                            | 76                                           | 76     | 76    | 76    | 76    | 76    | 76    | 76          |
| 3                                            | 75                                           | 75     | 75    | 75    | 75    | 75    | 75    | 75          |
| 4                                            | 74                                           | 74     | 74    | 74    | 74    | 74    | 74    | 74          |
| 5                                            | 74                                           | 74     | 74    | 75    | 80    | 74    | 74    | 74          |
| 6                                            | 74                                           | 76     | 74    | 110   | 93    | 74    | 74    | 74          |
| 7                                            | 75                                           | 91     | 75    | 123   | 100   | 75    | 75    | 75          |
| 8                                            | 77                                           | 106    | 77    | 126   | 103   | 82    | 78    | 77          |
| 9                                            | 80                                           | 119    | 80    | 125   | 104   | 93    | 86    | 80          |
| 10                                           | 83                                           | 129    | 83    | 117   | 100   | 102   | 93    | 83          |
| 11                                           | 87                                           | 137    | 87    | 108   | 96    | 110   | 99    | 87          |
| 12 Noon                                      | 90                                           | 142    | 90    | 92    | 92    | 114   | 104   | 96          |
| 1 PM                                         | 93                                           | 144    | 93    | 93    | 93    | 115   | 105   | 110         |
| 2                                            | 94                                           | 140    | 94    | 95    | 94    | 111   | 104   | 124         |
| 3                                            | 95                                           | 132    | 95    | 95    | 95    | 104   | 100   | 135         |
| 4                                            | 94                                           | 120    | 94    | 94    | 94    | 99    | 96    | 141         |
| 5                                            | 93                                           | 107    | 93    | 93    | 93    | 95    | 94    | 139         |
| 6                                            | 91                                           | 96     | 91    | 91    | 91    | 91    | 91    | 125         |
| 7                                            | 87                                           | 90     | 87    | 87    | 87    | 88    | 87    | 103         |
| 8                                            | 85                                           | 85     | 85    | 85    | 85    | 85    | 85    | 85          |
| 9                                            | 83                                           | 83     | 83    | 83    | 83    | 83    | 83    | 83          |
| 10                                           | 81                                           | 81     | 81    | 81    | 81    | 81    | 81    | 81          |
| 11                                           | 79                                           | 79     | 79    | 79    | 79    | 79    | 79    | 79          |
| 24 Hr Avg $t_m$                              | 83.1                                         | 100.5  | 83.1  | 93.0  | 88.4  | 89.0  | 86.2  | 93.0        |

<sup>a</sup>  $\alpha$  = surface absorptivity, dimensionless: roof = 0.9; dark walls = 0.9, and light walls = 0.5.  $f_{co}$  = unit convective conductance = 4.0 Btu per (hr) (F deg).

<sup>b</sup> values in this column are magnitudes of  $t_o$ , the outdoor air temperature.

of walls and roofs which appear in the literature.<sup>11, 12</sup> Both analytical and experimental studies have been made on the problem<sup>10</sup> of heat flow through walls and roofs. Those concerned with a further study of the details of cooling-load estimates in particular relation to periodic heat flow will find much of value and interest in the reports of experimental studies of these problems.<sup>10, 11, 12, 13, 14, 15</sup> The reader may also refer to the Cooling Load chapter of THE GUIDE 1952 for the theory of heat flow through walls and roofs.

#### PRACTICAL TABLES FOR CALCULATING SOLAR HEAT GAIN THROUGH WALLS AND ROOFS

The analytical<sup>10</sup> method reported by Mackey and Wright was used by Stewart<sup>16</sup> to obtain temperature differentials based on Table 8 and shown in Tables 9 and 10. These analytical procedures, as well as those using Tables 9 and 10, presented here, yield generally higher rates of heat gain

than reported for Pittsburgh in early A.S.H.A.E. experimental studies. Current authoritative opinion indicates a preference for analytical calculations. Thermal and physical properties of materials used in these tables are given in a paper.<sup>16</sup> The rate of heat flow is obtained by multiplying the overall heat transmission coefficient of the structure by the equivalent temperature differential obtained from the tables.

Tables 9 and 10 were developed by using an outside surface conductance of 4.0 and an inside film conductance of 1.65 Btu (hr) (sq ft) (F deg). A reduction was made in the temperature differentials for roofs amounting to some 20 percent of solar radiation as explained by Stewart.<sup>16</sup> This was to compensate for several factors, one of which is the radiant heat lost to the sky which is not included in the Mackey and Wright method. Recent experimental work by Parmelee<sup>17</sup> and previous work by Brunt<sup>18</sup> gives data showing the magnitude of this radiant heat loss from a roof or wall to the sky. Temperature differentials for roofs probably would be reduced below those shown in Table 9 whenever the radiant heat lost to the sky is included in calculation of sol-air temperature. The temperature differentials for roofs were based on an inside surface conductance of 1.65 because the charts prepared by Mackey and Wright<sup>10</sup> used this value, and it was not considered practicable to repeat their work using a different film coefficient. An examination of the values given in their paper indicates that the temperature differential would be changed very little even if a value 1.20 were used instead of 1.65. But to obtain the heat flow rates through roofs, more accurate values will be obtained if the overall heat transmission coefficient is calculated using 1.2 as the inside film conductance for summer.

The roof coefficients of transmission for summer shown in Table 11 are based on surface conductances  $f_{ro}$  of 4.0 for an outside roof surface and 1.20 for an inside ceiling surface. The outside conductance 4.0 is used for summer because it corresponds to a wind velocity of approximately 7.5 mph averaged for rough and smooth surfaces, and is more representative of summer wind velocities. Also, the lower wind velocity should be used in order to be on the safe side in determining the sol-air temperature. The inside conductance 1.20 is used because the convective portion of the film conductance for downward heat flow from a horizontal surface is appreciably less than the winter conductance for heat flowing upward.

Since there is little difference in wall transmission coefficients for summer, based on the conductances of 4.0 and 1.65, and the winter coefficients, based on 6.0 and 1.65, it is recommended that the overall coefficient  $U$ , for walls, be taken directly from the tables in Chapter 9 in which they are based on an outside film conductance of 6.0, corresponding to a 15 mph wind velocity.

#### Advantages of Equivalent Temperature Differential Method

The advantages of the equivalent temperature differential method of determining the total heat transmission are given in following paragraphs, and are apparent from Examples 5 to 7.

1. The total sensible heat flow is obtained by multiplying the overall heat transmission coefficient,  $U$ , and the equivalent temperature differential indicated in Tables 9 and 10.
2. The temperature differentials listed for a few representative types of construction may be used on all classes of walls and roofs, even though the overall heat transmission coefficient is different, provided the structure has thermal and physical properties similar to one of those listed in Tables 9 and 10.
3. Adjustments can be made, according to instructions given in the footnotes, for room and outdoor conditions different from those on which the tables are based.

TABLE 9. TOTAL EQUIVALENT TEMPERATURE DIFFERENTIALS FOR CALCULATING HEAT GAIN THROUGH SUNLIT AND SHADED ROOFS

| DESCRIPTION OF ROOF CONSTRUCTION*                                                                                              | SUN TIME |        |          |          |          |          |          |          |          |  |
|--------------------------------------------------------------------------------------------------------------------------------|----------|--------|----------|----------|----------|----------|----------|----------|----------|--|
|                                                                                                                                | A.M.     |        |          | P.M.     |          |          |          |          |          |  |
|                                                                                                                                | 8        | 10     | 12       | 2        | 4        | 6        | 8        | 10       | 12       |  |
| LIGHT CONSTRUCTION ROOFS—EXPOSED TO SUN                                                                                        |          |        |          |          |          |          |          |          |          |  |
| 1" Wood <sup>b</sup> or<br>1" Wood <sup>b</sup> + 1" or 2" Insulation                                                          | 12       | 38     | 54       | 62       | 50       | 26       | 10       | 4        | 0        |  |
| MEDIUM CONSTRUCTION ROOFS—EXPOSED TO SUN                                                                                       |          |        |          |          |          |          |          |          |          |  |
| 2" Concrete or<br>2" Concrete + 1" or 2" Insulation or<br>2" Wood <sup>b</sup>                                                 | 6        | 30     | 48       | 58       | 50       | 32       | 14       | 6        | 2        |  |
| 2" Gypsum or<br>2" Gypsum + 1" Insulation<br>1" Wood <sup>b</sup> or<br>2" Wood <sup>b</sup> or<br>2" Concrete or<br>2" Gypsum | 0        | 20     | 40       | 52       | 54       | 42       | 20       | 10       | 6        |  |
| + 4" Rock Wool in Furred Ceiling                                                                                               |          |        |          |          |          |          |          |          |          |  |
| 4" Concrete or<br>4" Concrete with 2" Insulation                                                                               | 0        | 20     | 38       | 50       | 52       | 40       | 22       | 12       | 6        |  |
| HEAVY CONSTRUCTION ROOFS—EXPOSED TO SUN                                                                                        |          |        |          |          |          |          |          |          |          |  |
| 6" Concrete<br>6" Concrete + 2" Insulation                                                                                     | 4<br>6   | 6<br>6 | 24<br>20 | 38<br>34 | 46<br>42 | 44<br>44 | 32<br>34 | 18<br>20 | 12<br>14 |  |
| ROOFS COVERED WITH WATER—EXPOSED TO SUN                                                                                        |          |        |          |          |          |          |          |          |          |  |
| Light Construction Roof with 1" Water                                                                                          | 0        | 4      | 16       | 22       | 18       | 14       | 10       | 2        | 0        |  |
| Heavy Construction Roof with 1" Water                                                                                          | -2       | -2     | -4       | 10       | 14       | 16       | 14       | 10       | 6        |  |
| Any Roof with 6" Water                                                                                                         | -2       | 0      | 0        | 6        | 10       | 10       | 8        | 4        | 0        |  |
| ROOFS WITH ROOF SPRAYS—EXPOSED TO SUN                                                                                          |          |        |          |          |          |          |          |          |          |  |
| Light Construction                                                                                                             | 0        | 4      | 12       | 18       | 16       | 14       | 10       | 2        | 0        |  |
| Heavy Construction                                                                                                             | -2       | -2     | 2        | 8        | 12       | 14       | 12       | 10       | 6        |  |
| ROOFS IN SHADE                                                                                                                 |          |        |          |          |          |          |          |          |          |  |
| Light Construction                                                                                                             | -4       | 0      | 6        | 12       | 14       | 12       | 8        | 2        | 0        |  |
| Medium Construction                                                                                                            | -4       | -2     | 2        | 8        | 12       | 12       | 10       | 6        | 2        |  |
| Heavy Construction                                                                                                             | -2       | -2     | 0        | 4        | 8        | 10       | 10       | 8        | 4        |  |

\* Includes  $\frac{1}{2}$  in. felt roofing with or without slag. May also be used for shingle roof. <sup>b</sup>Nominal thickness of the wood.

## NOTES FOR TABLE 9

Explanation:  $\left\{ \begin{array}{l} \text{Total heat transmission from solar} \\ \text{radiation and temperature difference} \\ \text{between outside and room air. Btu} \\ \text{per (hr) (sq ft) of roof area} \end{array} \right\} = \left\{ \begin{array}{l} \text{Equivalent temperature} \\ \text{differential from above} \\ \text{table} \end{array} \right\} \times \left\{ \begin{array}{l} \text{Heat transmission} \\ \text{coefficient for sum-} \\ \text{mer Btu per (hr)} \\ \text{(sq ft) (F deg)} \end{array} \right\}$

1. Source. Calculated by Mackey and Wright method (see reference list) and adjusted after studying ASHRAE original test data. Estimated for about August 1 in 40 deg north latitude. (For sol-air temperatures used in calculations see Table 8.) For typical design day where the maximum outdoor temperature is 95 F and minimum temperature at night is approximately 75 F (daily range of temperature, 20 F) mean 24 hr temperature 84 F for a room temperature of 80 F. All roofs have been assumed a dark color which absorbs 90 percent of solar radiation, and reflects only 10 percent.

2. Application. These values may be used for all normal air conditioning estimates; usually without correction, in latitude 0 deg to 50 deg north or south when the load is calculated for the hottest weather. Note 5 explains how to adjust the temperature differential for other room and outdoor temperatures.

3. Peaked Roofs. If the roof is peaked and the heat gain is primarily due to solar radiation, use for the area of the roof, the area projected on a horizontal plane.

4. Attics. If the ceiling is insulated and if a fan is used in the attic for positive ventilation, the total temperature differential for a roof exposed to the sun may be decreased 25 percent.

5. Corrections. For temperature difference when outdoor maximum design temperature minus room is different from 15 deg. If the outdoor design temperature minus room temperature is different from the base of 15 deg, correct as follows: When the difference is greater (or less) than 15 deg add the excess to (or subtract the deficiency from) the above differentials.

For outdoor daily range of temperature other than 20 deg. If the daily range of temperature is less than 20 deg, add 1 deg for every 2 deg lower daily range; if the daily range is greater than 20 deg, subtract 1 deg for every 2 deg higher daily range. For example, the daily range in Miami, Florida is 12 deg or 8 deg less than 20 deg, therefore, the correction is + 4 deg at all hours of the day.

Light Colors. Credit should not be taken for light colored roofs except where the permanence of the light color is established by experience, as in rural areas or where there is little smoke. When the exterior surface of roof exposed to the sun is a light color, such as white or aluminum (which absorb approximately 50 percent and reflect 50 percent of the solar radiation) add to the temperature differential for roof in shade 55 percent of the difference between the roof in sun and roof in shade. When the roof exposed to the sun is a medium color such as light grey, blue or green, or bright red, add 30 percent of this difference.

For solar transmission in latitudes other than 40 deg north, and in other months. The table values of temperature differentials will be approximately correct for a roof in the following months:

| NORTH LATITUDE |                                      | SOUTH LATITUDE |                                    |
|----------------|--------------------------------------|----------------|------------------------------------|
| Latitude (deg) | Months                               | Latitude (deg) | Months                             |
| 0              | All Months                           | 0              | All Months                         |
| 10             | All Months                           | 10             | All Months                         |
| 20             | All Months except Nov, Dec, Jan      | 20             | All Months except May, June, July  |
| 30             | Mar, Apr, May, June, July, Aug, Sept | 30             | Sept, Oct, Nov, Dec, Jan, Feb, Mar |
| 40             | April, May, June, July, Aug          | 40             | Oct, Nov, Dec, Jan, Feb            |
| 50             | May, June, July                      | 50             | Nov, Dec, Jan                      |

For other months, the total temperature differential ( $t_x$ ) may be approximated by the use of the following formula:

$$t_x = t_s + \frac{I_x}{I_y} (t_v - t_s)$$

where  $t_s$  = temperature differential for the same roof in shade for desired time of day; obtained from Table 9.

$I_y$  = maximum solar transmission through glass, Btu per (hr) (sq ft) for flat skylight in Aug., 40 deg north latitude (Note: this is maximum value irrespective of time).

$I_x$  = same as  $I_y$  except use the maximum value for flat skylight, for month, and latitude desired for  $t_x$ .

$t_v$  = temperature differential for particular roof exposed to sun for the desired time of day from Table 9.

(Note that this makes adjustment only for solar radiation and that there may be additional correction for outdoor temperature.)

## Examples of Use of Equivalent Temperature Tables

Example 5: Given: A roof is constructed of 6 in. of stone concrete with 2 in. of insulating board and tar felt roofing  $\frac{1}{2}$  in. thick, and is exposed to the sun. The location is the central part of the United States. Find the rate of heat flow into building at 2:00 p.m. during July for an outdoor design temperature 95 F, and an inside temperature 80 F.

Solution: From Table 9 in 2 p.m. column for 6 in. concrete plus 2 in. insulation, find the total equivalent temperature differential 34 deg. The overall heat transmission coefficient for summer is taken from Table 11 and is found to be 0.13. The heat flow rate equals  $34 \times 0.13 = 4.42$  Btu per (hr) (sq ft).

Example 6: For the conditions of Example 5, find the rate of heat flow into building at 2:00 p.m. during July for design temperatures of 105 F (outdoor) and 78 F (indoor). Daily range of temperature 30 deg, i.e., outdoor temperature minimum of 75 F which occurs at 4:00 or 5:00 a.m.; this being 30 deg less than the maximum.

Solution: Make correction in equivalent temperature differential in accordance with Note 5 in Table 9 as follows:

The correction for 27 deg design temperature difference is  $(27 - 15) = + 12$ .

The correction for 30 deg daily range is  $\left( -\frac{30 - 20}{2} \right) = - 5$ .

Net total correction is  $+ 12 - 5 = + 7$ .

The heat flow rate at 2:00 p.m. is  $(34 + 7) \times 0.13 = 5.32$  Btu per (hr) (sq ft).



TABLE 10. TOTAL EQUIVALENT TEMPERATURE DIFFERENTIALS FOR CALCULATING HEAT GAIN THROUGH SUNLIT AND SHADED WALLS.

| NORTH<br>LATITUDE<br>WALL<br>FACING                      | SUN TIME                                   |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    | SOUTH<br>LATITUDE<br>WALL<br>FACING |
|----------------------------------------------------------|--------------------------------------------|----|----|----|----|----|------|----|----|----|----|----|----|----|----|----|-------------------------------------|
|                                                          | A.M.                                       |    |    |    |    |    | P.M. |    |    |    |    |    |    |    |    |    |                                     |
|                                                          | 8                                          | 10 | 12 | 2  | 4  | 6  | 8    | 10 | 12 | 2  | 4  | 6  | 8  | 10 | 12 |    |                                     |
|                                                          | Exterior color of Wall—D = dark, L = light |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |                                     |
|                                                          | D                                          | L  | D  | L  | D  | L  | D    | L  | D  | L  | D  | L  | D  | L  | D  | L  |                                     |
| FRAME                                                    |                                            |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |                                     |
| NE                                                       | 22                                         | 10 | 24 | 12 | 14 | 10 | 12   | 10 | 14 | 14 | 14 | 14 | 10 | 10 | 6  | 4  | SE                                  |
| E                                                        | 30                                         | 14 | 36 | 18 | 32 | 16 | 12   | 12 | 14 | 14 | 14 | 14 | 10 | 10 | 6  | 4  | E                                   |
| SE                                                       | 13                                         | 6  | 26 | 16 | 28 | 18 | 24   | 16 | 16 | 14 | 14 | 14 | 10 | 10 | 6  | 4  | NE                                  |
| S                                                        | -4                                         | -4 | 4  | 0  | 22 | 12 | 30   | 20 | 26 | 20 | 16 | 14 | 10 | 10 | 6  | 4  | N                                   |
| SW                                                       | -4                                         | -4 | 0  | -2 | 6  | 4  | 26   | 22 | 40 | 28 | 42 | 28 | 24 | 20 | 6  | 4  | NW                                  |
| W                                                        | -4                                         | -4 | 0  | 0  | 6  | 6  | 20   | 12 | 40 | 28 | 48 | 34 | 22 | 22 | 8  | 8  | W                                   |
| NW                                                       | -4                                         | -4 | 0  | -2 | 6  | 4  | 12   | 10 | 24 | 20 | 40 | 26 | 34 | 24 | 6  | 4  | SW                                  |
| N (Shade)                                                | -4                                         | -4 | -2 | -2 | 4  | 4  | 10   | 10 | 14 | 14 | 12 | 12 | 8  | 8  | 4  | 4  | S (Shade)                           |
| 4 IN. BRICK OR STONE VENEER + FRAME                      |                                            |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |                                     |
| NE                                                       | -2                                         | -4 | 24 | 12 | 20 | 10 | 10   | 6  | 12 | 10 | 14 | 14 | 12 | 12 | 10 | 8  | SE                                  |
| E                                                        | 2                                          | 0  | 30 | 14 | 31 | 17 | 14   | 14 | 12 | 12 | 14 | 14 | 12 | 12 | 10 | 8  | E                                   |
| SE                                                       | 2                                          | -2 | 20 | 10 | 28 | 16 | 26   | 16 | 18 | 14 | 14 | 14 | 12 | 12 | 10 | 8  | NE                                  |
| S                                                        | -4                                         | -4 | -2 | -2 | 12 | 6  | 24   | 16 | 26 | 18 | 20 | 16 | 12 | 12 | 8  | 4  | N                                   |
| SW                                                       | 0                                          | -2 | 0  | -2 | 2  | 2  | 12   | 8  | 32 | 22 | 36 | 26 | 34 | 24 | 10 | 8  | NW                                  |
| W                                                        | 0                                          | -2 | 0  | 0  | 4  | 2  | 10   | 8  | 26 | 18 | 40 | 28 | 42 | 28 | 16 | 14 | W                                   |
| NW                                                       | -4                                         | -4 | 0  | -2 | 6  | 4  | 12   | 10 | 24 | 20 | 40 | 26 | 34 | 24 | 10 | 8  | SW                                  |
| N (Shade)                                                | -4                                         | -4 | -2 | -2 | 0  | 0  | 6    | 6  | 10 | 10 | 12 | 12 | 12 | 8  | 8  | 4  | S (Shade)                           |
| 8 IN. HOLLOW TILE OR 8 IN. CINDER BLOCK                  |                                            |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |                                     |
| NE                                                       | 0                                          | 0  | 0  | 0  | 20 | 10 | 16   | 10 | 10 | 6  | 12 | 10 | 14 | 12 | 12 | 10 | SE                                  |
| E                                                        | 4                                          | 2  | 4  | 2  | 24 | 12 | 26   | 14 | 20 | 12 | 12 | 14 | 14 | 12 | 10 | 8  | E                                   |
| SE                                                       | 2                                          | 0  | 2  | 0  | 16 | 8  | 20   | 12 | 20 | 14 | 14 | 14 | 12 | 12 | 10 | 8  | NE                                  |
| S                                                        | 0                                          | 0  | 0  | 0  | 2  | 0  | 12   | 6  | 24 | 14 | 26 | 16 | 14 | 12 | 10 | 8  | N                                   |
| SW                                                       | 2                                          | 0  | 2  | 0  | 2  | 0  | 6    | 4  | 12 | 10 | 26 | 18 | 30 | 20 | 26 | 18 | NW                                  |
| W                                                        | 4                                          | 2  | 4  | 2  | 4  | 2  | 6    | 4  | 10 | 8  | 18 | 14 | 30 | 22 | 22 | 18 | W                                   |
| NW                                                       | 0                                          | 0  | 0  | 0  | 2  | 0  | 4    | 2  | 8  | 6  | 12 | 10 | 22 | 18 | 30 | 22 | SW                                  |
| N (Shade)                                                | -2                                         | -2 | -2 | -2 | 0  | 0  | 0    | 0  | 6  | 6  | 10 | 10 | 10 | 10 | 10 | 6  | S (Shade)                           |
| 8 IN. BRICK OR 12 IN. HOLLOW TILE OR 12 IN. CINDER BLOCK |                                            |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |                                     |
| NE                                                       | 2                                          | 2  | 2  | 2  | 10 | 2  | 16   | 8  | 14 | 8  | 10 | 6  | 10 | 10 | 10 | 8  | SE                                  |
| E                                                        | 8                                          | 6  | 8  | 6  | 14 | 8  | 18   | 10 | 18 | 10 | 14 | 8  | 14 | 10 | 12 | 10 | E                                   |
| SE                                                       | 8                                          | 4  | 6  | 4  | 6  | 4  | 14   | 10 | 18 | 12 | 16 | 12 | 12 | 10 | 12 | 10 | NE                                  |
| S                                                        | 4                                          | 2  | 4  | 2  | 4  | 2  | 4    | 2  | 10 | 16 | 16 | 12 | 12 | 10 | 10 | 8  | N                                   |
| SW                                                       | 8                                          | 4  | 6  | 4  | 6  | 4  | 8    | 4  | 10 | 6  | 12 | 8  | 20 | 12 | 24 | 16 | NW                                  |
| W                                                        | 8                                          | 4  | 6  | 4  | 6  | 4  | 8    | 6  | 10 | 6  | 14 | 8  | 20 | 16 | 24 | 16 | W                                   |
| NW                                                       | 2                                          | 2  | 2  | 2  | 2  | 2  | 4    | 2  | 6  | 4  | 8  | 6  | 10 | 8  | 16 | 14 | SW                                  |
| N (Shade)                                                | 0                                          | 0  | 0  | 0  | 0  | 0  | 0    | 0  | 2  | 2  | 6  | 6  | 8  | 8  | 8  | 6  | S (Shade)                           |
| 12 IN. BRICK                                             |                                            |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |                                     |
| NE                                                       | 8                                          | 6  | 8  | 6  | 8  | 4  | 8    | 4  | 10 | 4  | 12 | 6  | 12 | 8  | 10 | 6  | SE                                  |
| E                                                        | 12                                         | 8  | 12 | 8  | 12 | 8  | 10   | 6  | 12 | 8  | 14 | 10 | 14 | 10 | 12 | 8  | E                                   |
| SE                                                       | 10                                         | 6  | 10 | 6  | 10 | 6  | 10   | 6  | 10 | 6  | 12 | 8  | 14 | 10 | 12 | 8  | NE                                  |
| S                                                        | 8                                          | 6  | 8  | 6  | 8  | 4  | 6    | 4  | 8  | 4  | 10 | 6  | 12 | 8  | 12 | 8  | N                                   |
| SW                                                       | 10                                         | 6  | 10 | 6  | 10 | 6  | 10   | 6  | 10 | 6  | 10 | 8  | 10 | 8  | 12 | 10 | NW                                  |
| W                                                        | 12                                         | 8  | 12 | 8  | 12 | 8  | 10   | 6  | 10 | 6  | 10 | 6  | 10 | 6  | 12 | 8  | W                                   |
| NW                                                       | 8                                          | 6  | 8  | 6  | 8  | 4  | 8    | 4  | 8  | 4  | 8  | 4  | 8  | 6  | 10 | 6  | SW                                  |
| N (Shade)                                                | 4                                          | 4  | 2  | 2  | 2  | 2  | 2    | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 4  | 4  | S (Shade)                           |
| 8 IN. CONCRETE OR STONE OR 6 IN. OR 8 IN. CONCRETE BLOCK |                                            |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |                                     |
| NE                                                       | 4                                          | 2  | 4  | 0  | 16 | 8  | 14   | 8  | 10 | 6  | 12 | 8  | 12 | 10 | 10 | 8  | SE                                  |
| E                                                        | 6                                          | 4  | 14 | 8  | 24 | 12 | 24   | 12 | 18 | 10 | 14 | 10 | 14 | 10 | 12 | 10 | E                                   |
| SE                                                       | 6                                          | 2  | 6  | 4  | 16 | 10 | 18   | 12 | 18 | 12 | 12 | 10 | 12 | 10 | 10 | 8  | NE                                  |
| S                                                        | 2                                          | 1  | 2  | 1  | 1  | 12 | 6    | 16 | 12 | 18 | 12 | 14 | 12 | 10 | 10 | 8  | N                                   |
| SW                                                       | 6                                          | 2  | 4  | 2  | 6  | 2  | 8    | 4  | 14 | 10 | 22 | 16 | 24 | 16 | 22 | 16 | NW                                  |
| W                                                        | 6                                          | 4  | 6  | 4  | 6  | 4  | 8    | 6  | 12 | 8  | 20 | 14 | 28 | 18 | 26 | 18 | W                                   |
| NW                                                       | 4                                          | 2  | 4  | 0  | 4  | 2  | 4    | 2  | 4  | 2  | 4  | 2  | 4  | 2  | 22 | 16 | SW                                  |
| N (Shade)                                                | 0                                          | 0  | 0  | 0  | 0  | 0  | 2    | 2  | 4  | 4  | 6  | 6  | 8  | 8  | 6  | 4  | S (Shade)                           |

TABLE 10. TOTAL EQUIVALENT TEMPERATURE DIFFERENTIALS FOR CALCULATING HEAT GAIN THROUGH SUNLIT AND SHADED WALLS—Concluded.

| NORTH<br>LATITUDE<br>WALL<br>FACING | SUN TIME                                   |    |    |   |   |   |      |    |    |    |    |    |    |    |    |    | SOUTH<br>LATITUDE<br>WALL<br>FACING |
|-------------------------------------|--------------------------------------------|----|----|---|---|---|------|----|----|----|----|----|----|----|----|----|-------------------------------------|
|                                     | A.M.                                       |    |    |   |   |   | P.M. |    |    |    |    |    |    |    |    |    |                                     |
|                                     | 8                                          | 10 | 12 | 2 | 4 | 6 | 8    | 10 | 12 |    |    |    |    |    |    |    |                                     |
|                                     | Exterior color of Wall—D = dark, L = light |    |    |   |   |   |      |    |    |    |    |    |    |    |    |    |                                     |
|                                     | D                                          | L  | D  | L | D | L | D    | L  | D  | L  | D  | L  | D  | L  | D  | L  |                                     |
|                                     | 12 IN. CONCRETE OR STONE                   |    |    |   |   |   |      |    |    |    |    |    |    |    |    |    |                                     |
| NE                                  | 6                                          | 4  | 6  | 2 | 6 | 2 | 14   | 8  | 14 | 8  | 10 | 8  | 10 | 8  | 12 | 10 | SE                                  |
| E                                   | 10                                         | 6  | 8  | 4 | 6 | 4 | 14   | 8  | 10 | 12 | 16 | 10 | 10 | 12 | 10 | 14 | E                                   |
| SE                                  | 8                                          | 4  | 8  | 4 | 6 | 4 | 14   | 8  | 16 | 10 | 16 | 10 | 14 | 10 | 12 | 10 | NE                                  |
| S                                   | 6                                          | 4  | 4  | 2 | 4 | 2 | 10   | 6  | 14 | 10 | 16 | 14 | 10 | 16 | 12 | 10 | N                                   |
| SW                                  | 8                                          | 4  | 8  | 4 | 6 | 4 | 6    | 4  | 6  | 4  | 8  | 6  | 10 | 8  | 18 | 14 | NW                                  |
| W                                   | 10                                         | 6  | 8  | 6 | 8 | 6 | 10   | 6  | 10 | 6  | 12 | 8  | 16 | 10 | 24 | 14 | W                                   |
| NW                                  | 6                                          | 4  | 6  | 2 | 6 | 2 | 6    | 4  | 6  | 4  | 8  | 6  | 10 | 8  | 18 | 12 | SW                                  |
| N (Shade)                           | 0                                          | 0  | 0  | 0 | 0 | 0 | 0    | 0  | 0  | 0  | 2  | 2  | 4  | 6  | 6  | 6  | S (Shade)                           |

## NOTES FOR TABLE 10

Explanation:  $\left( \frac{\text{Total heat transmission from solar radiation and temperature difference between outside and room air, Btu per (hr) (sq ft wall area)}}{\text{Equivalent temperature differential from above table}} \right) \times \left( \frac{\text{Heat transmission coefficient for wall, Btu per (hr) (sq ft) (F deg)}}{\text{table}} \right)$

## NOTES:

1. **SOURCE.** Same as Table 9. A north wall has been assumed to be a wall in the shade; this is practically true. Dark colors on exterior surface of walls have been assumed to absorb 90 percent of solar radiation and reflect 10 percent; white colors absorb 50 percent and reflect 50 percent. This includes some allowance for dust and dirt since clean, fresh white paint normally absorbs only 40 percent of solar radiation.

2. **APPLICATION.** These values may be used for all normal air conditioning estimates, usually without corrections, when the load is calculated for the hottest weather. Correction for latitude (Note 3) is necessary only where extreme accuracy is required. There may be jobs where the indoor room temperature is considerably above or below 80 F, or where the outdoor design temperature is considerably above 95 F, in which case it may be desirable to make correction to the temperature differentials shown. The solar intensity on all walls other than east and west varies considerably with time of year.

3. **CORRECTIONS.** Outdoor minus room temperature. If the outdoor maximum design temperature minus room temperature is different from the base of 15 deg, correct as follows: When the difference is greater (or less) than 15 deg, add the excess to (or subtract the deficiency from) the above differentials.

Outdoor daily range temperature. If the daily range of temperature is less than 20 deg, add 1 deg to every 2 deg lower daily range; if the daily range is greater than 20 deg, subtract 1 deg for every 2 deg higher daily range. For example, the daily range in Miami, Florida is 12 deg, or 8 deg less than 20 deg; therefore, the correction is +4 deg.

Color of exterior surface of wall. Use temperature differentials for light walls only where the permanence of the light wall is established by experience. For cream colors use the values for light walls. For medium colors interpolate half way between the dark and light values. Medium colors are medium blue, medium green, bright red, light brown, unpainted wood, natural color concrete, etc. Dark blue, red, brown, green, etc., are considered dark colors.

For latitudes other than 40 deg north, and in other months. These table values will be approximately correct for the east or west wall in any latitude (0 deg to 50 deg North or South) during the hottest weather. In the lower latitudes when the maximum solar altitude is approximately 80 deg to 90 deg (the maximum occurs at noon) the temperature differential for either a south or north wall will be approximately the same as a north, or shade wall. The temperature differential ( $t_x$ ) for any wall facing, and for any latitude for any month may be approximated as follows:

$$t_x = t_z + \frac{I_1}{I_2} \times (t_w - t_z)$$

where  $t_z$  = temperature differential for the same wall in shade for desired time of day; obtained from Table 10.

$I_1$  = maximum solar radiation intensity transmitted through glass, Btu per (hr) (sq ft) for particular wall facing, in July, 40 deg north latitude (note: this is maximum value irrespective of time).

$I_2$  = same as  $I_1$  except use the maximum value for wall facing, for month, and latitude desired for  $t_x$ .

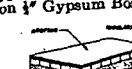
$t_w$  = temperature differential for particular wall facing, for the desired time of day from above table. (Note that this makes adjustment only for solar radiation, and that there may be additional correction for outdoor temperature.)

4. **FOR INSULATED WALLS** use same temperature differentials as used for uninsulated walls.

TABLE 11. SUMMER COEFFICIENTS OF HEAT TRANSMISSION  $U$  OF FLAT ROOFS COVERED WITH BUILT-UP ROOFING<sup>a</sup>  
Btu per (hour) (square foot) (F deg difference between the air on the two sides)

Btu per (hour) (square foot) (1" deg difference between inside and outside air)

INSULATION ON TOP OF DECK  
(Covered With Built-Up Roofing)

| TYPE OF ROOF DECK<br>Ceiling not shown                                                                                                            | THICKNESS OF<br>ROOF DECK<br>(Inches) | No Ceiling—<br>Underside of Roof<br>Exposed |                                                 |                     |                     | Furred Ceiling with<br>Air Space, Metal Lath<br>and Plaster |                     |                                                 |                     |                     |                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|---------------------------------------------|-------------------------------------------------|---------------------|---------------------|-------------------------------------------------------------|---------------------|-------------------------------------------------|---------------------|---------------------|------------------------|
|                                                                                                                                                   |                                       | No In-<br>sulation                          | Insulating Board <sup>d</sup><br>Thickness, in. |                     |                     |                                                             | No In-<br>sulation  | Insulating Board <sup>d</sup><br>Thickness, in. |                     |                     |                        |
|                                                                                                                                                   |                                       |                                             | 1/2                                             | 1                   | 1 1/2               | 2                                                           |                     | 1/2                                             | 1                   | 1 1/2               | 2                      |
| Flat Metal Roof Deck<br>                                         | 4 Ply Felt Roof                       | 0.73                                        | 0.35                                            | 0.23                | 0.17                | 0.13                                                        | 0.40                | 0.25                                            | 0.18                | 0.14                | 0.12                   |
|                                                                                                                                                   | Ditto + 1/2 in. Slag                  | 0.54                                        | 0.30                                            | 0.20                | 0.16                | 0.13                                                        | 0.34                | 0.22                                            | 0.16                | 0.13                | 0.11                   |
| Precast Cement Tile<br>                                          | 4 Ply Felt Roof 1 1/2                 | 0.67                                        | 0.33                                            | 0.22                | 0.17                | 0.13                                                        | 0.38                | 0.24                                            | 0.18                | 0.14                | 0.12                   |
|                                                                                                                                                   | Ditto + 1/2 in. Slag 1 1/2            | 0.50                                        | 0.28                                            | 0.20                | 0.15                | 0.12                                                        | 0.32                | 0.21                                            | 0.17                | 0.13                | 0.11                   |
| Concrete<br>                                                     | 4 Ply Felt Roof 2                     | 0.65                                        | 0.33                                            | 0.22                | 0.16                | 0.13                                                        | 0.37                | 0.24                                            | 0.18                | 0.14                | 0.12                   |
|                                                                                                                                                   | 4 4                                   | 0.59                                        | 0.31                                            | 0.21                | 0.16                | 0.13                                                        | 0.36                | 0.23                                            | 0.17                | 0.13                | 0.12                   |
|                                                                                                                                                   | 6 6                                   | 0.54                                        | 0.30                                            | 0.20                | 0.16                | 0.13                                                        | 0.33                | 0.22                                            | 0.17                | 0.13                | 0.11                   |
|                                                                                                                                                   | Ditto 2 4 6                           | 0.49 0.46 0.42                              | 0.28 0.27 0.26                                  | 0.20 0.19 0.19      | 0.15 0.15 0.14      | 0.12 0.12 0.12                                              | 0.31 0.30 0.29      | 0.21 0.21 0.20                                  | 0.16 0.16 0.16      | 0.13 0.13 0.13      | 0.11 0.11 0.10         |
| Gypsum and Wood Fiber <sup>b</sup><br>on 1/2" Gypsum Board<br> | 4 Ply Felt Roof 2 1/2                 | 0.34                                        | 0.23                                            | 0.17                | 0.13                | 0.12                                                        | 0.25                | 0.18                                            | 0.14                | 0.12                | 0.097                  |
|                                                                                                                                                   | 3 1/2 3 1/2                           | 0.28                                        | 0.20                                            | 0.15                | 0.12                | 0.11                                                        | 0.21                | 0.16                                            | 0.13                | 0.11                | 0.094                  |
|                                                                                                                                                   | 4 1/2 4 1/2                           | 0.25                                        | 0.20                                            | 0.16                | 0.13                | 0.11                                                        | 0.22                | 0.16                                            | 0.13                | 0.11                | 0.093                  |
|                                                                                                                                                   | Ditto + 1/2 in. Slag 3 1/2 3 1/2      | 0.25                                        | 0.18                                            | 0.14                | 0.12                | 0.10                                                        | 0.19                | 0.15                                            | 0.13                | 0.10                | 0.090                  |
| Wood <sup>c</sup><br>                                          | 4 Ply Felt Roof 1 1 1/2 3             | 0.43 0.33 0.29 0.22                         | 0.26 0.22 0.20 0.16                             | 0.19 0.17 0.16 0.13 | 0.15 0.13 0.12 0.11 | 0.12 0.11 0.11 0.09                                         | 0.29 0.24 0.22 0.17 | 0.20 0.18 0.16 0.13                             | 0.15 0.14 0.13 0.12 | 0.13 0.12 0.11 0.10 | 0.11 0.097 0.094 0.085 |
|                                                                                                                                                   | Ditto 1 1/2 2 3                       | 0.35 0.29 0.26 0.20                         | 0.23 0.20 0.19 0.15                             | 0.17 0.16 0.14 0.12 | 0.14 0.13 0.12 0.10 | 0.11 0.10 0.10 0.09                                         | 0.25 0.21 0.20 0.16 | 0.18 0.17 0.15 0.13                             | 0.14 0.13 0.13 0.11 | 0.12 0.11 0.10 0.09 | 0.10 0.093 0.090 0.081 |

<sup>a</sup> The summer coefficients are considered temporary, and have been calculated with an outdoor wind velocity of 8 mph. For summer an inside surface conductance of 1.2 has been used instead of the regular 1.65 value. In all of these roofs a 4 ply felt roof has been assumed 1/2 in. thick, thermal conductivity = 1.33. Pitch and slag have been assumed as an additional thickness of 1/2 in. which has been assigned thermal conductivity = 1.0. In both cases thermal conductivity refers to one inch thickness.

<sup>b</sup> 87 1/2 percent gypsum, 12 1/2 percent wood fiber. Thickness indicated includes 1/2 in. gypsum board. This is a poured roof.

<sup>c</sup> Nominal thickness of wood is specified, but actual thickness was used in calculations.

<sup>d</sup> If corkboard insulation is used, the coefficient  $U$  may be decreased 10 percent.

A method of determining heat flow rates, when structure is not given in Tables 9 or 10, is illustrated in Example 7.

Example 7: A 4 in. stone concrete roof covered with an average depth of 4 in. cinder concrete ( $k = 4.9$ ) on which is placed a 1/2 in. thick felt roof with 1/2 in. pitch and slag surface, is exposed to the sun. The location is the central part of the United States.

Design temperatures are: outdoor 95 F; daily range 20 deg; indoor temperature 80 F. Find the heat flow rate at 2:00 p.m. for a day in July.

Solution: For the purpose of selecting the equivalent temperature differential, this construction is assumed to be equal approximately to an uninsulated 6 in. concrete roof, for which the equivalent temperature is found to be 38 deg in the 2:00 p.m. column of Table 9. Calculate the overall heat transmission coefficient  $U$  (see Equation 3 of Chapter 9) of the roof as follows:

$$U = \frac{1}{\frac{1}{1.2} + \frac{4}{12} + \frac{4}{4.9} + \frac{0.375}{1.33} + \frac{0.50}{1.00} + \frac{1}{4.0}} = 0.33.$$

The heat flow rate is then  $38 \times 0.33$  equals 12.5 Btu per (hr) (sq ft).

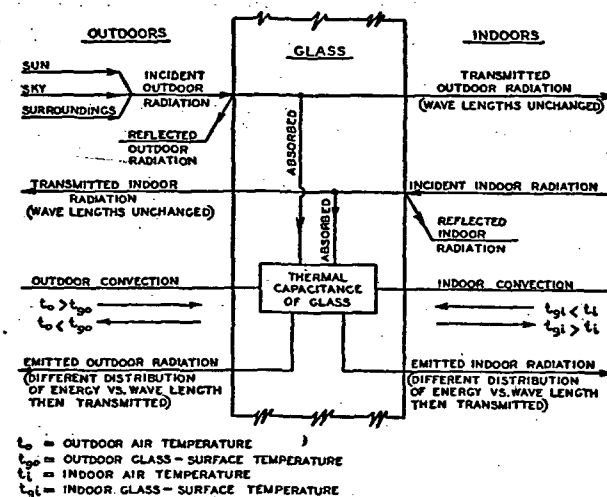


FIG. 2. INSTANTANEOUS HEAT-BALANCE CONDITIONS ON A GLASS SECTION

## TABLES FOR CALCULATING SOLAR HEAT GAIN THROUGH GLASS AREAS

### Basic Principles

In order to set forth the principles involved in calculating heat flow through glass areas, the general instantaneous heat-balance relation will be presented. It will be shown schematically in Fig. 2. The net heat gain for the indoor space is the result of several contributing phenomena. Some observations concerning the behavior of glass with respect to radiant energy will lead to a better understanding of the heat-balance relation. To various degrees glass transmits radiation having wave lengths between 0.29 and 4.75 microns. Of the portion not transmitted, part is absorbed, and the remainder is reflected. Outside these limits glass is opaque, absorbing approximately 94 percent and reflecting 6 percent. Only a negligible amount of radiant energy from a surface at 450 F has a wave length shorter than 4.75 microns. It is therefore convenient to treat all forms of solar radiant energy separately from radiant energy from other

sources, so long as the temperature of these sources is not over approximately 450 F.

The complete heat-balance for a glass section can be expressed for a unit time interval as follows:

$$\left[ \begin{array}{c} \text{Total heat flow,} \\ \text{through glass section} \end{array} \right] = \left[ \begin{array}{c} \text{Transmitted,} \\ \text{solar radiation} \end{array} \right] \pm \left[ \begin{array}{c} \text{Heat flow by convective} \\ \text{and radiative exchanges at} \\ \text{the indoor surface} \end{array} \right] \quad (2a)$$

The second term of the right side of Equation 2a can also be expressed by a heat balance equation as follows:

$$\left[ \begin{array}{c} \text{Heat flow by convective} \\ \text{and radiative exchanges} \\ \text{at the indoor surface} \end{array} \right] = \left[ \begin{array}{c} \text{Absorbed} \\ \text{solar} \\ \text{radiation} \end{array} \right] \pm \left[ \begin{array}{c} \text{Radiative exchanges be-} \\ \text{tween outer surface of glass} \\ \text{and outdoor surroundings} \end{array} \right] \\ \pm \left[ \begin{array}{c} \text{Convective exchanges} \\ \text{between outer surface of} \\ \text{glass and outdoor air} \end{array} \right] \pm \left[ \begin{array}{c} \text{Heat storage} \\ \text{within the} \\ \text{glass section} \end{array} \right] \quad (2b)$$

Equations 2a and 2b can be combined and expressed in symbolic terms by Equation 2c. Tabular values of the two bracketed terms of Equation 2a are presented later in this section for various types of glass for specific design conditions.

$$(q/A) = [\tau_D I_D + \tau_d I_d] + [\alpha_D I_D + \alpha_d I_d + \epsilon_{go} R_{go} - \epsilon_{ro} R_{ro} - f_{co} (t_{go} - t_o) - S], \quad \text{Btu per (hr) (sq ft)} \quad (2c)$$

where

- $(q/A)$  = instantaneous rate of heat flow, Btu per (hour)(square foot).  
 $\tau_D, \tau_d$  = transmittance of glass for direct and diffuse solar radiation, respectively.  
 $I_D, I_d$  = incident direct and diffuse solar radiation, respectively, Btu per (hour)(square foot).  
 $\alpha_D, \alpha_d$  = absorptance of glass for direct and diffuse solar radiation, respectively.  
 $\epsilon_{go}$  = emissivity of glass at temperature  $t_{go}$ .  
 $R_{go}$  = low temperature radiant energy falling on glass from outdoor surroundings, Btu per (hour)(square foot).  
 $R_{ro}$  = low temperature radiant energy emitted by a surface with emissivity equal to 1.0 at temperature  $t_{ro}$ .  
 $f_{co}$  = outdoor convective conductance, Btu per (hour)(square foot)(Fahrenheit degree).  
 $t_{go}$  = temperature of outdoor surface of glass, Fahrenheit degrees.  
 $t_o$  = temperature of outdoor air, Fahrenheit degrees.  
 $S$  = rate at which glass stores energy, Btu per (hour)(square foot).

Transmissivity and absorptivity vary with both wave length of the incident radiation and incident angle. Values of  $\tau$  and  $\alpha$  for a single sheet of the average ordinary drawn window glass are given in Table 12 for a standard distribution of solar energy.<sup>4</sup> Values for two air-spaced sheets are also given. Normal incidence transmittance values for some commonly-used types and combinations are given in Table 15. Some variation in these values can be expected in practice due to variations in manufacture and in solar energy distribution. However, a change in transmissivity causes an approximately equal and opposite change in absorptivity. Hence, the total heat flow is not greatly altered. Transmittance data for other types of glass and various patterns of 8-in. glass block are given in A.S.H.A.E. research papers.<sup>19, 20, 21, 22, 23</sup>

As stated earlier in this chapter, present data as to the value of  $R_{ro}$  are inadequate, so for the present it is suggested that  $f_{co}$  be increased to include radiation, and the term  $\epsilon_{go} R_{go} - \epsilon_{ro} R_{ro}$  be disregarded. It is not

practicable to give values of  $S$  in this chapter. However, for ordinary glass, the value of  $S$  is small.

Fig. 3 is a graphical solution, for single glass, of Equation 2b. Only absorbed solar radiation is considered, although low temperature radiation exchange and heat storage can be added algebraically to  $\alpha_d I_d$ , if such data are available. The small thermal resistance of the glass has been neglected. The heat flow rates are for a 75 F indoor temperature, an indoor surface conductance for convection  $f_{ci}$  as given by Equation 3, and an equivalent surface conductance for radiation  $f_{ri}$  as given by Equation 4. Indoor surfaces seen by the glass are assumed to radiate as a black body at room air temperature.

$$f_{ci} = 0.27 (t_{gi} - t_i)^{0.25} \quad (3)$$

$$f_{ri} = 0.162 \left[ \left( \frac{t_{gi} + 460}{100} \right)^4 - \left( \frac{t_i + 460}{100} \right)^4 \right] / (t_{gi} - t_i) \quad (4)$$

where

- $t_{gi}$  = temperature of indoor surface of glass, Fahrenheit.  
 $t_i$  = temperature of indoor air, Fahrenheit.

A more complete treatment of the problem is given in an A.S.H.A.E. research paper.<sup>22</sup>

**Example 8:** Find the total heat gain at 10 a.m. sun time for a single unshaded sheet of common window glass in a wall facing 18 deg east of south on August 1 at 50 deg north latitude. The indoor temperature is 75 F, the outdoor temperature is 83 F. Use clear atmosphere radiation values and  $f_{co} = 4.0$ .

**Solution:** From Example 2,  $K$  is 0.557; hence, the angle of incidence,  $\theta$ , is 56 deg 9 min. From Example 4,  $I_D = 152.0$ ,  $I_d = 26.6$ . By interpolation in Table 12,  $\tau_D$  is found to be 0.81,  $\alpha_D$  is 0.06;  $\tau_d$  and  $\alpha_d$  are 0.79 and 0.06, respectively.

The heat gain due to transmitted solar radiation is

$$(q/A)_\tau = 152.0 \times 0.81 + 26.6 \times 0.79 = 144.1 \text{ Btu per (hr)(sq ft).}$$

The heat gain by convection and radiation from the indoor surface is found from Fig. 3:

$$t_o + \frac{\alpha_d I_d}{f_{co}} = 83 + \frac{0.06 (152.0 + 26.6)}{4} = 85.7 \text{ F}$$

from which

$$(q/A)_{cr} = 11.5 \text{ Btu per (hr)(sq ft).}$$

From Equation 2a the total heat flow is

$$(q/A) = 144.1 + 11.5 = 155.6 \text{ Btu per (hr)(sq ft).}$$

### Design Tables for Flat Glass

Tables 13 and 14 give design values of instantaneous rates of heat gain for single unshaded common window glass for a solar declination of 18 deg. This corresponds to a nominal August 1 day. The tables are based upon the solar intensity values for a clear atmosphere as given in Table 4. Table 13 represents the first bracketed term of Equation 2a; therefore, the values are dependent only upon values of  $I$  and  $\tau$ . Table 14 is the second term of Equation 2a, and is based upon a 80 F indoor temperature and a

TABLE 12. TRANSMITTANCES AND ABSORPTANCES OF COMMON WINDOW GLASS FOR DIRECT AND DIFFUSE SOLAR RADIATION

| ANGLE OF INCIDENCE,<br>$\theta$ , DEG | SINGLE SHEETS        |            | TWO AIR-SPACED SHEETS |                             |                            |
|---------------------------------------|----------------------|------------|-----------------------|-----------------------------|----------------------------|
|                                       | $\tau_D$             | $\alpha_D$ | $\tau_D$              | $\alpha_D$<br>Outdoor Sheet | $\alpha_D$<br>Indoor Sheet |
|                                       | FOR DIRECT RADIATION |            |                       |                             |                            |
| 0                                     | 0.87                 | 0.05       | 0.76                  | 0.06                        | 0.04                       |
| 20                                    | 0.87                 | 0.05       | 0.76                  | 0.06                        | 0.04                       |
| 40                                    | 0.86                 | 0.06       | 0.74                  | 0.06                        | 0.04                       |
| 50                                    | 0.84                 | 0.06       | 0.72                  | 0.07                        | 0.05                       |
| 60                                    | 0.79                 | 0.06       | 0.66                  | 0.07                        | 0.05                       |
| 70                                    | 0.67                 | 0.06       | 0.52                  | 0.07                        | 0.05                       |
| 80                                    | 0.42                 | 0.06       | 0.25                  | 0.07                        | 0.05                       |
| 90                                    | 0.0                  | 0.0        | 0.0                   | 0.0                         | 0.05                       |
| FOR DIFFUSE OR SKY SOLAR RADIATION    |                      |            |                       |                             |                            |
|                                       | 0.79                 | 0.06       | 0.68                  | 0.07                        | 0.05                       |

dry-bulb temperature cycle, with a 95 F maximum as tabulated. *The total heat gain is the sum of the Table 13 and Table 14 values.* In preparing Table 14, convection and radiation heat exchange were combined, and a combined surface conductance of 4.0 used. Corrections to be applied for other design temperatures are given in Table 23 in a later section, Effect of Deviation from Design Conditions.

Tables 13 and 14 may be used for other types of glass with good accuracy, by using the factors given in Table 15. Table 13 values are multiplied by the appropriate factor given in Table 15 to obtain heat gain due to transmitted solar radiation. For glasses having a transmittance for normally incident radiation differing from the table values, factors may be found by linear interpolation. To obtain instantaneous rates of heat gain by convection and radiation, two steps are required. First, Table 14 values are multiplied by the appropriate coefficient of  $X$  listed in Table 15. Second, Table 16 values are multiplied by the appropriate coefficient of  $Y$  listed

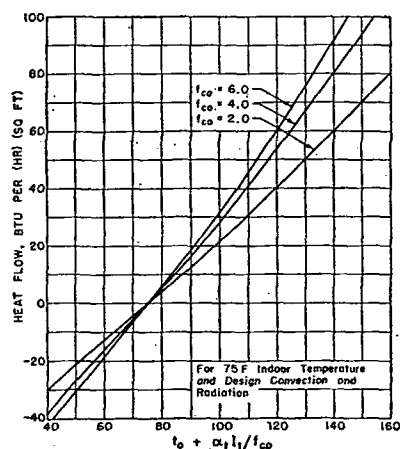


FIG. 3. CONVECTION AND RADIATION HEAT FLOW FOR VERTICAL SINGLE GLASS

TABLE 13. INSTANTANEOUS RATES OF HEAT GAIN DUE TO TRANSMITTED DIRECT AND DIFFUSE OR SKY SOLAR RADIATION BY A SINGLE SHEET OF UNSHADED COMMON WINDOW GLASS

*For Clear Atmospheres and 18 Deg Declination, North (August 1)*

Note: For total instantaneous heat gain, add these values to the Table 14 values.

| LATITUDE     | SUN TIME |        | INSTANTANEOUS HEAT GAIN IN BTU PER (HR) (SQ FT) |     |     |     |     |    |    |    |        |
|--------------|----------|--------|-------------------------------------------------|-----|-----|-----|-----|----|----|----|--------|
|              | AM →     |        | N                                               | NE  | E   | SE  | S   | SW | W  | NW | HORIZ  |
| 30 Deg North | 6 a.m.   | 6 p.m. | 25                                              | 98  | 108 | 52  | 5   | 5  | 5  | 5  | 17     |
|              | 7        | 4      | 23                                              | 155 | 190 | 110 | 10  | 10 | 10 | 10 | 71     |
|              | 8        | 4      | 16                                              | 148 | 205 | 136 | 14  | 13 | 13 | 13 | 137    |
|              | 9        | 3      | 16                                              | 106 | 180 | 136 | 21  | 15 | 15 | 16 | 195    |
|              | 10       | 2      | 17                                              | 54  | 128 | 116 | 34  | 17 | 16 | 16 | 241    |
| 30 Deg North | 11       | 1      | 18                                              | 20  | 59  | 78  | 45  | 19 | 18 | 18 | 267    |
|              | 12       |        | 18                                              | 19  | 19  | 35  | 49  | 35 | 19 | 19 | 276    |
|              | 5 a.m.   | 7 p.m. | 3                                               | 7   | 6   | 2   | 0   | 0  | 0  | 0  | 1      |
| 40 Deg North | 6        | 6      | 26                                              | 116 | 131 | 67  | 7   | 6  | 6  | 6  | 25     |
|              | 7        | 5      | 16                                              | 149 | 195 | 124 | 11  | 10 | 10 | 10 | 77     |
|              | 8        | 4      | 14                                              | 129 | 205 | 156 | 18  | 12 | 12 | 12 | 137    |
|              | 9        | 3      | 15                                              | 79  | 180 | 162 | 42  | 14 | 14 | 14 | 188    |
|              | 10       | 2      | 16                                              | 31  | 127 | 148 | 69  | 16 | 16 | 16 | 229    |
| 40 Deg North | 11       | 1      | 17                                              | 18  | 55  | 113 | 90  | 23 | 17 | 17 | 252    |
|              | 12       |        | 17                                              | 17  | 19  | 64  | 98  | 84 | 19 | 17 | 259    |
|              | 5 a.m.   | 7 p.m. | 20                                              | 54  | 54  | 20  | 3   | 3  | 3  | 3  | 6      |
| 50 Deg North | 6        | 6      | 25                                              | 128 | 149 | 81  | 8   | 7  | 7  | 7  | 34     |
|              | 7        | 5      | 12                                              | 139 | 197 | 136 | 12  | 10 | 10 | 10 | 80     |
|              | 8        | 4      | 13                                              | 107 | 202 | 171 | 32  | 12 | 12 | 12 | 129    |
|              | 9        | 3      | 14                                              | 54  | 176 | 183 | 72  | 14 | 14 | 14 | 173    |
|              | 10       | 2      | 15                                              | 18  | 124 | 174 | 110 | 16 | 15 | 15 | 206    |
| 50 Deg North | 11       | 1      | 16                                              | 16  | 57  | 143 | 138 | 42 | 16 | 16 | 227    |
|              | 12       |        | 16                                              | 16  | 38  | 96  | 144 | 96 | 18 | 16 | 234    |
|              | ↓ PM →   |        | N                                               | NW  | W   | SW  | S   | SE | E  | NE | HORIZ. |

TABLE 14. INSTANTANEOUS RATES OF HEAT GAIN BY CONVECTION AND RADIATION FROM A SINGLE SHEET OF UNSHADED COMMON WINDOW GLASS

For Clear Atmospheres and 18 Deg Declination, North (August 1)

For 80 F Indoor Temperature

Note: For total instantaneous heat gain, add these values to the Table 13 values.

[illegible]

TABLE 15. APPLICATION FACTORS TO APPLY TO TABLES 13, 14 and 16 TO OBTAIN INSTANTANEOUS RATES OF HEAT GAIN FOR VARIOUS TYPES OF SINGLE FLAT GLASS AND COMBINATIONS OF TWO SHEETS OF FLAT GLASS SPACED AT  $\frac{1}{4}$  IN.

| GLASS*                         | NORMAL INCIDENCE TRANSMITTANCE | FACTOR TO APPLY TO TABLE 13 | FACTOR TO APPLY TO TABLE 14 |
|--------------------------------|--------------------------------|-----------------------------|-----------------------------|
| Single Common Window           | 0.87                           | 1.00                        | $1.0(X)^a + 0.0(Y)^d$       |
| Single Regular Plate           | 0.77                           | 0.87 <sup>b</sup>           | $1.0(X) + 0.25(Y)$          |
| Single Heat Absorbing Plate    | 0.41                           | 0.46 <sup>b</sup>           | $1.0(X) + 1.00(Y)$          |
| Double Common Window           | 0.76                           | 0.83                        | $0.6(X) + 0.10(Y)$          |
| Double Regular Plate           | 0.60                           | 0.66 <sup>b</sup>           | $0.6(X) + 0.55(Y)$          |
| Heat Absorbing Plate Outdoors) | 0.35                           | 0.37 <sup>b</sup>           | $0.6(X) + 0.75(Y)$          |
| Regular Plate Indoors          |                                |                             |                             |

\* Common window glass  $\frac{1}{4}$  in. thick. Plate glass  $\frac{1}{2}$  in. thick.

<sup>b</sup> For better precision, increase factors 10 percent when glass is in the shade.

<sup>c</sup> X values are Table 14 values. <sup>d</sup> Y values are Table 16 values.

TABLE 16. HEAT ABSORBED IN GLASS. VALUES OF Y TO BE USED WITH FACTORS IN TABLE 15 AND TABLE 17 IN THE DETERMINATION OF INSTANTANEOUS RATES OF HEAT GAIN DUE TO CONVECTION AND RADIATION FOR VARIOUS TYPES OF SINGLE GLASS AND COMBINATIONS OF TWO SHEETS OF GLASS SPACED AT  $\frac{1}{4}$  IN.

For Clear Atmospheres and 18 Deg Declination, North (August 1)

|          |          | VALUES OF Y IN BTU PER (HR) (SQ FT)* |    |    |          |          |    |    |    |        |
|----------|----------|--------------------------------------|----|----|----------|----------|----|----|----|--------|
| SUN TIME |          | N                                    | NE | E  | SE       | S        | SW | W  | NW | HORIZ. |
| 5 a.m.   |          | 0                                    | 0  | 1  | 0        | 0        | 0  | 0  | 0  | 0      |
| 6        |          | 4                                    | 16 | 18 | 9        | 1        | 1  | 1  | 1  | 3      |
| 7        |          | 2                                    | 24 | 30 | 20       | 2        | 2  | 2  | 2  | 11     |
| 8        |          | 2                                    | 22 | 33 | 25       | 2        | 2  | 2  | 2  | 21     |
| 9        |          | 2                                    | 16 | 30 | 29       | 8        | 3  | 3  | 3  | 32     |
| 10       |          | 3                                    | 5  | 25 | 27       | 14       | 3  | 3  | 3  | 37     |
| 11       |          | 3                                    | 3  | 12 | 21       | 18       | 3  | 3  | 3  | 42     |
| 12       |          | 3                                    | 3  | 3  | 15       | 19       | 12 | 3  | 3  | 45     |
| 1 p.m.   |          | 3                                    | 3  | 3  | 3        | 19       | 22 | 10 | 3  | 44     |
| 2        |          | 3                                    | 3  | 3  | 3        | 16       | 27 | 24 | 4  | 41     |
| 3        |          | 3                                    | 3  | 3  | 3        | 10       | 30 | 31 | 15 | 35     |
| 4        |          | 3                                    | 3  | 3  | 3        | 4        | 29 | 36 | 23 | 26     |
| 5        |          | 2                                    | 2  | 2  | 2        | 2        | 23 | 34 | 27 | 17     |
| 6        |          | 4                                    | 1  | 1  | 1        | 1        | 14 | 24 | 21 | 6      |
| 7        |          | 0                                    | 0  | 0  | 0        | 0        | 2  | 3  | 3  | 1      |
|          |          |                                      |    |    |          |          |    |    |    |        |
| SUN TIME | LATITUDE | SE                                   | S  | SW | SUN TIME | LATITUDE | SE | S  | SW |        |
| 5 a.m.   |          | 0                                    | 0  | 0  | 5 a.m.   |          | 2  | 0  | 0  |        |
| 6        |          | 7                                    | 1  | 1  | 6        |          | 13 | 1  | 1  |        |
| 7        |          | 18                                   | 2  | 2  | 7        |          | 22 | 2  | 2  |        |
| 8        |          | 22                                   | 2  | 2  | 8        |          | 28 | 3  | 2  |        |
| 9        |          | 24                                   | 3  | 3  | 9        |          | 30 | 13 | 3  |        |
| 10       |          | 22                                   | 5  | 3  | 10       |          | 31 | 20 | 3  |        |
| 11       |          | 16                                   | 7  | 3  | 11       |          | 27 | 25 | 5  |        |
| 12       |          | 6                                    | 9  | 4  | 12       |          | 20 | 27 | 17 |        |
| 1 p.m.   |          | 3                                    | 9  | 14 | 1 p.m.   |          | 9  | 25 | 26 |        |
| 2        |          | 3                                    | 6  | 21 | 2        |          | 3  | 22 | 32 |        |
| 3        |          | 3                                    | 5  | 27 | 3        |          | 3  | 16 | 33 |        |
| 4        |          | 3                                    | 3  | 26 | 4        |          | 2  | 7  | 31 |        |
| 5        |          | 2                                    | 2  | 21 | 5        |          | 2  | 2  | 26 |        |
| 6        |          | 1                                    | 1  | 11 | 6        |          | 1  | 1  | 17 |        |
| 7        |          | 0                                    | 0  | 0  | 7        |          | 0  | 0  | 7  |        |

\* Values of Y for 8 and 9 p.m. are zero.

<sup>b</sup> For N, NE, E, W, NW and horizontal use 40 deg North Latitude values.

in Table 15, and added to the first value. All convection and radiation gain values for double glass were computed for a  $\frac{1}{4}$ -in. air space. No great error is involved in cooling load estimates if these are used for double glass with other air spaces.

*Example 9:* Find the total instantaneous heat gain through a single sheet of regular plate glass in a southwest wall at 2 p.m. sun time and 40 deg north latitude on August 1. The maximum dry-bulb temperature for design is 98 F; the atmosphere is clear. The indoor temperature is 80 F.

*Solution:* From Table 13 the heat gain due to transmitted radiation is 148 Btu per (hr) (sq ft) for common window glass; from Table 15, the factor for regular plate glass is 0.87. The coefficient of X in Table 15 is 1.0, while X is found from Table 14 for common window glass for the same hour, orientation and latitude. The coefficient of Y in Table 15 is 0.25, while the Y value is found from Table 16 for a southwest wall at 2:00 p.m. and 40 deg north latitude. The correction for design dry-bulb temperature is found from Table 23 to be 1.0 Btu per (hr) (sq ft) per degree difference from 95 F design temperature. The total instantaneous heat gain is, from Equation 2a,

$$q = 0.87 \times 148 + 1.0 \times 19 + 0.25 \times 27 + 1.0 (98 - 95) \\ = 157.5 \text{ Btu per (hr) (sq ft).}$$

#### Design Tables for Rolled Figured Glass

Tables 17 and 18 give design values of instantaneous rates of heat gain for a number of common patterns of single vertical sheets of rolled figured glass. The tables are for a solar declination of 18 deg, which corresponds to a nominal August 1 day, and are based upon the solar intensity values for a clear atmosphere as given in Table 4. The values are given in terms of corrections to apply to Tables 13 and 14. The heat gain due to transmitted solar radiation is found by multiplying the Table 13 values by the approximate percentages given in Table 18. To obtain instantaneous rates of heat gain by convection and radiation, Table 16 values are multiplied by the appropriate value of Y from Table 17 and then added to the corresponding Table 14 values. The total instantaneous heat gain is the sum of the gain due to transmitted solar radiation and the gain by convection and radiation.

The values given in Tables 17 and 18 are based upon an A.S.H.A.E. research paper<sup>23</sup> to which the reader is directed for additional data. The values in Tables 17 and 18 may be used with fair precision for other patterns of similar transmittance and surface characteristics. For example, the data for hammered glass may be used for glass having shallow, closely-spaced ribs or for glass having small, closely-spaced circular indentations. Because some patterns have distinct orientation properties, no attempt has been made to give values for non-vertical glass.

#### Design Tables for Glass Block Walls

Tables 20 and 21 give design values of instantaneous rates of heat gain for sunlit walls of Type I pattern 8-in. hollow glass block for a solar declination of 18 deg (see Table 19 for description of block patterns). These tables are based upon the solar intensity values for a clear atmosphere as given in Table 4. For solar energy transmittance data the reader is referred to reference 21. Table 20 presents values of transmitted direct and diffuse solar radiation, while Table 21 gives values of instantaneous rates of heat gain by convection and radiation from the wall. The latter values are for an indoor temperature of 80 F and a 95 F maximum dry-bulb temperature, as indicated in the table, and are based upon experimentally-

TABLE 17. APPLICATION FACTORS TO APPLY TO TABLES 14 AND 16 TO OBTAIN INSTANTANEOUS RATES OF HEAT GAIN FOR VERTICAL SINGLE SHEETS OF ROLLED FIGURED GLASS HAVING NORMAL INCIDENCE TRANSMITTANCES AND LISTED THICKNESSES  
(SMOOTH SIDE INDOORS, FIGURED SIDE OUTDOORS)  
(See Table 18 for Factors to Apply to Table 13 Values)

| GLASS PATTERN                              | NORMAL INCIDENCE TRANSMITTANCE | THICKNESS, INCHES | FACTOR TO APPLY TO TABLE 14 |
|--------------------------------------------|--------------------------------|-------------------|-----------------------------|
| Hammered                                   | 0.75                           | $\frac{1}{32}$    | $1.0(X)^a + 0.50(Y)^b$      |
| Hammered, etched both sides                | 0.67                           | $\frac{1}{32}$    | $1.0(X) + 0.65(Y)^c$        |
| Deep ribs on $\frac{1}{2}$ in. centers     | 0.77 approx.                   | $\frac{1}{32}$    | $1.0(X) + 0.50(Y)^d$        |
| Hammered heat absorbing                    | 0.21                           | $\frac{1}{4}$     | $1.0(X) + 1.15(Y)^e$        |
| Hammered heat absorbing, etched both sides | 0.14                           | $\frac{1}{4}$     | $1.0(X) + 1.40(Y)^e$        |

<sup>a</sup> X values are Table 14 values  
<sup>b</sup> Y values are Table 16 values  
<sup>c</sup> Use 0.40(Y) for east and west glass

<sup>d</sup> Use 0.50(Y) for east and west glass  
<sup>e</sup> Use 0.35(Y) for east and west glass  
<sup>f</sup> Use 0.95(Y) for south glass

TABLE 18. INSTANTANEOUS RATES OF HEAT GAIN DUE TO TRANSMITTED DIRECT AND DIFFUSE SOLAR RADIATION BY UNSHADED ROLLED FIGURED GLASS  
Multiply the Table 13 Values by These Percentage Factors  
For Clear Atmospheres and 18 Degrees Declination, North (August 1) For 30, 40, and 50 Degrees North Latitude  
Note: To obtain total instantaneous heat gain add adjusted Table 13 values to adjusted Table 14 values

| INSTANTANEOUS HEAT GAIN DUE TO TRANSMITTED SOLAR RADIATION AS A PERCENTAGE OF SINGLE SHEET OF COMMON WINDOW GLASS |        |                |    |    |    |                 |                     |    |    |    |    |
|-------------------------------------------------------------------------------------------------------------------|--------|----------------|----|----|----|-----------------|---------------------|----|----|----|----|
| SUN TIME                                                                                                          |        | HAMMERED       |    |    |    |                 | HAMMERED AND ETCHED |    |    |    |    |
| AM<br>↓                                                                                                           |        | N, NW<br>W, SW | NE | E  | SE | S               | N, NW<br>W, SW      | NE | E  | SE | S  |
| 5 a.m.                                                                                                            | 7 p.m. | 80             | 80 | 85 | 70 | 80              | 60                  | 65 | 75 | 55 | 60 |
| 6                                                                                                                 | 6      | 80             | 85 | 85 | 75 | 80              | 60                  | 65 | 75 | 50 | 60 |
| 7                                                                                                                 | 5      | 80             | 80 | 85 | 80 | 80              | 60                  | 60 | 70 | 55 | 60 |
| 8                                                                                                                 | 4      | 80             | 75 | 85 | 80 | 75              | 60                  | 55 | 65 | 55 | 60 |
| 9                                                                                                                 | 3      | 80             | 60 | 80 | 80 | 60              | 60                  | 50 | 55 | 55 | 50 |
| 10                                                                                                                | 2      | 80             | 65 | 75 | 75 | 65              | 60                  | 55 | 50 | 55 | 50 |
| 11                                                                                                                | 1      | 80             | 80 | 60 | 70 | 65 <sup>a</sup> | 60                  | 60 | 50 | 50 | 50 |
| 12                                                                                                                |        | 80             | 80 | 80 | 60 | 65 <sup>a</sup> | 60                  | 60 | 60 | 50 | 50 |

| SUN TIME |        | RIBBON 1/2 IN. CENTERS |    |    |    |                 | HAMMERED HEAT ABSORBING |    |    |    |    |
|----------|--------|------------------------|----|----|----|-----------------|-------------------------|----|----|----|----|
| 5 a.m.   | 7 p.m. | 60                     | 75 | 85 | 25 | 60              | 25                      | 20 | 25 | 20 | 25 |
| 6        | 6      | 60                     | 80 | 85 | 30 | 60              | 25                      | 20 | 25 | 20 | 25 |
| 7        | 5      | 60                     | 65 | 85 | 40 | 60              | 25                      | 20 | 25 | 20 | 25 |
| 8        | 4      | 60                     | 40 | 80 | 50 | 55              | 25                      | 20 | 20 | 20 | 25 |
| 9        | 3      | 60                     | 30 | 70 | 55 | 35              | 25                      | 20 | 20 | 20 | 20 |
| 10       | 2      | 60                     | 40 | 40 | 55 | 35              | 25                      | 20 | 20 | 20 | 20 |
| 11       | 1      | 60                     | 60 | 35 | 40 | 35 <sup>b</sup> | 25                      | 25 | 20 | 20 | 20 |
| 12       |        | 60                     | 60 | 60 | 35 | 45 <sup>b</sup> | 25                      | 25 | 25 | 20 | 20 |

| SUN TIME |        | HAMMERED AND ETCHED HEAT ABSORBING |    |    |    |    | HAMMERED HEAT ABSORBING |    |   |    |   |
|----------|--------|------------------------------------|----|----|----|----|-------------------------|----|---|----|---|
| AM<br>↓  |        | N, NW<br>W, SW                     | NE | E  | SE | S  | N, NE<br>E, SE          | NW | W | SW | S |
| 5 a.m.   | 7 p.m. | 20                                 | 15 | 15 | 10 | 20 |                         |    |   |    |   |
| 6        | 6      | 20                                 | 15 | 15 | 10 | 20 |                         |    |   |    |   |
| 7        | 5      | 20                                 | 10 | 15 | 10 | 20 |                         |    |   |    |   |
| 8        | 4      | 20                                 | 10 | 10 | 10 | 10 |                         |    |   |    |   |
| 9        | 3      | 20                                 | 10 | 10 | 10 | 10 |                         |    |   |    |   |
| 10       | 2      | 20                                 | 15 | 10 | 10 | 10 |                         |    |   |    |   |
| 11       | 1      | 20                                 | 20 | 10 | 10 | 10 |                         |    |   |    |   |
| 12       |        | 20                                 | 20 | 20 | 10 | 10 |                         |    |   |    |   |

| SUN TIME |        | HAMMERED AND ETCHED HEAT ABSORBING |    |    |    |    | HAMMERED HEAT ABSORBING |    |   |    |   |
|----------|--------|------------------------------------|----|----|----|----|-------------------------|----|---|----|---|
| AM<br>↓  |        | N, NW<br>W, SW                     | NE | E  | SE | S  | N, NE<br>E, SE          | NW | W | SW | S |
| 5 a.m.   | 7 p.m. | 20                                 | 15 | 15 | 10 | 20 |                         |    |   |    |   |
| 6        | 6      | 20                                 | 15 | 15 | 10 | 20 |                         |    |   |    |   |
| 7        | 5      | 20                                 | 10 | 15 | 10 | 20 |                         |    |   |    |   |
| 8        | 4      | 20                                 | 10 | 10 | 10 | 10 |                         |    |   |    |   |
| 9        | 3      | 20                                 | 15 | 10 | 10 | 10 |                         |    |   |    |   |
| 10       | 2      | 20                                 | 20 | 10 | 10 | 10 |                         |    |   |    |   |
| 11       | 1      | 20                                 | 20 | 10 | 10 | 10 |                         |    |   |    |   |
| 12       |        | 20                                 | 20 | 20 | 10 | 10 |                         |    |   |    |   |

\* Decrease values 10 percent for 30 deg latitude; increase 15 percent for 50 deg latitude

<sup>b</sup> Increase values 30 percent for 50 deg latitude

| SUN TIME |        | HAMMERED AND ETCHED HEAT ABSORBING |    |    |    |    | HAMMERED HEAT ABSORBING |    |   |    |   |
|----------|--------|------------------------------------|----|----|----|----|-------------------------|----|---|----|---|
| AM<br>↓  |        | N, NW<br>W, SW                     | NE | E  | SE | S  | N, NE<br>E, SE          | NW | W | SW | S |
| 5 a.m.   | 7 p.m. | 20                                 | 15 | 15 | 10 | 20 |                         |    |   |    |   |
| 6        | 6      | 20                                 | 15 | 15 | 10 | 20 |                         |    |   |    |   |
| 7        | 5      | 20                                 | 10 | 15 | 10 | 20 |                         |    |   |    |   |
| 8        | 4      | 20                                 | 10 | 10 | 10 | 10 |                         |    |   |    |   |
| 9        | 3      | 20                                 | 15 | 10 | 10 | 10 |                         |    |   |    |   |
| 10       | 2      | 20                                 | 20 | 10 | 10 | 10 |                         |    |   |    |   |
| 11       | 1      | 20                                 | 20 | 10 | 10 | 10 |                         |    |   |    |   |
| 12       |        | 20                                 | 20 | 20 | 10 | 10 |                         |    |   |    |   |

| SUN TIME |        | HAMMERED AND ETCHED HEAT ABSORBING |    |    |    |    | HAMMERED HEAT ABSORBING |    |   |    |   |
|----------|--------|------------------------------------|----|----|----|----|-------------------------|----|---|----|---|
| AM<br>↓  |        | N, NW<br>W, SW                     | NE | E  | SE | S  | N, NE<br>E, SE          | NW | W | SW | S |
| 5 a.m.   | 7 p.m. | 20                                 | 15 | 15 | 10 | 20 |                         |    |   |    |   |
| 6        | 6      | 20                                 | 15 | 15 | 10 | 20 |                         |    |   |    |   |
| 7        | 5      | 20                                 | 10 | 15 | 10 | 20 |                         |    |   |    |   |
| 8        | 4      | 20                                 | 10 | 10 | 10 | 10 |                         |    |   |    |   |
| 9        | 3      | 20                                 | 15 | 10 | 10 | 10 |                         |    |   |    |   |
| 10       | 2      | 20                                 | 20 | 10 | 10 | 10 |                         |    |   |    |   |
| 11       | 1      | 20                                 | 20 | 10 | 10 | 10 |                         |    |   |    |   |
| 12       |        | 20                                 | 20 | 20 | 10 | 10 |                         |    |   |    |   |

TABLE 21. INSTANTANEOUS RATES OF HEAT GAIN BY CONVECTION AND RADIATION FROM UNSHADED WALLS OF 8-IN. HOLLOW GLASS BLOCK OF PATTERNS TYPE I, II, III, IV, IVA AND V<sup>a</sup>

For Clear Atmospheres and 18 Deg Declination, North (August 1)  
For 80 F Indoor Temperature

Note: For total instantaneous heat gain add these values to values in Table 18, or Table 20 adjusted by Table 22 factors.

| SUN TIME | DRY-BULB FAHR. |                        | INSTANTANEOUS HEAT GAIN IN BTU PER (HR) (SQ FT) |    |                 |    |    |    |                 |    |
|----------|----------------|------------------------|-------------------------------------------------|----|-----------------|----|----|----|-----------------|----|
|          |                |                        | N                                               | NE | E               | SE | S  | SW | W               | NW |
| 5 a.m.   | 74             |                        | -3                                              | -3 | -3              | -3 | -3 | -3 | -3              | -3 |
| 6        | 74             |                        | 0                                               | 3  | 4 <sup>a</sup>  | 3  | -2 | -2 | -2              | -2 |
| 7        | 75             |                        | 1                                               | 15 | 17 <sup>a</sup> | 13 | -1 | -1 | -1              | -1 |
| 8        | 77             |                        | 0                                               | 21 | 26 <sup>a</sup> | 21 | 1  | 0  | 0               | 0  |
| 9        | 77             |                        | 0                                               | 20 | 33              | 27 | 5  | 1  | 2               | 1  |
| 10       | 83             |                        | 2                                               | 12 | 36              | 32 | 12 | 3  | 3               | 3  |
| 11       | 87             |                        | 4                                               | 6  | 29              | 32 | 19 | 5  | 6               | 5  |
| 12       | 90             |                        | 6                                               | 8  | 16              | 26 | 23 | 9  | 8               | 7  |
| 1 p.m.   | 93             | 40                     | 8                                               | 10 | 14              | 14 | 26 | 25 | 12              | 9  |
| 2        | 94             | Degrees North Latitude | 9                                               | 10 | 15              | 11 | 25 | 37 | 28              | 11 |
| 3        | 95             |                        | 11                                              | 11 | 18              | 11 | 21 | 44 | 41              | 17 |
| 4        | 94             |                        | 11                                              | 11 | 15              | 11 | 16 | 45 | 44              | 30 |
| 5        | 93             |                        | 11                                              | 10 | 13              | 10 | 13 | 43 | 42 <sup>a</sup> | 35 |
| 6        | 91             |                        | 13                                              | 9  | 11              | 9  | 11 | 35 | 35 <sup>a</sup> | 29 |
| 7        | 87             |                        | 11                                              | 7  | 8               | 7  | 8  | 19 | 21 <sup>a</sup> | 15 |
| 8        | 85             |                        | 7                                               | 4  | 4               | 4  | 4  | 7  | 7               | 4  |
| 9        | 83             |                        | 4                                               | 3  | 2               | 3  | 2  | 3  | 4               | 3  |

| SUN TIME | DRY-BULB | LATITUDE               | SE | S  | SW | LATITUDE               | SE | S  | SW |
|----------|----------|------------------------|----|----|----|------------------------|----|----|----|
| 5 a.m.   | 74       |                        | -3 | -3 | -3 |                        | -3 | -3 | -3 |
| 6        | 74       |                        | 1  | -2 | -2 |                        | 5  | -2 | -2 |
| 7        | 75       |                        | 11 | -1 | -1 |                        | 13 | -1 | -1 |
| 8        | 77       |                        | 20 | 0  | 0  |                        | 21 | 0  | 0  |
| 9        | 80       |                        | 26 | 1  | 2  |                        | 27 | 6  | 1  |
| 10       | 83       |                        | 29 | 4  | 4  |                        | 32 | 15 | 2  |
| 11       | 87       |                        | 26 | 8  | 5  |                        | 35 | 22 | 4  |
| 12       | 90       |                        | 18 | 12 | 7  | 50 <sup>b</sup>        | 33 | 28 | 17 |
| 1 p.m.   | 93       | 30 <sup>b</sup>        | 10 | 15 | 16 | Degrees North Latitude | 23 | 31 | 31 |
| 2        | 94       | Degrees North Latitude | 11 | 16 | 30 |                        | 12 | 32 | 39 |
| 3        | 95       |                        | 12 | 14 | 39 |                        | 11 | 28 | 43 |
| 4        | 94       |                        | 12 | 13 | 43 |                        | 11 | 20 | 44 |
| 5        | 93       |                        | 11 | 11 | 41 |                        | 10 | 12 | 43 |
| 6        | 91       |                        | 10 | 9  | 32 |                        | 9  | 10 | 36 |
| 7        | 87       |                        | 6  | 6  | 15 |                        | 7  | 7  | 23 |
| 8        | 85       |                        | 4  | 4  | 6  |                        | 4  | 4  | 10 |
| 9        | 83       |                        | 3  | 3  | 3  |                        | 3  | 3  | 3  |

<sup>a</sup> For types III, IV, IVA and V patterns and 30, 40 and 50 deg latitudes, multiply east wall values for 6 and 8 a.m. by 1.40, and west wall values for 5, 6 and 7 p.m. by 1.25.

<sup>b</sup> For N, NE, E, W and NW use 40 deg North Latitude values.

determined values of solar energy absorption and temperature difference between the two faces. Because the exact dependence of the latter on weather conditions has not been determined, the values of convection and radiation gain cannot be regarded as exact for the assumed design conditions. Indoor and outdoor convection and radiation heat transfer data are the same as those used for common window glass. Table 23 gives corrections to be applied for other design temperatures.

To obtain transmitted direct and diffuse solar radiation for other types of 8-in. block, the Table 20 values are multiplied by the approximate percentages given in Table 22. Note that corrections are the same for all latitudes, and that they vary only on the surfaces exposed to the direct sun. The convection and radiation gain values for all blocks are so nearly

TABLE 22. INSTANTANEOUS RATES OF HEAT GAIN DUE TO TRANSMITTED DIRECT AND DIFFUSE SOLAR RADIATION BY UNSHADED WALLS OF 8-IN HOLLOW GLASS BLOCK OF TYPES II, III, IV, IVA AND V PATTERNS

Multiply the Table 20 Values for Type I by These Percentage Factors

For Clear Atmospheres and 18 Deg Declination, North (August 1)

For 30, 40, and 50 Deg North Latitude

Note: To obtain total instantaneous heat gain add adjusted Table 20 values to the Table 21 values.

| INSTANTANEOUS HEAT GAIN DUE TO TRANSMITTED SOLAR RADIATION AS A PERCENTAGE OF TYPE I PATTERN |        |                 |     |     |     |                  |              |    |    |    |
|----------------------------------------------------------------------------------------------|--------|-----------------|-----|-----|-----|------------------|--------------|----|----|----|
| SUN TIME                                                                                     |        | TYPE II PATTERN |     |     |     | TYPE III PATTERN |              |    |    |    |
|                                                                                              |        | N, NW, W, SW    | NE  | E   | SE  | S                | N, NW, W, SW | NE | E  | SE |
| 5 a.m.                                                                                       | 7 p.m. | 100             | 100 | 100 | 100 | 100              | 70           | 70 | 70 | 70 |
| 6                                                                                            | 6      | 100             | 95  | 95  | 90  | 100              | 70           | 65 | 65 | 70 |
| 7                                                                                            | 5      | 100             | 90  | 90  | 90  | 100              | 70           | 65 | 60 | 70 |
| 8                                                                                            | 4      | 100             | 95  | 90  | 90  | 100              | 70           | 65 | 60 | 70 |
| 9                                                                                            | 3      | 100             | 95  | 85  | 90  | 100              | 70           | 65 | 60 | 70 |
| 10                                                                                           | 2      | 100             | 95  | 85  | 95  | 95               | 70           | 65 | 60 | 70 |
| 11                                                                                           | 1      | 100             | 100 | 95  | 95  | 100              | 70           | 70 | 70 | 75 |
| 12                                                                                           |        | 100             | 100 | 100 | 100 | 100              | 70           | 70 | 70 | 75 |
| PM →                                                                                         |        | N, NE, E, SE    | NW  | W   | SW  | S                | N, NE, E, SE | NW | W  | SW |

| INSTANTANEOUS HEAT GAIN DUE TO TRANSMITTED SOLAR RADIATION AS A PERCENTAGE OF TYPE I PATTERN |        |                 |    |    |    |                  |              |    |     |     |
|----------------------------------------------------------------------------------------------|--------|-----------------|----|----|----|------------------|--------------|----|-----|-----|
| SUN TIME                                                                                     |        | TYPE IV PATTERN |    |    |    | TYPE IVA PATTERN |              |    |     |     |
|                                                                                              |        | N, NW, W, SW    | NE | E  | SE | S                | N, NW, W, SW | NE | E   | SE  |
| 5 a.m.                                                                                       | 7 p.m. | 55              | 45 | 35 | 75 | 55               | 55           | 45 | 35  | 30  |
| 6                                                                                            | 6      | 55              | 45 | 35 | 80 | 55               | 55           | 45 | 35  | 30  |
| 7                                                                                            | 5      | 55              | 45 | 35 | 60 | 55               | 55           | 45 | 35  | 30  |
| 8                                                                                            | 4      | 55              | 45 | 30 | 40 | 55               | 55           | 45 | 35  | 30  |
| 9                                                                                            | 3      | 55              | 50 | 25 | 30 | 60               | 55           | 50 | 45  | 45  |
| 10                                                                                           | 2      | 55              | 55 | 35 | 30 | 60               | 55           | 55 | 65  | 60  |
| 11                                                                                           | 1      | 55              | 55 | 45 | 35 | 60               | 55           | 55 | 70  | 105 |
| 12                                                                                           |        | 55              | 55 | 55 | 60 | 45               | 55           | 55 | 100 | 115 |
| PM →                                                                                         |        | N, NE, E, SE    | NW | W  | SW | S                | N, NE, E, SE | NW | W   | SW  |

| INSTANTANEOUS HEAT GAIN DUE TO TRANSMITTED SOLAR RADIATION AS A PERCENTAGE OF TYPE I PATTERN |        |                |    |     |     |                           |  |  |  |  |
|----------------------------------------------------------------------------------------------|--------|----------------|----|-----|-----|---------------------------|--|--|--|--|
| SUN TIME                                                                                     |        | TYPE V PATTERN |    |     |     | Designation of Block Type |  |  |  |  |
|                                                                                              |        | N, NW, W, SW   | NE | E   | SE  | S                         |  |  |  |  |
| 5 a.m.                                                                                       | 7 p.m. | 60             | 35 | 35  | 30  | 60                        |  |  |  |  |
| 6                                                                                            | 6      | 60             | 35 | 35  | 30  | 60                        |  |  |  |  |
| 7                                                                                            | 5      | 60             | 35 | 40  | 35  | 60                        |  |  |  |  |
| 8                                                                                            | 4      | 60             | 50 | 65  | 50  | 60                        |  |  |  |  |
| 9                                                                                            | 3      | 60             | 80 | 90  | 90  | 60                        |  |  |  |  |
| 10                                                                                           | 2      | 60             | 70 | 105 | 105 | 90 <sup>a</sup>           |  |  |  |  |
| 11                                                                                           | 1      | 60             | 60 | 80  | 110 | 105 <sup>a</sup>          |  |  |  |  |
| 12                                                                                           |        | 60             | 60 | 85  | 85  | 115 <sup>a</sup>          |  |  |  |  |
| PM →                                                                                         |        | N, NE, E, SE   | NW | W   | SW  | S                         |  |  |  |  |

<sup>a</sup> Reduce by 30% for 30 deg N latitude only.

TABLE 23. APPROXIMATE CORRECTIONS TO TABLES 14 AND 21 FOR DEVIATIONS FROM INDOOR AND OUTDOOR DESIGN TEMPERATURES

For each degree the design room temperature exceeds 80 F, subtract correction. For each degree the design outdoor dry-bulb temperature exceeds 95 F, add correction. Apply these corrections to each value in Table 14 or Table 21.

| GLASS TYPE                          | CORRECTION BTU PER (HR) (SQ FT) |
|-------------------------------------|---------------------------------|
| Single Flat or Rolled Figured Glass | 1.0                             |
| Double Flat Glass and Glass Block   | 0.5                             |



the same that a single table suffices. Note, however, that corrections must be made for certain hours for east and west facing walls of some patterns.

**Example 10:** Find the total instantaneous heat gain through an east wall of 8-in. hollow glass block of Type V pattern at 8 a.m. and 50 deg north latitude. The design temperatures are 80 F indoors, and 95 F maximum outdoor dry-bulb, clear atmosphere.

**Solution:** The gain due to transmitted solar radiation is found from Table 20 for Type I pattern. The factor for Type V is found from Table 22. The convection and radiation gain is found from Table 21 (note the footnote).

The total instantaneous heat gain is, from Equation 2a,

$$q = 86 \times 0.65 + 26 \times 1.4 = 92.3 \text{ Btu per (hr)(sq ft).}$$

### Effect of Deviations from Design Conditions

If the indoor temperature differs from 80 F, or the design outdoor dry-bulb temperature differs from 95 F, corrections can be made to the convection and radiation gain values for flat glass, rolled figured glass, and glass block according to the schedule in Table 23.

The effect of the humid industrial type atmosphere is to cause a considerable reduction in heat gain, if all factors except solar intensity remain the same. Reference 22 gives heat gain values for four orientations at 40 deg north latitude on August 1 for several types of flat glass and glass block, and solar intensities typical of humid industrial atmospheres. These data show that the following approximate reductions, based on total gain for the day, can be expected: 20 percent for all types of glass and glass block in east or west facing walls; 10 percent for south facing flat glass; 5 percent for south facing glass block walls.

### Shading of Glass Areas—Design Tables

The effects and possibilities of shading should be carefully investigated whenever the heat gain from glass is a large portion of the cooling load.

Vertical glass, which is not mounted in the plane of the building surface, is partially shaded by the setback. If a vertical window of height  $l$  and width  $w$  be set back from the plane of the building a distance  $s$ , the fraction of the total area of the window which receives direct solar radiation is:

$$G_t = 1 - \frac{r_1 \tan \beta}{\cos \gamma} - r_2 \tan \gamma + \frac{r_1 r_2 \tan \beta \tan \gamma}{\cos \gamma} \quad (5)$$

where

$r_1 = s/l$ ,  $r_2 = s/w$ ,  $\beta$  = solar altitude, and  $\gamma$  is the wall solar azimuth (see Fig. 1)

Values of  $\beta$  and  $\gamma$  for various latitudes and August 1 are given in Table 6. Special cases not covered by the tabulated data may be solved analytically,<sup>24</sup> however, the design conditions chosen will yield a satisfactory approximation if used without correction for any time during the summer period.

**Example 11:** Estimate the total instantaneous rate of heat gain for a west window 3 ft wide by 5 ft high, with a setback of 6 in., for August 1 and 40 deg north latitude at 3:00 pm (sun time).

**Solution:** From Table 13, the instantaneous rate of heat gain, due to transmitted direct and diffuse solar radiation, is 180 Btu per hr. From Table 6,  $\beta$  is 45.5 deg and

### Cooling Load

$\gamma$  is 16 deg. From Equation 5, the fraction of the total window area that is receiving direct solar radiation is:

$$G_t = 1 - \frac{0.1 \tan 45.5}{\cos 16} - 0.167 \tan 16 + \frac{0.0167 \tan 45.5 \tan 16}{\cos 16} \\ = 1 - 0.106 - 0.048 + 0.005 = 0.851$$

In this instance the convection and radiation heat gain is due principally to temperature difference, so that shading has but a small effect on that portion of the absorbed radiation. Hence, the factor 0.851 is applied

TABLE 24. EFFECT OF SHADING UPON INSTANTANEOUS SOLAR HEAT GAIN THROUGH SINGLE THICKNESS OF COMMON WINDOW GLASS

| TYPE OF SHADING                                                                                     | FINISH ON SIDE EXPOSED TO SUN     | FRACTION OF GAIN THROUGH UNSHADOWED WINDOW |
|-----------------------------------------------------------------------------------------------------|-----------------------------------|--------------------------------------------|
| Canvas awning sides open                                                                            |                                   |                                            |
| Canvas awning top and sides tight against building                                                  | Dark or medium                    | 0.25                                       |
| Inside roller shade, fully drawn <sup>a</sup>                                                       | Dark or medium                    | 0.35                                       |
| Inside roller shade, fully drawn <sup>a</sup>                                                       | White, cream                      | 0.41 <sup>f</sup>                          |
| Inside roller shade, fully drawn <sup>a</sup>                                                       | Medium                            | 0.62                                       |
| Inside roller shade, fully drawn <sup>a</sup>                                                       | Dark                              | 0.81                                       |
| Inside roller shade, half drawn <sup>a</sup>                                                        | White, cream                      | 0.71                                       |
| Inside roller shade, half drawn <sup>a</sup>                                                        | Medium                            | 0.81                                       |
| Inside roller shade, half drawn <sup>a</sup>                                                        | Dark                              | 0.91                                       |
| Inside venetian blind, slats set at 45 deg <sup>b</sup>                                             | White, cream                      | 0.56 <sup>f</sup>                          |
| Inside venetian blind, slats set at 45 deg <sup>b</sup>                                             | Diffuse reflecting aluminum metal | 0.45 <sup>f</sup>                          |
| Inside venetian blind, slats set at 45 deg <sup>b</sup>                                             | Medium                            | 0.65 <sup>f</sup>                          |
| Inside venetian blind, slats set at 45 deg <sup>b</sup>                                             | Dark                              | 0.75 <sup>f</sup>                          |
| Outside venetian blind, slats set at 45 deg <sup>b</sup>                                            | White, cream                      | 0.15 <sup>f</sup>                          |
| Outside venetian blind, slats set at 45 deg <sup>b</sup> extended as awning                         | White, cream                      | 0.15                                       |
| Outside venetian blind, slats set at 45 deg, extended as awning covering 3/4 of window <sup>c</sup> | White, cream                      | 0.43                                       |
| Outside shading screen solar altitude 10 deg                                                        | Dark <sup>d, f</sup>              | 0.52                                       |
| Outside shading screen solar altitude 20 deg                                                        | Green tint <sup>e, f</sup>        | 0.46                                       |
| Outside shading screen solar altitude 30 deg                                                        |                                   | 0.40                                       |
| Outside shading screen solar altitude, above 40 deg                                                 |                                   | 0.35                                       |
|                                                                                                     |                                   | 0.24                                       |
|                                                                                                     |                                   | 0.15                                       |
|                                                                                                     |                                   | 0.22                                       |

<sup>a</sup> Roller shades are assumed to be opaque. Some white shades may transmit considerable solar radiation. For white translucent shades fully drawn use 0.55 and for half drawn use 0.77.  
<sup>b</sup> Venetian blinds are fully drawn and cover window. It is assumed that the occupant will adjust slats to prevent direct rays from passing between slats. If slats are fully closed (slats set at 90 deg.) use same factors as used for roller shade fully drawn.  
<sup>c</sup> Commercial shade with wide slats. The sun may shine on window through sides of shade. Estimate the exposed portion of glass as unshaded.  
<sup>d</sup> Commercial shade, bronze. Metal slats 0.05 inches wide 17 per inch and set at 17 deg angle with horizontal. At solar altitudes below 40 deg some direct solar rays are allowed to pass between slats, and this amount becomes progressively greater at low solar altitudes.  
<sup>e</sup> Commercial aluminum shade. Slats 0.057 inches wide, 17.5 per inch, set at 17 deg angle with horizontal. At solar altitudes below 40 deg some direct solar rays are allowed to pass between slats and this amount becomes progressively greater at low solar altitude.  
<sup>f</sup> From first paper in Reference 9.

only to the Table 13 value. Note also a small error results from the fact that the diffuse radiation is not shaded to the same extent as the direct radiation. The total instantaneous heat gain therefore is:

$$q = 3 \times 5 (0.851 \times 180 + 26) = 2690 \text{ Btu per (hr)(sq ft)}$$

A window such as the one used in Example 11 would customarily be provided with an additional shading means for use particularly when directly sunlit. Conventional shading devices include awnings, shades, and screens of various types.

Much experimental and analytical work conducted at the A.S.H.A.E.

Research Laboratory<sup>25</sup> as well as earlier experimental work,<sup>24, 26</sup> and other research<sup>27</sup> to determine the effectiveness of various types of window shades, have been used as the basis for the recommended ratios in column 3 of Table 24. A study of absorptivity of the shade to solar radiation and heat transfer from the shade to the outdoors and indoors, was used to determine these ratios.

There are a number of variables affecting these ratios such as color, fit, solar altitude, and angle of incidence of the solar radiation. These values, therefore, must be considered as approximate, only, and will have to be used with considerable judgment. An inside shade is effective to the extent of its reflectivity, since the portion of the solar radiation directly transmitted by the glass that is absorbed by the shade is transferred by convection to the room air, and by radiation to the solid room surfaces.

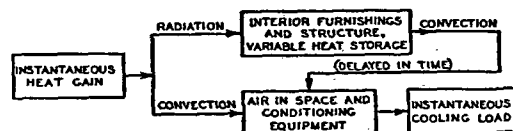


FIG. 4. ORIGIN OF THE DIFFERENCE BETWEEN THE MAGNITUDES OF THE INSTANTANEOUS HEAT GAIN AND INSTANTANEOUS COOLING LOAD

The radiation absorbed by the interior furnishings and structure reaches the conditioning equipment after a considerable delay in time.

### INSTANTANEOUS HEAT GAINS VS. INSTANTANEOUS COOLING LOADS

The difference between instantaneous heat gain and instantaneous cooling load has been mentioned previously; its practical importance is sufficient to warrant further consideration. Fig. 4 offers a simplified schematic illustration showing how the *radiative* part of the instantaneous heat gain is first absorbed by solid objects, and is not encountered by the conditioning equipment as a cooling load until some later time, when it finally appears in the air stream entering the equipment. While it is true that some lag also is inherent in convective heat transfer and the time required to change the air in the conditioned space, this is usually of the order of a few minutes to perhaps half an hour. Heat storage in the interior furnishings and structure increases according to the proportion of the instantaneous heat gain which is in the form of radiation, and also as the thermal capacitance of the objects and materials involved is increased.

Constituents of the total instantaneous heat gain which have appreciable radiation components include those due to glass areas, exposed walls and roofs, lighting, appliances, and people.

No comprehensive data are presently available for use in design load estimates to evaluate the interior load-lag effect, but several investigators<sup>14, 28, 29, 30</sup> have made a study of the problem and have presented many useful data. Tables 9, 10, 13, 14, 18, 20, and 21 are all based on instantaneous rates of heat transfer. Hence, practical judgment and experience offer the only basis of procedure. Until the needed data become available, it is recommended that the non-continuous load be averaged over two or three hours during the time of maximum load, when determining the total instantaneous cooling load where a large portion of the heat gain is radiant. This suggestion applies only to conditions near the time of maximum heat

gain, as the heat stored within the structure would necessarily appear in the cooling load eventually; but if it appears at a time when the gain from outside is relatively low, the equipment will be able to maintain satisfactory conditions within the range of maximum capacity.

### LOAD FROM INTERIOR PARTITIONS, CEILINGS, AND FLOORS

Whenever a conditioned space is adjacent to another space in which a different temperature prevails, the transfer of heat through the separating structural section must be considered. Calculations are made according to the relation:

$$q = U_1 A_1 (t_b - t_i) \text{ Btu per hour.} \quad (6)$$

where  $U_1$  = coefficient of overall heat transfer between the adjacent and the conditioned space, Btu per (hour) (square foot) (Fahrenheit degree).

$A_1$  = area of separating section concerned, square feet.

$t_b$  = air temperature in adjacent space, Fahrenheit degrees.

$t_i$  = air temperature in conditioned space, Fahrenheit degrees.

Magnitudes of  $U_1$  may be obtained from Chapter 9. The temperature  $t_b$  may have any value over a considerable range, according to conditions in the adjacent space. The temperature in a kitchen or boiler room may be as much as 15 to 50 deg above the outdoor air temperature. It is recommended that actual temperatures be measured in adjoining spaces wherever practicable. Where nothing is known, except that the adjacent space is of conventional construction and contains no heat sources, it is recommended that the difference  $(t_b - t_i)$  be taken as the difference between the outdoor-air and conditioned-space design dry-bulb temperatures *minus* 5 deg. In some cases it may be that the air temperature in the adjacent space will correspond closely to the outdoor air temperature at all times. Under these latter conditions, the heat gain through the partition will be periodic in nature, and the value of a shaded wall should be used from Table 10.

For floors directly in contact with the ground, or over an underground basement that is neither ventilated nor warmed, the heat transfer may be neglected for cooling-load estimates.

### LOAD FROM OUTDOOR AIR, VENTILATION AND INFILTRATION

**Ventilation.** Data for determining the necessary ventilation rate have been presented previously in this chapter. Ventilation required is primarily dependent upon the number of occupants and upon the materials and apparatus within the space which may give off odors. For spaces having ceiling heights 10 ft or less, the total requirement should be checked against the volume, and in no case should the ventilation air rate be less than one air change per hour. In spaces having ceilings higher than 10 ft where the occupant load is low, a check calculation can be made against the volume of the space below an assumed 10-ft ceiling.

Infiltration must never be counted upon to provide ventilation, because on still days there will be little or no infiltration.

**Infiltration.** The principles of infiltration calculations have been discussed in Chapters 11 and 12, with emphasis on the heating season. For the cooling season, infiltration calculations are usually limited to doors and windows.

To compute cooling-load infiltration for windows by the crack method,

use the data of Table 2, Chapter 11, for a wind velocity of 10 mph. Note that for double-hung windows the length of crack is three times the width plus twice the height; while for metal-sash windows the crack length is the total perimeter of the movable or ventilating sections. In calculating window infiltration for an entire structure, it is not necessary to consider the total crack length on all sides of the building, for the wind would not act simultaneously on all sides at once. In no case, however, should less than half of the total crack length be figured. A knowledge of the prevailing wind direction will aid judgment in this consideration.

Cooling-load infiltration for doors<sup>32</sup> may be obtained from Table 3, Chapter 11. For conditions other than those covered, the notes appended to the table will provide a basis for estimates. The tabulated data may also be used as the basis of estimates for interior doors between an air-conditioned and a non-air-conditioned space.

Infiltration load must be included whenever the new air introduced through the system is not sufficient to maintain excess pressure within the enclosure to prevent the infiltration. Whenever economically feasible, it is desirable to introduce sufficient outdoor air through the air-conditioning equipment to maintain a constant outward escape of air, and thus eliminate the infiltration portion of the load. The pressure maintained must, of course, be sufficient to overcome wind pressure through cracks and door openings. When this condition prevails it is not necessary to include any infiltration load. When the quantity of new air introduced through the cooling equipment is not sufficient to build up the required pressure to offset infiltration, the entire infiltration load should be included in the cooling load calculations.

**Total Outside Air Load.** Many cooling coil manufacturers publish tables giving psychrometric data based on the *average* conditions of the leaving air for various coil temperatures, air velocities, and entering dry-bulb and wet-bulb conditions. When these tables are used, it is necessary to calculate the mixed air condition entering the coil, and determine from the tables what coil and air velocity will produce the desired leaving air conditions as required for the space to be conditioned. When cooling coils are listed as 80 to 95 percent efficient, the manufacturer indicates that 20 to 5 percent of the air passes through the coil without being cooled. If data of this nature are used, the uncooled portion of the air must be added to the space load before determining the effective air quantity. See later section on Apparatus Dew Point.

To determine the design cooling load caused by the introduction of outside air, the maximum rate of outside-air entry is first established. In some applications the use of special exhausters from the conditioned space may add to the outdoor-air requirements in determining the maximum rate. Once this design quantity is established, and with the design indoor and outdoor air states known, the cooling load may be computed. There are several methods in use; the more accurate of these require rather detailed calculations. Refer to Chapter 3, and also section on Apparatus Dew Point in this chapter. The following equations are considered to be of sufficient precision for use at usual design conditions, as their accuracy is within 1 percent.

$$\begin{aligned} \text{Sensible Load } q_s &= Q \times 60 \times 0.244 \times 0.075 \left( 1 - \frac{0.00923}{0.62} \right) (t_o - t_i) \\ &= Q \times 1.08 (t_o - t_i), \text{ Btu per hour} \end{aligned} \quad (7)$$

### Cooling Load

313

$$\begin{aligned} \text{Latent Load } q_l &= Q \times 60 \times 0.075 \times 1076 (W_o - W_i) \\ &= Q \times 4840 (W_o - W_i), \text{ Btu per hour} \end{aligned} \quad (8)$$

$$\text{Total Load } q_t = q_s + q_l \quad (9)$$

where

$Q$  = rate of entry of outside air, cubic feet per minute.

$t_o$  = outdoor dry-bulb temperature, Fahrenheit.

$t_i$  = indoor dry-bulb temperature, Fahrenheit.

$W_o$  = outdoor humidity ratio, pounds moisture per pound of dry air.

$W_i$  = indoor humidity ratio, pounds moisture per pound of dry air.

0.075 = standard air density, pounds per cubic foot.

0.244 = a constant approximating the specific heat of dry air corrected for moisture Btu per (pound) (Fahrenheit degree).

1076 = a factor approximating the average Btu released in condensing one pound of water vapor from air.

As explained later in the section on Apparatus Dew Point, some methods of load calculations break down the ventilation air into two parts: one portion which does not contact the coil surfaces (i.e. bypasses the coil) in passing through the coil and thus becomes a part of the room load; and a second portion, the remainder of the air which contacts the coil surfaces and is cooled down to the apparatus dew point. This detailed method explained in the literature by Ashley,<sup>31</sup> is believed to be very easy and accurate to use. Similar equations, therefore, can be written:

$$\begin{aligned} \text{Space Sensible Ventilation Load,} \\ q_{s1} &= Q \times 1.08 (t_o - t_i) \times b \end{aligned} \quad (10)$$

$$\begin{aligned} \text{Space Latent Ventilation Load,} \\ q_{l1} &= Q \times 4840 (W_o - W_i) \times b \end{aligned} \quad (11)$$

$$\begin{aligned} \text{Remaining Sensible Ventilation Load,} \\ q_{s2} &= Q \times 1.08 (t_o - t_i) (1 - b) \end{aligned} \quad (12)$$

$$\begin{aligned} \text{Remaining Latent Ventilation Load,} \\ q_{l2} &= Q \times 4840 (W_o - W_i) (1 - b) \end{aligned} \quad (13)$$

$$q_t = q_{s1} + q_{s2} + q_{l1} + q_{l2} \quad (14)$$

where

$b$  = fraction of air passing through coil which does not contact surfaces, coil bypass factor.

Standard air weight (0.075) lb per cu ft) is recommended for use in all calculations, as this is the basis for rating fans and its consistent use keeps all parts of the calculations in conformity.

### HOW OUTDOOR AIR LOAD AFFECTS ROOM LOAD

Actually, the outdoor air used for ventilation would pass through the conditioning equipment, and be cooled and dehumidified to a lower temperature and humidity ratio than room conditions before entering the room; but for heat-balance purposes the cooling load chargeable to the outdoor air is that corresponding to the difference between the outdoor and indoor air conditions.

One important purpose of the cooling load estimate is to determine the

conditions and quantity of air supplied to the space. All the various sensible and latent heat loads within the space must be included. Infiltration must be included in the space load since this air enters the doors and windows, and its heat and moisture load must be offset by the introduction of cooler, dryer air to the space. However, since outdoor air is taken through the conditioning equipment and cooled, this portion does not become a part of the space load, except a small portion which passes through the coil untreated. To determine the total load on the refrigeration machine, the remaining outdoor air load must be included in the grand total load.

TABLE 25. RATES OF HEAT GAIN FROM OCCUPANTS OF CONDITIONED SPACES<sup>a</sup>

| DEGREE OF ACTIVITY                           | TYPICAL APPLICATION                 | TOTAL HEAT ADULTS, MALE Btu/Hr | TOTAL HEAT ADJUSTED <sup>b</sup> Btu/Hr | SENSIBLE HEAT Btu/Hr | LATENT HEAT Btu/Hr |
|----------------------------------------------|-------------------------------------|--------------------------------|-----------------------------------------|----------------------|--------------------|
| Seated at Rest.....                          | Theater-Matinee.....                | 390                            | 330                                     | 180                  | 150                |
|                                              | Theater-Evening.....                | 390                            | 350                                     | 195                  | 155                |
| Seated, Very Light Work.....                 | Offices, Hotels, Apartments.....    | 450                            | 400                                     | 195                  | 205                |
| Moderately Active Office Work.....           | Offices, Hotels, Apartments.....    | 475                            | 450                                     | 200                  | 250                |
| Standing, Light Work; or Walking Slowly..... | Department Store, Retail Store..... | 550                            | 450                                     | 200                  | 250                |
| Walking: Seated.....                         | Drug Store.....                     | 550                            | 500                                     | 200                  | 300                |
| Standing; Walking Slowly.....                | Bank.....                           | 490                            | 550                                     | 220                  | 330                |
| Sedentary Work.....                          | Restaurant <sup>c</sup> .....       | 800                            | 750                                     | 220                  | 530                |
| Light Bench Work.....                        | Factory.....                        | 900                            | 850                                     | 245                  | 605                |
| Moderate Dancing.....                        | Dance Hall.....                     |                                |                                         |                      |                    |
| Walking 3 mph; Moderately Heavy Work.....    | Factory.....                        | 1000                           | 1000                                    | 300                  | 700                |
| Bowling.....                                 | Bowling Alley.....                  |                                |                                         |                      |                    |
| Heavy Work.....                              | Factory.....                        | 1500                           | 1450                                    | 465                  | 985                |

<sup>a</sup> Note: Tabulated values are based on 80 F room dry-bulb temperature. For 78 F room dry-bulb, the total heat remains the same, but the sensible heat values should be increased by approximately 10 percent, and the latent heat values decreased accordingly.

<sup>b</sup> Adjusted total heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85 percent of that for an adult male, and that the gain from a child is 75 percent of that for an adult male.

<sup>c</sup> Adjusted total heat value for sedentary work, restaurant, includes 60 Btu per hour for food per individual (30 Btu sensible and 30-Btu latent).

<sup>d</sup> For bowling figure one person per alley actually bowling, and all others as sitting (400 Btu per hour) or standing (550 Btu per hour).

**Example 12:** For outdoor design conditions of 95 F dry-bulb and 75 F wet-bulb, and indoor design conditions of 80 F dry-bulb and 67 F wet-bulb, and for the supply of outdoor air at the rate of 1000 cfm and the exhaust of room air at the corresponding rate, calculate the total, sensible and latent heat gains.

**Solution:** Substituting in Equation 7:

$$q_s = 1000 \times 1.08 (95 - 80) = 16,200 \text{ Btu per hr.}$$

From psychrometric data  $W_o = 0.01413$ ,  $W_i = 0.01122$ .

Substituting in Equations 8 and 9:

$$q_s = 1000 \times 4840 (0.01413 - 0.01122) = 14,100 \text{ Btu per hr.}$$

$$q_t = q_s + q_s = 30,300 \text{ Btu.}$$

### HEAT SOURCES WITHIN THE CONDITIONED SPACE

**People.** The rates at which heat and moisture are given off by human beings under different states of activity are given in Table 25. In many applications these sensible and latent heat gains become a large fraction of

the total load. Appreciable variations in heat-emission rates must be recognized according to the age and sex of the individual; state of activity, environmental influences, and duration of occupancy (since for short occupancy the extra heat and moisture brought in by people may be a significant factor).

While Chapter 6 should be referred to for detailed information, Table 25 in this chapter summarizes practical data representing conditions commonly encountered.

**Lighting.** In general, the instantaneous rate of heat gain from electric lighting<sup>22</sup> may be calculated from the following relation:

$$q_l = \left\{ \frac{\text{total light}}{\text{wattage}} \times \left\{ \frac{\text{use}}{\text{factor}} \times \left\{ \frac{\text{special allow-}}{\text{ance factor}} \right\} \times 3.41, \text{ Btu per hr.} \right. \right. \quad (15)$$

The *total light wattage* is obtained from the ratings of all fixtures installed, both for general illumination and for display use.

The *use factor* is the ratio of the wattage in use, for the conditions under which the load estimate is being made, to the total installed wattage. For commercial applications such as stores, the use factor would be unity.

The *special allowance factor* is introduced to care for fluorescent fixtures, and for fixtures which are either ventilated or installed so that only part of their heat goes to the conditioned space. For *fluorescent fixtures*, the special allowance factor is recommended to be taken as 1.20 in order to allow for power consumed in the ballast. For *ventilated fixtures*, *recessed fixtures*, and the like, manufacturers' or other data<sup>23</sup> must be sought to establish the fraction of the total wattage which may be expected to enter the conditioned space.

**Power.** When equipment of any sort is operated within the conditioned space by electric motors, the heat equivalent of this operation must be considered in the cooling load. The general equation for calculating this load is:

$$q_{em} = \left( \frac{\text{Horsepower Rating}}{\text{Motor Efficiency}} \right) \times \left( \frac{\text{Load}}{\text{Factor}} \right) \times 2544, \text{ Btu per hr.} \quad (16)$$

It is assumed that both the motor and the driven equipment are within the conditioned space. If the motor is without the space, then *do not divide* by the motor efficiency in Equation 16. The *load factor* is merely the fraction of the rated load which is being delivered under the conditions of the cooling-load estimate. *Motor efficiencies* may be approximated as follows: about 50 to 60 percent at  $\frac{1}{2}$  hp rating, increasing to 80 percent at 1 hp, and to 88 percent at 10 hp and above.

**Appliances.** Care must be taken in a cooling-load estimate to take into account the heat gain from all appliances, electrical, gas, or steam. Table 26 presents recommended data.<sup>24</sup> Note that the *maintaining rate* in Table 26 is the heat input required to maintain the appliance at the normal operating temperature even though it is not being used, i.e., no coffee is being made, no toast is being made, no food is being cooked in the fry kettle, etc. The maintaining rate is useful in setting up a lower limit to the heat gain to a room from the appliance when in operation.

Experienced judgment must be used in the application of data given in Table 26. Consideration must be given to the heat contributed by appliances which are in use at the time of peak load. The quantity of heat will depend upon whether products of combustion are vented to a flue, whether they escape into the space to be conditioned, or whether appliances are hooded allowing part of the heat to escape through a stack. There are no generally accepted data available on the effects of venting and shielding

TABLE 26. RATE OF HEAT GAIN FROM APPLIANCES WITHOUT HOODS.<sup>a,b</sup>

| APPLIANCE                                                | CAPACITY       | OVER-ALL DIMEN-<br>SIONS (LESS LEGS<br>AND HANDLES;<br>LAST DIMENSION<br>IS HEIGHT) INCHES | CONTROL<br>A—AUTOMATIC<br>M—MANUAL | MISCELLANEOUS DATA                                               | MANT-<br>FACTURES'S<br>RATING<br>WATTS | Btu/Hr         | MAIN-<br>TAINING<br>RATE<br>Btu per<br>hour | RECOMMENDED RATE OF<br>HEAT GAIN Btu per hour |              |
|----------------------------------------------------------|----------------|--------------------------------------------------------------------------------------------|------------------------------------|------------------------------------------------------------------|----------------------------------------|----------------|---------------------------------------------|-----------------------------------------------|--------------|
|                                                          |                |                                                                                            |                                    |                                                                  |                                        |                |                                             | SENSIBLE                                      | LATENT       |
| Restaurant Electrical Appliances                         |                |                                                                                            |                                    |                                                                  |                                        |                |                                             |                                               |              |
| Coffee Brewer and Warmer                                 | 1/2 gal        |                                                                                            | M                                  | Brewer 660 w<br>Warmer 80 w                                      | 600<br>90                              | 2000<br>300    | 306                                         | 900<br>230<br>60                              | 220<br>1120  |
| Coffee Brewer Unit with tank                             | 1/2 gal        | 20 x 30 x 26                                                                               | M                                  | 2000 w Water heater,<br>2660 w brewer                            | 4960                                   | 17000          |                                             | 4800<br>1200                                  | 6000         |
| Coffee Urn                                               | 3 gal<br>5 gal | 12 x 23 x 21<br>18 (Diam.) x 37                                                            | A                                  | Nickel plated<br>Nickel plated                                   | 4500<br>5000                           | 15000<br>17000 | 2800<br>3600                                | 2200<br>3400                                  | 3700<br>5700 |
| Doughnut Machine                                         |                | 22 x 22 x 57                                                                               | A                                  | Exhaust System                                                   | 4700                                   | 16000          |                                             | 5000<br>0                                     | 5000         |
| Egg Boiler                                               | 2 cups         | 10 x 13 x 25                                                                               | M                                  |                                                                  | 1100                                   | 3750           |                                             | 1200<br>800                                   | 2000         |
| Food Warmer, with Plate Warmer, per sq ft of top surface |                |                                                                                            | A                                  | Insulated, separate heat unit for each pot; plate warmer in base | 400                                    | 1350           | 500                                         | 350                                           | 700          |
| Food Warmer, alone, per sq ft of top surface             |                |                                                                                            | A                                  |                                                                  | 300                                    | 1000           | 400                                         | 200<br>350                                    | 550          |
| Fry Kettle                                               | 11 1/2 lb fat  | 12 (Diam.) x 14                                                                            | A                                  |                                                                  | 2600                                   | 8900           | 1100                                        | 1600<br>2400                                  | 4000         |
| Fry Kettle                                               | 25 lb fat      | 16 x 18 x 12                                                                               | A                                  | Area 12 x 14 in.                                                 | 7000                                   | 24000          | 2000                                        | 3850<br>5700                                  | 9500         |
| Griddle, Frying                                          |                | 18 x 18 x 8                                                                                | A                                  | Area 18 x 14 in.                                                 | 2350                                   | 8000           | 2800                                        | 3100<br>1700                                  | 4800         |
| Griddle, Frying                                          |                | 24 x 20 x 10                                                                               | A                                  | Area 23 x 18 in.                                                 | 4000                                   | 13500          | 5000                                        | 5300<br>2900                                  | 8200         |
| Grill, Meat                                              |                | 14 x 14 x 10                                                                               | A                                  | Area 10 x 12 in.                                                 | 3000                                   | 10250          | 1900                                        | 3900<br>2100                                  | 9000         |
| Grill, Sandwich                                          |                | 13 x 14 x 10                                                                               | A                                  | Area 12 x 12 in.                                                 | 1650                                   | 5600           | 1800                                        | 2700<br>700                                   | 3400         |
| Roll Warmer                                              |                | 23 x 23 x 29                                                                               | A                                  | Three drawers                                                    | 1000                                   | 3400           | 900                                         | 2400<br>300                                   | 2700         |
| Toaster, continuous                                      | 360 slices/hr  | 15 x 15 x 28                                                                               | A                                  | 2 slices wide                                                    | 2200                                   | 7500           | 5000                                        | 5100<br>1300                                  | 6400         |
| Toaster, continuous                                      | 720 slices/hr  | 20 x 15 x 28                                                                               | A                                  | 4 slices wide                                                    | 3000                                   | 10250          | 6000                                        | 6100<br>2800                                  | 8700         |
| Toaster, pop-up                                          | 216 slices/hr  | 12 x 11 x 9                                                                                | A                                  | 4 slice                                                          | 2450                                   | 8400           | 2000                                        | 4900<br>900                                   | 5800         |
| Waffle Iron                                              | 20 waffles/hr  | 12 x 13 x 10                                                                               | A                                  | 7 in. diam. waffle                                               | 750                                    | 2500           | 600                                         | 1100<br>750                                   | 1850         |

*Restaurant Gas-Burning Appliances*

|                                       |                |                                 |   |                                                                                                   |  |             |              |              |              |              |
|---------------------------------------|----------------|---------------------------------|---|---------------------------------------------------------------------------------------------------|--|-------------|--------------|--------------|--------------|--------------|
| Coffee Brewer and Warmer              | 1/2 gal        |                                 | M | Brewer<br>Warmer                                                                                  |  | 3400<br>500 |              | 1380<br>400  | 350<br>100   | 1700<br>500  |
| Coffee Brewer Unit with Tank          | 4 1/2 gal Tank | 19 x 30 x 26                    | M | 4 Brewers and Tank                                                                                |  |             |              | 7200         | 1800         | 9000         |
| Coffee Urn                            | 3 gal<br>5 gal | 12 x 23 x 21<br>18 (Diam.) x 37 | A | Nickel plated<br>Nickel plated                                                                    |  |             | 3400<br>4700 | 2500<br>3900 | 2500<br>3900 | 5000<br>7800 |
| Food Warmer, per sq ft of top surface |                |                                 | M | Water bath                                                                                        |  | 2000        | 900          | 850          | 430          | 1280         |
| Fry Kettle                            | 15 lb fat      | 12 x 20 x 18                    | A | Area 10 x 10                                                                                      |  | 14250       | 3000         | 4200         | 2800         | 7000         |
| Fry Kettle                            | 23 lb fat      | 15 x 35 x 11                    | A | Area 11 x 16                                                                                      |  | 24000       | 4500         | 7200         | 4800         | 12000        |
| Grill                                 |                | 22 x 14 x 17                    | M | Insulated, Grill surface<br>of 4 sq ft<br>Top burner 22,000 Btu/hr<br>Bottom burner 15,000 Btu/hr |  | 37000       |              | 14400        | 3600         | 18000        |
| Stoves, Short Order                   |                |                                 |   |                                                                                                   |  |             |              |              |              |              |
| Open Top, per sq ft top               |                |                                 | M | Ring type burners                                                                                 |  | 14000       |              | 4200         | 4200         | 8400         |
| Closed Top, per sq ft top             |                |                                 | M | Ring type burners                                                                                 |  | 11000       |              | 3300         | 3300         | 6600         |
| Fry Top, per sq ft top                |                |                                 | M | Tubular type burners                                                                              |  | 12000       |              | 3600         | 3600         | 7200         |
| Toaster, Continuous                   | 360 slices/hr  | 15 x 15 x 28                    | A | 2 slices wide                                                                                     |  | 13000       | 10000        | 7700         | 3300         | 11000        |
| Toaster, Continuous                   | 640 slices/hr  | 20 x 15 x 28                    | A | 4 slices wide                                                                                     |  | 20000       | 14000        | 12000        | 5000         | 17000        |

*Restaurant Steam-Heated Appliances*

|                                       |                |                                 |   |                                |  |  |  |              |              |              |
|---------------------------------------|----------------|---------------------------------|---|--------------------------------|--|--|--|--------------|--------------|--------------|
| Coffee Urn                            | 3 gal<br>5 gal | 12 x 23 x 21<br>18 (Diam.) x 37 | T | Nickel plated<br>Nickel plated |  |  |  | 2400<br>3400 | 1000<br>2200 | 4000<br>3700 |
| Coffee Urn                            | 3 gal<br>5 gal | 12 x 23 x 21<br>18 (Diam.) x 37 | M | Nickel plated<br>Nickel plated |  |  |  | 2600<br>3700 | 2000<br>3700 | 5200<br>7400 |
| Food Warmer, per sq ft of top surface |                |                                 | T |                                |  |  |  | 400          | 500          | 900          |
| Food Warmer, per sq ft of top surface |                |                                 | M |                                |  |  |  | 450          | 1150         | 1600         |

<sup>a</sup> For restaurant appliances, miscellaneous electrical and miscellaneous gas burning appliances.<sup>b</sup> When these appliances are hooded and provided with adequate exhaust, use 50 percent of recommended rate of heat gain from unhooded appliances.

TABLE 26. RATE OF HEAT GAIN FROM APPLIANCES WITHOUT HOODS<sup>a,b</sup> (CONCLUDED)

| APPLIANCE | CAPACITY | OVER-ALL DIMENSIONS (LESS LEGS AND HANDLES; LAST DIMENSION IS HEIGHT) INCHES | CONTROL<br>A—AUTOMATIC<br>M—MANUAL | MISCELLANEOUS DATA | MANUFACTURER'S RATING WATTS | BTU/Hr | MAIN-TAINING RATE BTU PER HOUR | RECOMMENDED RATE OF HEAT GAIN BTU PER HOUR |        |       |
|-----------|----------|------------------------------------------------------------------------------|------------------------------------|--------------------|-----------------------------|--------|--------------------------------|--------------------------------------------|--------|-------|
|           |          |                                                                              |                                    |                    |                             |        |                                | SENSEBLE                                   | LATENT | TOTAL |

|                                            |  |  |   |                                                            |      |      |  |          |      |          |
|--------------------------------------------|--|--|---|------------------------------------------------------------|------|------|--|----------|------|----------|
| <i>Miscellaneous Electrical Appliances</i> |  |  |   |                                                            |      |      |  |          |      |          |
| Hair Dryer, Blower Type                    |  |  | M | Fan, 165 w;<br>Low, 915 w;<br>High, 1880 w                 | 1880 | 5400 |  | 2300     | 400  | 2700     |
| Hair Dryer, Helmet Type                    |  |  | M | Fan, 80 w;<br>Low, 300 w;<br>High, 710 w                   | 705  | 2400 |  | 1870     | 330  | 2200     |
| Permanent Wave Machine                     |  |  | M | 60 heaters at 25 w each,<br>36 in normal use               | 1800 | 5000 |  | 850      | 150  | 1000     |
| Neon Sign, per linear ft of tube           |  |  |   | 1/2 in. outside diam.<br>3/4 in. outside diam.             |      |      |  | 30<br>60 |      | 30<br>60 |
| Sterilizer, Instrument                     |  |  | A | For physicians', thermo-stat cuts off 350 w before boiling | 1100 | 3750 |  | 650      | 1200 | 1850     |

|                                             |  |                 |   |                                       |  |       |      |       |      |       |
|---------------------------------------------|--|-----------------|---|---------------------------------------|--|-------|------|-------|------|-------|
| <i>Miscellaneous Gas-Burning Appliances</i> |  |                 |   |                                       |  |       |      |       |      |       |
| Burners, Laboratory                         |  | 1/4 in. Barrel  | M | Manufactured Gas                      |  | 1800  |      | 950   | 240  | 1200  |
| Small Burners                               |  | 1/4 in. Barrel  | M | Natural Gas                           |  | 3000  |      | 1680  | 420  | 2100  |
| Fish-tail                                   |  | 1/4 in. Barrel  | M | Manufactured Gas                      |  | 3500  |      | 1900  | 450  | 2450  |
| Large Burners                               |  | 1 1/2 in. Mouth | M | Natural Gas                           |  | 6000  |      | 3050  | 770  | 3850  |
| Cigar Lighter                               |  |                 | M | Adjustable orifice                    |  | 2500  |      | 900   | 100  | 1000  |
| Hair Dryer, 5 helmets                       |  |                 | M | Continuous Flame                      |  | 33000 |      | 15000 | 4000 | 19000 |
| Stoves, Oven                                |  |                 | A | Heater and fan blowing air to helmets |  | 25000 | 9000 | 7200  | 1800 | 9000  |
|                                             |  |                 |   | Insulated, modern                     |  | 28000 | 8600 | 9200  | 2300 | 11500 |
|                                             |  |                 |   | Not insulated                         |  |       |      |       |      |       |

<sup>a</sup> For restaurant appliances, miscellaneous electrical and miscellaneous gas burning appliances.<sup>b</sup> When these appliances are hooded and provided with adequate exhaust, use 50 percent of recommended rate of heat gain from unhooded appliances.

heating appliances, but it is believed that when they are properly hooded with a positive fan exhaust system through the hood, 50 percent of the heat will be carried away and 50 percent dissipated in the space to be conditioned. The same effectiveness of the hood should be figured for both latent and sensible heat.

### LOAD FROM MOISTURE TRANSFER THROUGH PERMEABLE BUILDING MATERIALS

The diffusion of moisture through all common building materials is a natural phenomenon which is always present to a greater or lesser degree.

The permeability and permeance values for various building materials are given in Table 2 of Chapter 10, together with an explanation of moisture transmission through these materials.

In the usual comfort air-conditioning application, it is common practice to neglect moisture transfer through walls, for the actual rate is quite small and the corresponding latent-heat load is hardly significant. So-called *vapor barriers* are frequently employed in modern construction for the purpose of keeping moisture transfer to a minimum, and reducing the deteriorating and insulation-destroying effects of moisture.

Industrial jobs, on the other hand, frequently call for a low moisture content to be maintained in a conditioned space. Here the matter of moisture transfer cannot be neglected; indeed, it is quite possible to have the latent-heat load accompanying this transfer be of greater magnitude than any other latent-heat load. The equation for computing this load is:

$$\left(\frac{q_m}{A}\right) = \frac{M}{7000} \times \left(\frac{\text{Vapor Pressure}}{\text{Difference, In. Hg}}\right) \times 1076, \text{ Btu per (hr) (sq ft)} \quad (17)$$

where

$M$  = permeance of the specimen in perms, or grains per (square foot) (hour) (inch of mercury vapor pressure difference).

7000 = grains per pound.

The factor 1076 is defined in list of symbols at Equation 9. (Sensible cooling of the water vapor is included in the factor 1076.)

The only means of preventing moisture transfer is to use a vapor proof wall, or to apply a special lining, which is vapor proof. All openings in moisture proof construction must be equipped with special gaskets to prevent entrance of moisture.

When moisture transfer contributes an appreciable part of the latent-heat load, it is recommended that estimates should be made intentionally liberal in order to avoid later difficulties with insufficient dehumidifying capacity. Storage spaces, for example, would require sufficient dehumidifying capacity to handle the moisture brought in with goods to be stored, in addition to moisture leaking in subsequently.

### MISCELLANEOUS HEAT LOADS

This designation is intended to cover the various small heat gains from exposed piping, ducts, work done by circulating fan, and unforeseen contingencies. Where sufficient data are available, these various heat gains may be estimated individually. In the majority of cases, however, common practice is to lump these factors together and combine them with a *safety*

factor according to the experience and judgment of the estimator. On this basis, a small safety factor is added to the calculated cooling load to compensate for miscellaneous effects. No rules can be given for this procedure, as experience in air conditioning is indispensable for application of suitable safety factors.

### APPARATUS DEW POINT AND REQUIRED AIR QUANTITY THROUGH CONDITIONING EQUIPMENT

In ordinary practice, with commercial apparatus, complete saturation of the air is seldom obtained. Four-row finned cooling coils contact approximately 80 percent of the air, whereas six-row finned coils contact approximately 95 percent of the air. In spray type dehumidifiers of good

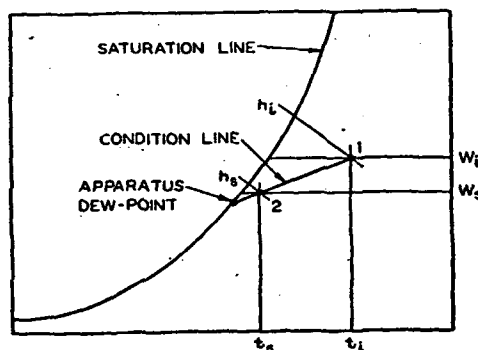


FIG. 5. APPARATUS DEW-POINT SHOWN ON A.S.H.A.E. PSYCHROMETRIC CHART

design the air leaves the dehumidifier at 1 to 2 deg higher wet-bulb temperature than the spray water leaving the dehumidifier, and the difference between the dry-bulb and wet-bulb temperatures leaving the dehumidifier may be as low as 1 deg. A spray type dehumidifier having sufficient length of spray chamber and density of spray, together with proper arrangement of nozzles, may approach saturation very closely.

As explained in Chapter 3, and shown in Fig. 5, the slope of the line on the psychrometric chart connecting the room condition with the apparatus dew point on the saturation line, determines the ratio of sensible heat absorbing capacity to the moisture absorbing capacity of the supply air. Therefore the room condition can be maintained as long as the supply air temperature lies on this line, but a greater volume of supply air must be used to satisfy the room load if the cooling coil does not contact 100 percent of the air. For a given room load, the same apparatus dew point will be required whether the cooling appliance contacts all the air or only part of the air.

From the point of view of satisfying the given cooling load requirements, the air passing through the apparatus without being cooled below the dew point temperature produces two effects:

1. The air quantity which must be passed through the dehumidifier must be in-

creased. Thus, if 20 percent of the air passing is contacted, then  $(20 \div 80) \times 100 = 25$  percent more air must be used than would be necessary if all of it were contacted.

2. Passing untreated air may change the room cooling load, which in turn may change the enthalpy-humidity difference ratio (sometimes called the sensible heat factor). If return air only is passed through the dehumidifier or if room air only is bypassed, the room load will not change, but if some outside air is passed through, the room sensible heat gain and room latent heat gain will be changed due to the addition of untreated outside air, which changes the enthalpy-humidity difference ratio. When a load calculation is made, it is necessary to know the percentage of air affected in the dehumidifier, and calculation must be made accordingly.

If the ventilation air is drawn through the dehumidifier before it goes into the room, only that portion of the air not saturated must be included in the room load for the purpose of determining the apparatus dew point and supply air quantity. It should be noted when evaluating the load added by untreated outside air that the temperature difference between room air and outside air, and the moisture content difference between room air and outside air, should be used, rather than the difference between outside air and apparatus dew point, since the rise from the apparatus dew-point to room condition is charged against the dehumidifier as the cooling and dehumidifying load.

The procedure for determining the required air quantity is based upon the thermodynamic principles of Chapter 3 and the use of the A.S.H.A.E. psychrometric chart. Readers are advised to review these principles, paying particular attention to the illustrative examples.

Calculation of the cooling load for a conditioned space is equivalent to making, for the space, a heat balance in which all heat, moisture, and infiltration are treated as directly entering the space. As explained in the section, *Load from Outside Air, Ventilation, and Infiltration*, the outside air load normally does not become a part of the space load, because heat and moisture are removed in the air conditioner before this air gets into the conditioned space. The desired conditions are maintained by considering a certain quantity of air to be withdrawn from the space, passed through the conditioning equipment, and returned to the space with such a temperature and humidity ratio that its net effect will be to counterbalance or remove the given entering amounts of heat and water vapor. This quantity of indoor air, which is considered to be circulated in this manner, is called the *required air quantity* and its determination is normally part of every cooling-load estimate. The procedure is as follows:

1. Determine the total sensible and latent heat loads in Btu per hour for the space.
2. Compute the quantity called the enthalpy-humidity difference ratio (also referred to as heat-moisture ratio) of the room load,  $\frac{h_1 - h_s}{W_1 - W_s}$ . Use the equation

$$\frac{h_1 - h_s}{W_1 - W_s} = \frac{(\text{Space sensible load} + \text{space latent load})}{\text{Space latent load}/1076} \quad (18)$$

where

$h_s$  = enthalpy of moist air supplied to the space, Btu per pound of dry air.

$h_1$  = enthalpy of moist air at room design conditions, Btu per pound of dry air.

$W_s$  = humidity ratio of moist air supplied to the space, pounds of vapor per pound of dry air.)

$W_1$  = humidity ratio of moist air at room design conditions, pounds of vapor per pound of dry air.



Note that the ratio (space latent load/1076) is the equivalent of the required rate of water vapor removal in pounds per hour. If the rate of water removed is known, it may be used directly in Equation 18.

3. Draw a line through the reference point on the A.S.H.V.E. psychrometric chart and the value of  $(h_i - h_e)/(W_i - W_e)$  determined above. Draw a second line through the state point of the room air (design wet-bulb and dry-bulb temperatures) parallel to this line. This is the *condition line* for the process.

4. Read the temperature where the condition line from step 3 intersects the saturation line. This is called the *apparatus dew point*.

See Fig. 5. Note that instead of using this graphical method the left hand side of Equation 18 may be solved by trial and error by substituting values of  $h_e$  and  $W_e$  corresponding to assumed apparatus dew-point temperatures.

5. Compute the *required air quantity* from the relation

$$Q_m = \frac{(\text{Space sensible load})}{1.08 \left[ \left( \frac{\text{Space}}{\text{dry-bulb}} \right) - \left( \frac{\text{Apparatus}}{\text{dew-point}} \right) \right]} \times \left( 1 - \frac{\text{Coil}}{\text{bypass factor}} \right) \quad (19)$$

The magnitude of  $Q_m$  is substantially the quantity, cfm, of cooled and dehumidified air for which the distribution system must be designed.

The numerical factor 1.08 is derived from the product  $1 \text{ cfm} \times 60 \text{ min} \times 0.244 \times 0.075 \left( 1 - \frac{0.00923}{0.62} \right) = 1.08$ , assuming an average supply air dew point of 55 F. Since standard air density (0.075) includes the weight of the water vapor, it is desirable to reduce it to the basis of dry air by the last factor where  $0.00923 =$  humidity ratio of air at 55 F dew point, and  $0.62 =$  ratio of density of water vapor to dry air at same temperature and pressure. Refer to Chapter 36 for coil selection.

Note that the product  $[(\text{space dry-bulb}) - (\text{apparatus dew point})] \times (1 - \text{coil bypass factor})$  is equal to the dry-bulb range through which the conditioned air is cooled. Hence, in rare instances when the *condition line* of the process may not intersect the saturation line, any other convenient reference temperature on the *condition line* may be used instead, provided that the coil bypass factor is specified accordingly on the proper basis.

### MINIMUM ENTERING AIR TEMPERATURE

Due consideration must be given to the temperature of the air entering the conditioned space in order to prevent objectionable drafts. With ceiling type diffusers or wall grilles with a high aspect ratio (see Chapter 31), many engineers consider 20 deg as the maximum difference for good design under average conditions. This difference can only be exceeded with extremely high ceiling outlets or wall grilles. Thus, if 80 F dry-bulb is to be maintained in a space with average ceiling height, the minimum delivered air temperature would be limited to about 60 F dry-bulb temperature. If the latent heat load is relatively high, it is often necessary to circulate more air with a higher delivered dry-bulb temperature in order to produce a thermodynamic balance. If the dry-bulb temperature of the air supplied to the space is known, the required air quantity can be calculated from the formula,

$$Q_m = \frac{q_s}{1.08 (t_i - t_e)} \quad (20)$$

or the supply temperature  $t_e$  can be determined as follows,

$$t_e = t_i - \frac{q_s}{1.08 \times Q_m} \quad (21)$$

### EXAMPLE—COOLING LOAD CALCULATION

*Example 13:* A one-story office building Fig. 6 is located in an eastern state near 40 deg latitude. The adjoining buildings on the north and west are not conditioned, and the air temperature within them is known to be substantially equal to the outdoor air temperature at any time of the day.

South wall construction: 8 in. concrete block, 4 in. brick veneer,  $\frac{1}{2}$  in. plaster on walls. (Table 9, Chapter 9, No. 92B,  $U = 0.41$ .)

East wall and outside north wall construction: 8 in. concrete block, painted white,  $\frac{1}{2}$  in. plaster on walls. (Table 8, Chapter 9, No. 82B,  $U = 0.52$ .)

West wall and adjoining north party wall construction: 13 in. solid brick, no plaster:

$$\frac{1}{U} = \frac{1}{1.65} + \frac{13}{5} + \frac{1}{1.65} \quad \text{or,} \quad U = 0.263. \quad \text{Use } U = 0.26.$$

Roof construction: 2 $\frac{1}{2}$  in. flat roof deck of 2 in. gypsum fiber concrete on gypsum board surfaced with built-up roofing. (Table 11,  $U = 0.34$  for summer.)

Floor construction: 4 in. concrete on ground.

Window: 3 ft x 5 ft, non-opening type, with medium colored Venetian blinds for windows on south wall. Approximately 4 in. reveal on all windows.

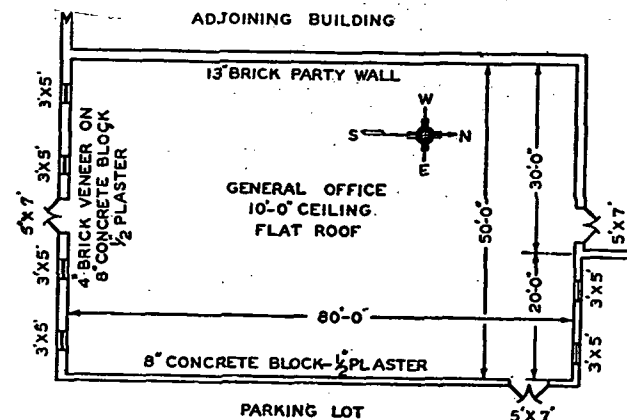


FIG. 6. PLAN OF ONE-STORY OFFICE BUILDING

- Front doors: Two 2 ft-6 in. x 7 ft (glass panels).
- Side doors: Two 2 ft-6 in. x 7 ft ( $\frac{1}{2}$  glass panels).
- Rear doors: Two 2 ft-6 in. x 7 ft (wood panels).
- Outside design conditions: Maximum dry-bulb 95 F, wet-bulb 78 F;  $W_o = 0.0169$  lbs vapor per lb dry air;  $h_o = 41.38$  Btu per lb dry air.
- Indoor design conditions: Dry-bulb 80 F, wet-bulb 65 F;  $W_i = 0.0098$  lb vapor per lb dry air;  $h_i = 29.95$  Btu per lb dry air.
- Occupancy: 85 office workers.
- Lights: 12,000 watts, fluorescent; 4000 watts tungsten.
- Fan motor:  $7\frac{1}{2}$  hp.

Assume that cooling coil has a bypass factor of 0.15, i.e., that 15 percent of the air passes through the coil without contacting the coil surface.

Conditioning equipment to be located in adjoining structure to north.

Find: Total, sensible, and latent maximum cooling loads and required air quantity through conditioning equipment.

**Solution:** From Table 3, the recommended ventilation rate is 15 cfm per person. Total necessary =  $85 \times 15 = 1275$  cfm or 76,500 cu ft per hr.

As the room volume is 40,000 cu ft; the air changes per hour will be  $76,500/40,000 = 1.91$  which is more than one air change.

#### Estimated Time of Maximum Cooling Load:

For this job, judgment indicates that the roof will make the greatest single contribution to the cooling load. Hence, the time of maximum cooling load probably will be the time of maximum heat gain through the roof. From Table 9 the maximum temperature differential for a 2 in. gypsum roof of medium weight construction is 54 deg at 4:00 p.m., and 53 deg at 3:00 p.m. Examination of Table 13 (40 deg N Latitude) shows that solar heat gain through glass on the south wall is 18 Btu per (hr) (sq ft) at 4:00 p.m., and 42 Btu at 3:00 p.m. This indicates that the maximum cooling load occurs at approximately 3:00 p.m. Therefore make load calculations at 3:00 p.m. sun time. (This may be slightly different from 3:00 p.m. local time.) In some cases, there would be no clear-cut evidence of this nature, and consequently, it would be necessary to estimate the load for several successive times, and then to select the maximum.

#### Heat Gain Through Outer Wall and Roof Areas:

From Table 10 the temperature differential for the south wall (8 in. concrete block with 4 in. brick veneer) may be about the same as a 12 in. brick which is 6 deg at 3:00 p.m. for a dark colored wall. From the same table, the temperature differential for the east wall (8 in. concrete block with plaster) will be 11 deg at 3:00 p.m. for a light colored wall (interpolating between 2:00 and 4:00 p.m.). Likewise, the temperature differential for the north exposed wall (8 in. concrete block plus plaster) will be 3 deg at 3:00 p.m. (by interpolation) for a light wall.

The party wall of 13 in. brick on the west side and part of the north side may be treated as if it were an outside wall in the shade which has a temperature differential (from Table 10) of 2 deg.

For the door in north wall estimate  $U = 0.59$  from Chapter 9, Table 10, No. 5A. The outdoor temperature at 3:00 p.m. is 95 F. Neglect time lag and any decrement factor. The temperature differential is  $(t_o - t_i) = 95 - 80 = 15$  deg. The tabulation of the preceding values at 3:00 p.m. is given in the following table:

| SECTION                 | NET AREA<br>Sq Ft | TEMPERATURE<br>DIFFERENTIAL<br>F Deg | HEAT<br>TRANSMISSION<br>COEFFICIENT<br>(U) | HEAT FLOW<br>RATE PER<br>HOUR<br>Btu |
|-------------------------|-------------------|--------------------------------------|--------------------------------------------|--------------------------------------|
| Roof                    | 4000              | 53                                   | 0.34                                       | 72,000                               |
| South Wall              | 405*              | 6                                    | 0.41                                       | 995                                  |
| East Wall               | 765*              | 11                                   | 0.52                                       | 4,339                                |
| North Exposed Wall      | 170*              | 3                                    | 0.52                                       | 265                                  |
| West & North Party Wall | 1065*             | 2                                    | 0.26                                       | 550                                  |
| Door in North Wall      | 35                | 15                                   | 0.59                                       | 310                                  |
| Total                   |                   |                                      |                                            | 78,500                               |

\* Calculated from gross wall area, less windows and doors.

#### Heat Gain Through Glass Areas

In computing the load for 3:00 p.m., only the south windows and doors will be exposed to direct sunlight. Tables 13 and 14 will give the total heat gain from the glass areas. The window reveals will shade the south windows; the fraction of the window area receiving direct radiation is obtained from Equation 5 by substituting values as follows:

$$r_1 = s/l = 4/60; r_2 = 4/36; \beta = 45.5 \text{ deg}, \tan \beta = 1.02$$

$$\gamma = 74 \text{ deg}, \tan \gamma = 3.487, \cos \gamma = 0.276$$

$$G_t = 1 - \frac{4}{60} \left( \frac{1.02}{0.276} \right) - \frac{4}{36} (3.487) + \left( \frac{4}{60} \right) \left( \frac{4}{36} \right) \frac{(1.02)(3.487)}{0.276} = 0.462$$

The south doors will be considered entirely sunlit. The outdoor air temperature

is 95 F at 3:00 p.m. From Table 24 the inside Venetian blind factor is 0.65. The instantaneous heat gains due to transmitted direct and diffuse solar radiation, and from convection and radiation gain, are found in Tables 13 and 14 as listed below for the south facing doors and windows, the north facing windows and the 4-glass doors in the east wall. The gain through the solid portion of the east doors may be approximated by use of Fig. 3, since the wood panels have little heat capacity. From Table 4, the diffuse radiation value is taken as 18 Btu per (hr)(sq ft) from which  $t_o + \alpha_o I_o / f_{ro}$  is found to be 98.2 for  $\alpha = 0.7$  and  $f_{ro} = 4.0$ . From Fig. 3,  $q = 27.0$  Btu per (hr)(sq ft). These heat gains are itemized in the following table (note that there are no corrections to Table 14 values since table is based on 80 F temperature, but Fig. 3 is based on 75 F room temperature).

| LOCATION           | AREA<br>Sq Ft | FRAC-<br>TION<br>SUNLIT | SHADE<br>FACTOR | TRANS-<br>MIS-<br>SION<br>GAIN<br>BTU/<br>(HR)<br>(SQ FT) | CONV<br>AND RAD<br>GAIN<br>BTU/<br>(HR)<br>(SQ FT) | CORR<br>FROM<br>75 F TO<br>80 F<br>INDOOR<br>TEMPER-<br>ATURE<br>BTU/(HR)<br>(SQ FT) | TOTAL<br>GAIN<br>BTU/<br>(HR)<br>(SQ FT) | TOTAL<br>GAIN<br>BTU/HR |
|--------------------|---------------|-------------------------|-----------------|-----------------------------------------------------------|----------------------------------------------------|--------------------------------------------------------------------------------------|------------------------------------------|-------------------------|
| South Windows      | 60            | 0.462                   | 0.65            | 13                                                        | 19                                                 | —                                                                                    | —                                        | —                       |
| South Doors        | 35            | 1.00                    | —               | 42                                                        | 19                                                 | —                                                                                    | 32                                       | 1920                    |
| East Doors (Glass) | 18            | —                       | —               | 14                                                        | 17                                                 | —                                                                                    | 61                                       | 2135                    |
| Wood               | 18            | —                       | —               | —                                                         | 27                                                 | —                                                                                    | 31                                       | 560                     |
| North Windows      | 30            | —                       | —               | 15                                                        | 17                                                 | —                                                                                    | 22                                       | 395                     |
| Total              |               |                         |                 |                                                           |                                                    |                                                                                      | 32                                       | 960                     |
|                    |               |                         |                 |                                                           |                                                    |                                                                                      |                                          | 5970                    |

In some jobs it would be desirable to increase (or decrease) the instantaneous radiation heat gain by a load-lag factor. The reason for not doing so in this case is that the solar gain is of a low magnitude, and reference to the table indicates that 0.8 of the previous hour would not affect the results materially.

#### Heat Gain from Ventilation and Infiltration:

Since the desired outdoor air rate 1275 cfm is greater than one air change per hour, it will be satisfactory for determining the ventilation component of the heat gain.

Window infiltration can be taken as negligible since the windows do not open.

Door infiltration requires some judgment. Assume that for each person passing through the double doors, the infiltration will be 100 cu ft of outdoor air, see Chapter 10, Table 3. Assume that the outside doors will be used at the rate of 10 persons per hour and the inside doors at the rate of 30 persons per hour. Total infiltration will then be  $40 \times 100 = 4000$  cfh or 67 cfm.

The design rate of entry of outside air is then:

$$Q = 1275 + 67 = 1342 \text{ cfm.}$$

The sensible, latent and total loads are determined from Equations 7, 8, and 9, respectively, at 3:00 p.m. (Table 8)  $t_o = 95$ ,  $t_i = 80$ ,  $W_o = 0.0169$ ,  $W_i = 0.0098$ . All the air entering the room as infiltration becomes a part of the space load.

#### Infiltration (see Equations 7, 8, and 9):

$$q_s = 67 \times 1.08 (95 - 80) = 1085 \text{ Btuh, sensible.}$$

$$q_l = 67 \times 4840 (0.0169 - 0.0098) = 2300 \text{ Btuh, latent.}$$

$$q_t = q_s + q_l = 1085 + 2300 = 3385 \text{ Btuh, total.}$$

#### Ventilation Air Taken through Cooling Unit Which Becomes a Part of the Space Load (see Equations 10 and 11):

$$q_{si} = 1275 \times 1.08 (95 - 80) (0.15) = 3,100 \text{ Btuh, sensible.}$$

$$q_{li} = 1275 \times 4840 (0.0169 - 0.0098) (0.15) = 6,570 \text{ Btuh, latent.}$$

*Ventilation Air Taken through Cooling Unit Which Does Not Become a Part of the Space Load (see Equations 12 and 13):*

$$q_{sx} = 1275 \times 1.08 (95-80) (1-0.15) = 17,600 \text{ Btuh, sensible.}$$

$$q_{lx} = 1275 \times 4840 (0.0169-0.0098) (1-0.15) = 37,230 \text{ Btuh, latent.}$$

$$q_t = q_{s1} + q_{sx} + q_{l1} + q_{lx} = 3100 + 17600 + 6570 + 37230 = 64,500 \text{ Btuh total.}$$

*Heat Gain from Sources within the Conditioned Space:*

For the occupants, use the data of Table 25 for moderately active office work.

$$\text{Sensible heat gain} = 85 \times 200 = 17,000 \text{ Btu per hr.}$$

$$\text{Latent heat gain} = 85 \times 250 = 21,250 \text{ Btu per hr.}$$

$$\text{Total} = 38,250 \text{ Btu per hr.}$$

For the gain from *lighting*, use Equation 15 with a use factor of unity, and a special allowance factor of 1.20 for the fluorescents and of unity for the tungsten globes.

$$q_{l1} = (12,000 \times 1.20 + 4000) \times 3.41 = 62,700 \text{ Btu per hr.}$$

For the *fan motor*, use Equation 16 with a load factor of unity, and omit term *Motor Efficiency* because the motor is not within the space.

$$q_{fm} = 7.5 \times 2544 = 19,100 \text{ Btu per hr.}$$

*Moisture Permeation, Miscellaneous Allowance, and the Load-Lag Estimate:*

Moisture permeation will be negligible, since this is a comfort job with a good building construction.

There would be some heat gain in the ductwork, but this would not be great because of the short run involved. Practical judgment for this job would suggest that no adjustment for load-lag need be made to the load as computed. (Refer to Fig. 4). While it is true that inside radiation forms an important part of the total heat gain, it is advisable to be conservative in recognizing the effect of the large, flat, hot roof on the *comfort sensations of the occupants*. Radiation from the relatively low ceiling, augmented by heat absorption from the lighting fixtures, would produce a sensation of warmth in excess of the nominal effective temperature (see Chapter 6) established by the wet-bulb and dry-bulb temperatures. Hence, it is not desirable to take advantage of every small decrease possible in the peak design load, especially since the peak occurs in mid-afternoon when everything would be rather well warmed.

*Total Loads and Required Air Quantity through Conditioning Equipment:*

The total loads are summarized in the following table:

SUMMARY OF TOTAL LOADS—EXAMPLE 13

| LOAD COMPONENT                         | SENSIBLE<br>Btu/hr | LATENT<br>Btu/hr |
|----------------------------------------|--------------------|------------------|
| All walls, roof and doors.....         | 78,500             | .....            |
| Glass areas.....                       | 6,030              | .....            |
| Infiltration 67 cfm.....               | 1,085              | 2,300            |
| Ventilation Air (1275 cfm × 0.15)..... | 3,100              | 6,570            |
| Occupants.....                         | 17,000             | 21,250           |
| Lighting.....                          | 62,700             | .....            |
| Motor, fan.....                        | 19,100             | .....            |
| Space Load.....                        | 187,515            | 30,120           |
| Ventilation 1275 cfm × (1-0.15).....   | 17,600             | 37,230           |
| Totals.....                            | 205,115            | 67,350           |
| Grand Total Sensible and Latent.....   |                    | 272,465          |

Compute the enthalpy difference ratio from Equation 18.

$$\frac{h_1 - h_2}{W_1 - W_2} = \frac{(187,455 + 30,120)}{30,120} \times 1076 = 7770.$$

From the A.S.H.A.E. psychrometric chart Chapter 3, determine that the apparatus dew-point is 53.9 F.

Compute the effective air quantity (Equation 19). Then,

$$Q_{ra} = \frac{187,455}{1.08 (80 - 53.9) \times 0.85} = 7830 \text{ cfm.}$$

(Refer to Chapter 36 for coil selection.)

From note under Equation 19 the dry-bulb range will be  $(80 - 53.9) \times 0.85 = 22.2$  deg, and the dry-bulb temperature of air leaving the coil will be  $80 - 22.2 = 57.8$  F. The dry-bulb temperature leaving the fan (including the heat supplied by the fan motor), or delivered into the room, will be (from Equation 16):

$$t_s = 80 - \frac{187,455 - 19,100}{1.08 \times 7830} = 80 - 19.9 = 60.1 \text{ F.}$$

With good distribution and diffusion, this temperature should not produce objectionable drafts.

The various calculations for the sensible, latent, and total heat loads for Example 13 may be summarized as follows:

EXAMPLE 13: SUMMARY

|                         |       |       |                       |
|-------------------------|-------|-------|-----------------------|
| Outdoor Conditions..... | 95 DB | 78 WB | 0.0169 Humidity Ratio |
| Space Conditions.....   | 80 DB | 65 WB | 0.0098 Humidity Ratio |
| DIFFERENCE.....         | 15    |       | 0.0071                |

#### SENSIBLE LOAD

| Transmission                                      | Btu/Hr |
|---------------------------------------------------|--------|
| Roof 4000 sq ft × 53° × 0.34 = .....              | 72,000 |
| S. Wall 405 sq ft × 6° × 0.41 = .....             | 995    |
| E. Wall 765 sq ft × 11° × 0.52 = .....            | 4,380  |
| N. Wall Ex. 170 sq ft × 3° × 0.52 = .....         | 265    |
| N. & W. Party Wall 1065 sq ft × 2° × 0.26 = ..... | 550    |
| Floor None.....                                   |        |
| Door 35 sq ft × 15 × 0.59 = .....                 | 310    |
| All Glass and Rest of Doors = .....               | 3,020  |

#### Solar Radiation

|                                        |       |
|----------------------------------------|-------|
| S. Glass 60 sq ft × 13 = .....         | 780   |
| S. Glass (Doors) 35 sq ft × 42 = ..... | 1,470 |
| E. Glass (Doors) 18 sq ft × 14 = ..... | 250   |
| N. Glass 30 sq ft × 15 = .....         | 450   |

#### Internal Load

|                                               |        |
|-----------------------------------------------|--------|
| Infiltration 67 cfm × 1.08 × 15° = .....      | 1,085  |
| Ventilation 1275 cfm × 1.08 × 15° × 0.15..... | 3,100  |
| Lights (12,000 × 1.20 + 4000) 3.41 = .....    | 62,700 |
| People 85 × 200 = .....                       | 17,000 |
| Motor, Fan 7.5 hp × 2544 = .....              | 19,100 |

TOTAL SENSIBLE SPACE LOAD..... 187,455

#### LATENT LOAD

|                                                  |        |
|--------------------------------------------------|--------|
| Infiltration 67 cfm × 4840 × 0.0071 = .....      | 2,300  |
| Ventilation 1275 cfm × 4840 × 0.0071 × 0.15..... | 6,570  |
| People 85 × 250 = .....                          | 21,250 |

TOTAL LATENT SPACE LOAD..... 30,120

#### VENTILATION AIR WHICH DOES NOT BECOME PART OF SPACE LOAD

|                                                    |        |
|----------------------------------------------------|--------|
| Sensible 1275 cfm × 1.08 × 15° × (1-0.15) = .....  | 17,600 |
| Latent 1275 cfm × 4840 × 0.0071 × (1-0.15) = ..... | 37,230 |

GRAND TOTAL LOAD..... 272,405

## LETTER SYMBOLS USED IN CHAPTER 13

- $\alpha$  = fraction of incident solar radiation absorbed, dimensionless; subscripts D, d, and t refer to direct, diffuse and total, respectively.
- $\beta$  = solar altitude, degrees.
- $\gamma$  = wall solar azimuth, degrees.
- $\epsilon$  = emissivity, dimensionless.
- $\theta$  = incident angle, degrees.
- $\lambda$  = amplitude decrement factor, dimensionless.
- $\tau$  = fraction of incident solar radiation transmitted, dimensionless. Subscripts D, d and t refer to direct, diffuse and total, respectively.
- $\phi$  = solar azimuth, degrees.
- $\psi$  = wall azimuth, degrees.
- $A$  = area across which heat is being transferred, square feet.
- $b$  = fraction of air passing through coil which does not contact surfaces, coil by-pass factor.
- $f$  = unit surface conductance, Btu per (hour) (square foot) (Fahrenheit degree). Subscripts c, r, o, and i refer to convection, radiation, outdoor, and indoor, respectively.
- $G_f$  = fraction of total window area receiving direct solar radiation when shaded by window reveal, dimensionless.
- $h$  = enthalpy of air per pound of dry air, Btu per pound. Subscripts i, o, and s refer to indoor, outdoor, and supply air, respectively.
- $I$  = incident solar radiation, Btu per (hour) (square foot). Subscripts D, d, Dn, and t refer to direct, diffuse, direct normal and total solar radiation, respectively.
- $K$  = cosine of angle of incidence for direct solar radiation striking a surface, dimensionless.
- $k$  = thermal conductivity of building material, Btu per (square foot) (hour) (Fahrenheit degree per inch).
- $l$  = height of window, feet.
- $M$  = the permeance of the specimen in perms or grains per (square foot) (hour) (inch of mercury vapor pressure difference).
- $Q$  = rate of entry of outdoor air, cubic feet per minute.
- $Q_{ra}$  = required air quantity through conditioning equipment, cubic feet per minute.
- $q$  = instantaneous rate of heat transfer, Btu per hour.
- $q_s$  = instantaneous latent heat load, Btu per hour.
- $q_{s1}$  = instantaneous space latent ventilation load, Btu per hour.
- $q_{sx}$  = instantaneous latent ventilation load which does not become a part of space load, Btu/h.
- $q_m$  = latent heat load due to moisture transmission through materials, Btu per (hour)(square foot).
- $q_s$  = instantaneous sensible heat load, Btu per hour.
- $q_{s1}'$  = instantaneous space sensible ventilation load, Btu per hour.
- $q_{sx}$  = instantaneous sensible ventilation load which does not become a part of space load, Btu per hour.
- $q_t$  =  $q_s + q_{s1}$ , also  $q_{s1} + q_{sx} + q_{s1} + q_{sx}$ , Btu per hour.
- $R_s$  = low temperature-radiant energy received from outdoor surroundings (does not include solar radiation), Btu per (hour) (square foot of receiving surface).
- $R$  = radiant energy emitted by a black body, Btu per (hour) (square foot). Subscripts go and L refer to outdoor surfaces of glass and building, respectively.
- $S$  = rate of heat storage within a glass section, Btu per (hour) (square foot).
- $t_s$  = sol-air temperature, Fahrenheit.

- $t_s^*$  = sol-air temperature at a time earlier than the time for which heat gain is being found by an amount that is equal to the time lag of the wall or roof, Fahrenheit.
- $t_{s1}$  = temperature of indoor glass surface, Fahrenheit.
- $t_{s0}$  = temperature of outdoor glass surface, Fahrenheit.
- $t_i$  = indoor air temperature, Fahrenheit.
- $t_m$  = 24-hr cyclic average sol-air temperature, Fahrenheit.
- $t_o$  = outdoor air temperature, Fahrenheit.
- $t_r$  = room supply air dry-bulb temperature, Fahrenheit.
- $U$  = overall coefficient of heat transfer of a structural section, Btu per (square foot) (hour) (Fahrenheit degree).
- $v_o$  = volume of outdoor air per pound of dry air, cubic feet.
- $w$  = width of window, feet.
- $W$  = humidity ratio, pounds moisture per pound of dry air. Subscripts i, o, and s refer to indoor, outdoor, and supply air, respectively.

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## CHAPTER 14

## FUELS AND COMBUSTION

Solid Fuels: Analysis, Classification of Coals, Dustless Treatment, Classification of Cokes, Combustion of Solid Fuels, Firing Methods for Solid Fuels, Secondary Air, Draft Requirements and Regulation, Furnace Volume; Fuel Oils: Classification, Analysis, Combustion, Air Required; Fuel Gases: Classification, Heat Value, Combustion; General Combustion Principles; Air Required; Efficiency from Flue Gas Analysis; Heat Balance; Condensation and Corrosion; Soot

**F**UELS may be classified according to their physical state as solid, liquid, or gaseous. The principal fuels used for domestic heating are coal, oil, and gas. However, coke, wood, kerosene, sawdust, briquettes, and other substances are used for heating in special applications or in localities where an adequate supply is available. Experiments are in progress in the use of a colloidal suspension of coal particles in fuel oil, but this fuel has not attained wide-spread usage as yet. The choice of fuel is usually based on dependability, cleanliness, availability, economy, operating requirements, and control.

## SOLID FUELS

## Analysis of Fuels

Coal has a complex composition that makes classification into clear-cut types difficult. Chemically it consists of carbon, hydrogen, oxygen, nitrogen, sulfur, and a mineral residue called ash. A chemical analysis provides some indication of the quality of a coal, but does not define its burning characteristics sufficiently. The coal user is interested principally in the available heat per pound of coal, the handling and storing properties, the amount of ash and dust produced, and the burning characteristics. A description of the relationship between the qualities of coals and these characteristics requires considerable space; a treatment applicable to heating boilers is given in a Bureau of Mines Bulletin.<sup>1</sup>

There are two forms of coal analyses, namely, the *proximate analysis* and the *ultimate analysis*. In the *proximate analysis* the proportions of moisture, volatile matter, fixed carbon, sulfur, and ash are determined. This analysis is more easily made and is satisfactory for indicating most of the characteristics which are of interest to the user. For the proximate analysis the moisture is determined by observing the loss of weight of a sample of coal when dried at about 220 F. To determine the volatile matter, the dried sample is heated to about 1750 F in a closed crucible, and the loss of weight is noted. The remaining sample is then burned in an open crucible, and the accompanying loss of weight represents the fixed carbon. The unburned residue is ash. Although determined separately, the sulfur content is frequently reported with the proximate analysis because the usefulness of a coal for certain purposes depends on its sulfur content.

In the *ultimate analysis*, which is difficult to make, the percentages of carbon, hydrogen, oxygen, nitrogen, sulfur, and ash in the coal sample are determined. It is used for detailed studies of fuels, and in computing

a heat balance when required in testing of heating devices. Typical ultimate analyses of the various kinds of coal are shown in Table 1.<sup>2</sup>

Other important qualities of coals are the screen sizes, ash fusion temperature, friability, caking tendency, and the qualities of the volatile matter. In considering these factors the following points are of interest. The volatile products given off by coals when they are heated differ materially in the ratios by weight of the gases to the oils and tars. No heavy oils or tars are given off by anthracite, and very small quantities are given off by semi-anthracite. As the volatile matter in the coal increases to as much as 40 percent of ash and moisture-free coal, increasing amounts of oils and tars are released. For coals of higher volatile content, the relative quantity of oils and tars decreases and is therefore low in the sub-bituminous

TABLE 1. TYPICAL ULTIMATE ANALYSES FOR COALS

| RANK                            | BTU PER LB                              |                    | CONSTITUENTS, PER CENT |          |        |          |        |      |                                     |
|---------------------------------|-----------------------------------------|--------------------|------------------------|----------|--------|----------|--------|------|-------------------------------------|
|                                 | Moist, Mineral-matter-free <sup>a</sup> | Moist, as Received | Oxygen                 | Hydrogen | Carbon | Nitrogen | Sulfur | Ash  | O <sub>2</sub> + H <sub>2</sub> + C |
| Anthracite.....                 | 14,600                                  | 12,910             | 5.0                    | 2.9      | 80.0   | 0.9      | 0.7    | 10.5 | 87.9                                |
| Semi-Anthracite.....            | 15,200                                  | 13,770             | 5.0                    | 3.9      | 80.4   | 1.1      | 1.1    | 8.5  | 89.3                                |
| Low-Volatile Bituminous.....    | 15,350                                  | 14,340             | 5.0                    | 4.7      | 81.7   | 1.4      | 1.2    | 6.0  | 91.4                                |
| Medium-Volatile Bituminous..... | 15,200                                  | 13,840             | 5.0                    | 5.0      | 79.0   | 1.4      | 1.5    | 8.1  | 89.0                                |
| High-Volatile Bituminous A..... | 14,500                                  | 13,090             | 9.2                    | 5.3      | 73.2   | 1.5      | 2.0    | 8.8  | 87.7                                |
| High-Volatile Bituminous B..... | 13,500                                  | 12,130             | 13.8                   | 5.5      | 68.0   | 1.4      | 2.1    | 9.2  | 87.3                                |
| High-Volatile Bituminous C..... | 12,000                                  | 10,750             | 21.0                   | 5.8      | 60.6   | 1.1      | 2.1    | 9.4  | 87.4                                |
| Sub Bituminous A.....           | 10,250                                  | 9,150              | 29.5                   | 6.2      | 52.5   | 1.0      | 1.0    | 9.8  | 88.2                                |
| Sub Bituminous B.....           | 9,000                                   | 8,940              | 35.8                   | 6.5      | 46.7   | 0.8      | 0.6    | 9.6  | 89.0                                |
| Sub Bituminous C.....           | 7,500                                   | 6,900              | 44.0                   | 6.9      | 40.1   | 0.7      | 1.0    | 7.3  | 91.0                                |
| Lignite.....                    |                                         |                    |                        |          |        |          |        |      |                                     |

<sup>a</sup> (Btu as received)  $\times 100 \div (100 - 1.1 \text{ Ash})$

coals and in lignite. The percentage of ash and its fusion temperature do not indicate the composition or distribution of its constituents.

### Classification of Coals

A classification of coals is given in Table 2, and a brief description of the kinds of fuel is given in the following paragraphs, but it should be recognized that there are no distinct lines of demarcation between the kinds, and that they graduate into each other.

**Anthracite** is a clean, dense, hard coal which creates little dust in handling. It is comparatively hard to ignite, but it burns freely when well started. It is non-caking, it burns uniformly and smokelessly with a short flame, and it requires no attention to the fuel bed between firings. It is capable of giving a high efficiency in the common types of hand-fired furnaces. A tabulation of the quality of the various anthracite sizes will be found in a Bureau of Mines Report.<sup>3</sup> Standard anthracite sizing specifications are shown in Table 3.

**Semi-anthracite** has a higher volatile content than anthracite. It is not so hard, and ignites somewhat more easily. Otherwise their properties are similar.

**Semi-bituminous coal** is soft and friable, and fines and dust are created by handling it. It ignites somewhat slowly and burns with a medium length of flame. Its caking properties increase as the volatile matter increases, but the coke formed is relatively weak. Having only half the volatile matter content of the bituminous coals, it can be burned with less production of smoke, and is sometimes called a *smokeless coal*.

The term *bituminous coal* covers a large range of coals and includes many types having distinctly different composition, properties, and burning characteristics. The coals range from the high-grade bituminous coals of the East to the poorer coals of the West. Their caking properties range from coals which melt completely, to those from which the volatiles and tars are distilled without change of form, so that they are classed as non-caking or free-burning. Most bituminous coals are strong

TABLE 2. CLASSIFICATION OF COALS BY RANK<sup>a</sup>  
Legend: F.C. = Fixed Carbon. V.M. = Volatile Matter. Btu = British thermal units.

| CLASS                       | GROUP                                   | LIMITS OF FIXED CARBON OR BTU MINERAL-MATTER-FREE BASIS                                                                    | REQUISITE PHYSICAL PROPERTIES                                    |
|-----------------------------|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| I. Anthracite               | 1. Meta-anthracite.....                 | Dry F.C., 98 per cent or more (Dry V.M., 2 per cent or less)                                                               | Non-agglomerating                                                |
|                             | 2. Anthracite.....                      | Dry F.C., 92 per cent or more and less than 98 per cent (Dry V.M., 8 per cent or less and more than 2 per cent)            |                                                                  |
|                             | 3. Semi-anthracite.....                 | Dry F.C., 86 per cent or more and less than 92 per cent (Dry V.M., 14 per cent or less and more than 8 per cent)           |                                                                  |
| II. Bituminous <sup>d</sup> | 1. Low volatile bituminous coal.....    | Dry F.C., 78 per cent or more and less than 86 per cent (Dry V.M., 22 per cent or less and more than 14 per cent)          | Either agglomerating <sup>e</sup> or non-weathering <sup>f</sup> |
|                             | 2. Medium volatile bituminous coal..... | Dry F.C., 69 per cent or more and less than 78 per cent (Dry V.M., 31 per cent or less and more than 22 per cent)          |                                                                  |
|                             | 3. High volatile A bituminous coal..... | Dry F.C., less than 69 per cent (Dry V.M., more than 31 per cent); and moist <sup>g</sup> Btu, 14,000 <sup>h</sup> or more |                                                                  |
|                             | 4. High volatile B bituminous coal..... | Moist <sup>g</sup> Btu, 13,000 or more and less than 14,000 <sup>h</sup>                                                   |                                                                  |
|                             | 5. High volatile C bituminous coal..... | Moist <sup>g</sup> Btu, 11,000 or more and less than 13,000 <sup>h</sup>                                                   |                                                                  |
| III. Sub-bituminous         | 1. Sub-bituminous A coal.....           | Moist Btu, 11,000 or more and less than 13,000 <sup>h</sup>                                                                | Both weathering and non-agglomerating <sup>e</sup>               |
|                             | 2. Sub-bituminous B coal.....           | Moist Btu, 9500 or more and less than 11,000 <sup>h</sup>                                                                  |                                                                  |
|                             | 3. Sub-bituminous C coal.....           | Moist Btu, 8300 or more and less than 9500 <sup>h</sup>                                                                    |                                                                  |
| IV. Lignite                 | 1. Lignite.....                         | Moist Btu less than 8300                                                                                                   | Consolidated                                                     |
|                             | 2. Brown coal.....                      | Moist Btu less than 8300                                                                                                   |                                                                  |

<sup>a</sup> This classification does not include a few coals which have unusual physical and chemical properties and which come within the limits of fixed carbon or Btu of the high-volatile bituminous and sub-bituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon, or have more than 15,500 moist, mineral-matter-free Btu.

<sup>b</sup> If agglomerating, classify in low-volatile group of the bituminous class.

<sup>c</sup> Moist Btu refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

<sup>d</sup> It is recognized that there may be non-caking varieties in each group of the bituminous class.

<sup>e</sup> Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of Btu.

<sup>f</sup> There are three varieties of coal in the high-volatile C bituminous coal group, namely, Variety 1, agglomerating and non-weathering; Variety 2, agglomerating and weathering; Variety 3, non-agglomerating and non-weathering.

Adapted from A.S.T.M. Standards, 1937, Supplement, p. 145, American Society for Testing Materials.

and non-friable enough to permit the screened sizes being delivered free from fines.

In general, they ignite easily and burn freely; the length of flame varies with different coals, but it is long. Much smoke and soot are possible, if improperly fired, especially at low rates of burning.

**Sub-bituminous coals** occur in the western states; they are high in moisture when mined and tend to break up as they dry or when exposed to the weather; they are liable to ignite spontaneously when piled or stored. They ignite easily and quickly, and have a medium length flame; are non-caking and free-burning; the lumps tend to break into small pieces if poked; very little smoke and soot are formed.

**Lignite** is of woody structure, very high in moisture as mined, and of low heating

value; it is clean to handle. It has a greater tendency than the sub-bituminous coals to disintegrate as it dries, and it also is more liable to spontaneous ignition. Freshly mined lignite, because of its high moisture, ignites slowly. It is non-caking. The char left after the moisture and volatile matter are driven off burns very easily, like charcoal. The lumps tend to break up in the fuel bed, and pieces of char falling into the ashpit continue to burn. Very little smoke or soot is formed.

### Dustless Treatment

In order to allay the dust, the more friable coals are sometimes sprayed with various petroleum products, a solution of calcium chloride, or a mixture of calcium and magnesium chlorides.

The coal is usually treated at the mine, but sometimes by the local distributor just before delivery. The salt solutions are sprayed under high

TABLE 3. STANDARD ANTHRACITE SPECIFICATIONS<sup>a</sup>  
Test Mesh Round

| SIZE OF COAL | THROUGH IN. | OVER IN.   | OVERSIZE MAX. % | UNDERSIZE <sup>b</sup> |        | MAXIMUM IMPURITIES   |                                           |    |
|--------------|-------------|------------|-----------------|------------------------|--------|----------------------|-------------------------------------------|----|
|              |             |            |                 | Max. %                 | Min. % | Slate <sup>b</sup> % | Bone <sup>b</sup> % or Ash <sup>c</sup> % |    |
| Broken       | 4 3/4       | 3 1/4 to 3 | —               | 15                     | 7 1/4  | 1 1/4                | 2                                         | 11 |
| Egg          | 3 1/4 to 3  | 2 3/4      | 5               | 15                     | 7 1/4  | 1 1/4                | 2                                         | 11 |
| Stove        | 2 3/4       | 1 5/8      | 7 1/4           | 15                     | 7 1/4  | 2                    | 3                                         | 11 |
| Nut          | 1 5/8       | 1 1/4      | 7 1/4           | 15                     | 7 1/4  | 3                    | 4                                         | 11 |
| Pea          | 1 1/4       | 1          | 10              | 15                     | 7 1/4  | 4                    | 5                                         | 12 |
| Buckwheat    | 1           | 3/4        | 10              | 15                     | 7 1/4  | .....                | .....                                     | 13 |
| Rice         | 3/4         | 1/2        | 10              | 17                     | 7 1/4  | .....                | .....                                     | 13 |
| Barley       | 1/2         | 3/8        | 10              | 20                     | 10     | .....                | .....                                     | 15 |
| No. 4        | 3/8         | .....      | 20              | 30                     | 10     | .....                | .....                                     | 15 |
| No. 5        | 3/16        | .....      | 30              | No limit               | .....  | .....                | .....                                     | 16 |

<sup>a</sup> Approved and adopted, effective July 28, 1947, by the Anthracite Committee (Manual of Statistical Information, Anthracite Institute).

<sup>b</sup> When slate content in the sizes from Broken to Nut inclusive is less than above standards, bone content may be increased by one and one-half times the decrease in the slate content under the allowable limits, but slate content specified above shall not be exceeded in any event.

<sup>c</sup> Ash determinations are on a dry basis. A tolerance of 1 percent is allowed on the maximum percentage of undersize and the maximum percentage of ash content. The maximum percentage of undersize is applicable only to anthracite as it is produced at the preparation plant.

Slate is defined as any material which has less than 40 percent of fixed carbon. Bone is defined as any material which has 40 percent or more, but less than 75 percent of fixed carbon.

pressure, using from 2 to 4 gal or from 5 to 10 lb of the salt per ton of coal, depending on its friability and size. Oil for the dustless treatment of coal is also applied under high pressure, in concentrations of 1 to 8 qt per ton of coal, depending upon the characteristics of the coal and oil.

Dustless treatments, which are of such a corrosive nature that they may damage coal handling or burning equipment, should not be used.

### Classification of Cokes

Coke is produced by the distillation of the volatile matter from coal. The type of coke depends on the coal or mixture of coals used, the temperatures and time of distillation and, to some extent, on the type of retort or oven. Coke is also produced as a residue from the destructive distillation of oil.

**High-temperature cokes.** Coke, as usually available, is of the high-temperature type, and contains between 1 and 2 percent volatile matter. High-temperature cokes are subdivided into *beehive coke* of which comparatively little is now sold for domestic use, *by-product coke*, which covers the greater part of the coke sold, and *gas-house coke*. The differences among these three cokes are relatively small; their denseness and hardness decrease and friability increases in the order named. In general, the lighter and more friable cokes ignite and burn more readily.

**Low-temperature cokes** are produced at low coking temperatures, and only a portion of the volatile matter is distilled off. Cokes, as made by various processes under development, have contained from 10 to 15 percent volatile matter. In general, these cokes ignite and burn more readily than high-temperature cokes. The properties of various low-temperature cokes may differ more than those of the various high-tem-

perature cokes because of the differences in the quantities of volatile matter, and because some may be light and others briquetted.

**Petroleum cokes**, which are obtained by coking the residue left from the distillation of petroleum, vary in the amount of volatile matter they contain, but all have the common property of a very low ash content, which necessitates the use of refractory pieces to protect the grates from being burned.

## COMBUSTION OF SOLID FUELS

### Firing Methods for Anthracite

An anthracite fire should never be poked or disturbed, as this serves to bring ash to the surface of the fuel bed, where it may melt into clinker.

**Egg size** is suitable for large fire-pots (grates 24 in. and over) if the fuel can be fired at least 16 in. deep. For best results this coal should be fired deeply.

**Stove** is the proper size of anthracite for many boilers and furnaces. It burns well on grates at least 16 in. in diameter, on which it is fired about 12 in. deep. The fuel should be fired deeply and uniformly.

**Chestnut size** coal is in demand for fire-pots up to 20 in. in diameter, and is usually fired to a depth of from 10 to 15 in.

**Pea size** coal is often an economical fuel to burn. When fired carefully, pea coal can be burned on standard grates. Care should be taken to shake the grates only until the first bright coals begin to fall through the grates. The fuel bed, after a new fire has been built, should be increased in thickness by the addition of small charges until it is at least level with the sill of the fire-door. A satisfactory method of firing pea coal consists of drawing the red coals toward the front end, and piling fresh fuel toward the back of the firebox.

Pea size coal requires a strong draft, and therefore the best results generally will be obtained by keeping the choke damper open, and regulating solely by means of the cold air check and the air inlet damper.

**Buckwheat size** coal, for best results, requires more attention than pea size coal, and in addition the smaller size of the fuel makes it more difficult to burn on ordinary grates. Greater care must be taken in shaking the grates than with the pea coal on account of the danger of having fuel fall through the grate. In house heating furnaces, the coal should be fired lightly and more frequently than pea coal. When banking a buckwheat coal fire, it is advisable after coaling to expose a small spot of hot fire by putting a straight poker down through the bed of fresh coal. This will serve to ignite the gas that will be distilled from the fresh coal and prevent delayed ignition which, in some cases, depending upon the thickness of the bed of fresh coal, is severe enough to blow open the doors and dampers of the furnace. Where frequent attention can be given and care exercised in manipulation of the grates, this fuel can be burned satisfactorily without the aid of any special equipment, except small mesh grates.

In general, it will be found more satisfactory with buckwheat coal to maintain a uniform heat output and, consequently, to keep the system warm all the time, rather than to allow the system to cool off at times and then to attempt to burn the fuel at a high rate while warming up. A uniform low fire will minimize the clinker formation and keep any clinker formed in an easily broken up condition so that it readily can be shaken through the grate. Forced draft and small mesh grates or, for greater convenience, domestic stokers are frequently used.

Buckwheat anthracite No. 2, or rice size, is used principally in stokers



of the domestic, commercial and industrial type. No. 3 buckwheat anthracite, or barley, has no application in domestic heating.

#### Firing Methods for Bituminous Coal

A commonly recommended procedure for firing domestic heating units, called the side-bank method, requires the movement of live coals to one side or the back of the grate, and placing the fresh fuel charge on the opposite side. The results are a more uniform release of volatile gases, and the subjection of these gases to the high temperature of the red coals. If the fresh charge is covered with a layer of fine coal, still better results may be obtained because of slower release of volatile matter.

Bituminous coal should never be fired over the entire fuel bed at one time. A portion of the glowing fuel should always be left exposed to ignite the gases leaving the fresh charge.

The importance of firing bituminous coal in small quantities at short intervals is discussed in a *U. S. Bureau of Mines* technical paper.<sup>1</sup> Better combustion is obtained by this method in that the fuel supply is maintained more nearly proportional to the air supply.

If the coal is of the caking kind, the fresh charge will fuse into one solid mass which can be broken up with the stoking bar and leveled from 20 min to one hr after firing, depending on the temperature of the firebox. Care should be exercised when stoking not to bring the bar up to the surface of the fuel, as this will tend to bring ash into the high temperature zone at the top of the fire, where it will melt and form clinker. The stoking bar should be kept as near the grate as possible, and should be raised only enough to break up the fuel. With fuels requiring stoking it may not be necessary to shake the grates, as the ash is usually dislodged during stoking.

It is acknowledged that it may be difficult to apply the outlined methods to domestic heating boilers of small size, especially when frequent attendance is impracticable. The adherence to these methods insofar as practicable, however, will result in better combustion.

The output obtained from any heater with bituminous coal will usually exceed that obtained with anthracite, since bituminous coal burns more rapidly than anthracite, and with less draft. Bituminous coal, however, will usually require frequent attention to the fuel bed.

#### Preventing Smoke

In general, time, temperature and turbulence are the essential requirements for smokeless combustion. Anything that can be done to increase any one of these factors will reduce the quantity of smoke discharged. Special care must be taken in hand-firing bituminous coals.

*Checker or alternate firing*, in which the fuel is fired alternately on separate parts of the grate, maintains a higher furnace temperature and thereby decreases the amount of smoke.

*Coking and firing*, in which the fuel is first fired close to the firing door and the coke pushed back into the furnace just before firing again, produces the same effect. The volatiles as they are distilled thus have to pass over the hot fuel bed where they will be burned if they are mixed with sufficient air, and are not cooled too quickly by the heat-absorbing surfaces of the boiler.

*Steam or compressed air jets*, admitted over the fire, create turbulence in the furnace and bring the volatiles of the fuel more quickly into contact

with the air required for combustion. These jets are especially helpful for the first few minutes after each firing. *Frequent firings* of small charges shorten the smoking period, and reduce the density. *Thinner fuel beds* on the grate increase the effective combustion space in the furnace, supply more air for combustion, and are sometimes effective in reducing the smoke emitted, but care should be taken that holes are not formed in the fire. A *lower volatile coal* or a higher *A.P.I.* gravity oil always produces less smoke than a high volatile coal or low *A.P.I.* gravity oil used in the same furnace and fired in the same manner.

The installation of more modern or better designed fuel-burning equipment, or a change in the construction of the furnace, will often reduce smoke. The installation of a Dutch oven, which will increase the furnace volume and raise the furnace temperature, often produces satisfactory results.

In the case of new installations, the problem of smoke abatement can be solved by the selection of the proper fuel-burning equipment and furnace design for the particular fuel to be burned, and by the proper operation of that equipment. Constant vigilance is necessary to make certain that the equipment is properly operated. In old installations the solution of the problem presents many difficulties, and a considerable investment in special apparatus is often necessary.

Lower rates of combustion per square foot of grate area will reduce the quantity of solid matter discharged from the chimney with the gases of combustion. The burning of coke, coking coal, and sized coal from which the extremely fine coal has been removed, will not, as a general rule, produce as much dust and cinders as will result from the burning of non-coking coals and slack coals when they are burned on a grate.

Modern boiler installations are usually designed for high capacity per square foot of floor space, because such designs give the lowest cost of construction per unit of capacity. Designs of this type discharge a large quantity of dust and cinders with the gases of combustion, and if pollution of the atmosphere is to be prevented, some type of dust and cinder catcher must be installed.

#### Firing Methods for Semi-Bituminous Coal

The *Pocahontas Operators' Association* recommends the central cone method of firing, in which the coal is heaped on to the center of the bed forming a cone, the top of which should be level with the middle of the firing door. This allows the larger lumps to fall to the sides, and the fines to remain in the center and be coked. The poking should be limited to breaking down the coke without stirring. Grates should be rocked gently. It is recommended that the slides in the firing door be kept closed, as the thinner fuel bed around the sides admits the required air.

#### Firing Methods for Coke

Coke ignites less readily than bituminous coal and more readily than anthracite, and burns rapidly with little draft. In order to control the air admitted to the fuel it is very important that all openings or leaks into the ashpit be closed tightly. A coke fire responds rapidly to the opening of the dampers. This is an advantage in warming up the system, but it also makes it necessary to watch the dampers more closely in order to prevent the fire from burning too rapidly. In order to obtain the same interval of attention as with other fuels, a deep fuel bed always should be maintained when burning coke. The grates should be shaken only

slightly in mild weather, and should be shaken only until the first red particles drop from the grates in cold weather. The best size of coke for general use, for small fire-pots where the fuel depth is not over 20 in., is that which passes over a 1 in. screen and through a  $1\frac{1}{2}$  in. screen. For large fire-pots where the fuel can be fired over 20 in. deep, coke which passes over a 1 in. screen and through a 3 in. screen can be used, but a coke of uniform size is always more satisfactory. Large sizes of coke should either be mixed with fine sizes or broken up before using.

### SECONDARY AIR

When bituminous coal is hand-fired in a furnace, the volatile matter in the fuel distills off leaving coke on the grate. The product of combustion of the coke is  $CO_2$ , and under certain conditions some  $CO$  may arise from the bed. The combustion of the volatile matter and the  $CO$  may amount to the liberation of from 40 to 60 percent of the heat in the fuel in the combustion space over the fuel bed.

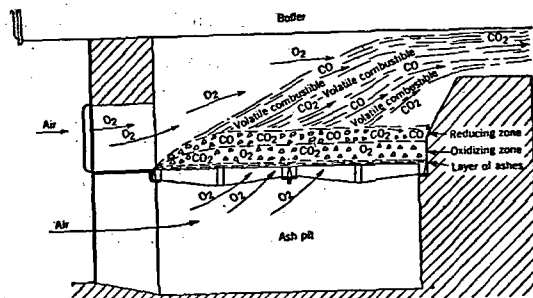


FIG. 1. COMBUSTION OF FUEL IN A HAND-FIRED FURNACE

The air that passes through the fuel bed is called *primary air*, and the air that is admitted over the fuel bed in order to burn the volatile matter and  $CO$  is called *secondary air*.

This process of combustion is illustrated in Fig. 1.<sup>4</sup> The free oxygen of the air passes through the grate and the ash above it, and burns the carbon in the lower 3 or 4 in. of the fuel bed forming carbon dioxide. This layer noted as the oxidizing zone, is indicated by the symbols  $CO_2$  and  $O_2$ . Some of the carbon dioxide of the oxidizing zone is reduced to carbon monoxide in the upper layer of the fuel bed, noted as the reducing zone and indicated by the symbols  $CO_2$  and  $CO$ . The gases leaving the fuel bed are mainly carbon monoxide, carbon dioxide, nitrogen, and a small amount of free oxygen. Free oxygen is admitted through the firing door in an attempt to burn carbon monoxide, as well as the volatile combustible distilled from the freshly fired fuel.

The division of the total into primary and secondary air necessary to produce the same rate of burning and the same excess air, depends on a number of factors which include size and type of fuel, depth of fuel bed, and size of fire-pot.

Size of the fuel is a very important factor in fixing the quantity of secondary air required for non-caking coals. With caking coals it is not so important, because small pieces fuse together and form large lumps. Fortunately, a smaller size fuel gives more resistance to air flow through

the fuel bed, and thus automatically causes a larger draft above the fuel bed. More secondary air is drawn through the same slot openings, but, nevertheless, the smallest size of fuel will require the largest secondary air openings. For certain sizes of fuel, no secondary air openings are required, and for large sizes, too much excess air may pass through the fuel bed.

In general, the efficiency of domestic hand-fired furnaces and boilers burning either anthracite or bituminous coal, can be increased for an hour or two after firing, if some secondary air is admitted through the slots of the fire door. However, unless the slots are closed when secondary air is no longer beneficial, the decrease in efficiency during the remainder of the firing cycle, because of excess air, may more than offset the gain resulting from the secondary air at the beginning of the firing period. Unless the secondary air can be readjusted between firings, it is probable that a greater average efficiency will be obtained for domestic hand-fired devices by leaving the secondary air slots closed at all times. There is usually an appreciable amount of air leakage around the firing door and secondary air slots of domestic furnaces and boilers.

When attention is given between firings, the efficiency of combustion can be raised appreciably by admitting secondary air over a bituminous coal fire, to burn the gases and reduce the smoke. The smoke produced is a good indicator, and that opening is best which reduces the smoke to a minimum. Too much secondary air will cool the gases below the ignition point, and prove harmful instead of beneficial.

Secondary air that enters the combustion chamber too far removed from the zone of combustion, will also be harmful, because the oxygen in the secondary air will not react with any unburned gases, unless the mixture is subjected to high temperatures.

### Draft Requirements for Coal and Coke Firing

The draft required to effect a given rate of burning the fuel is dependent on the following factors: (1) kind and size of fuel; (2) grate area; (3) thickness of fuel bed; (4) type and amount of ash and clinker accumulation; (5) amount of excess air present in the gases; (6) resistance offered by the boiler passes to the flow of the gases; and (7) accumulation of soot in the passes.

Insufficient draft will necessitate additional manipulation of the fuel bed, and more frequent cleanings to keep its resistance down. Insufficient draft also restricts the control that can be accomplished by adjustment of the dampers. For draft requirements see Chapter 17.

The quantity of excess air present has a marked effect on the draft required to produce a given rate of burning. If the excess is caused by holes in the fuel bed, or an extremely thin fuel bed, it is often possible to produce a higher rate of burning by increasing the thickness of the bed. The thickness of the fuel bed should not, however, be increased too much, because the increased draft resistance will reduce the rate of primary air supply and the rate of burning.

### Draft Regulation for Coal and Coke Firing

Because of the varying heating load demands present in most installations, it is necessary to vary the rate of fuel burning. The maintenance of the proper air supply for the various rates of burning is accomplished by regulation of the drafts. Methods of draft regulation used for solid fuel are shown in Fig. 2. The air enters through the ashpit draft door, firing

door, and by leaks in the setting, whereas the gases leave only through the outlet. By throttling the gases with the damper in the outlet all the air entering by each of the three intakes is reduced in the same proportion, thus maintaining about the same percent of excess air. If inlet air is controlled by the ashpit draft door, the air admitted through the ashpit is reduced, while it is increased through the other two intake openings, resulting in an increase of excess air. A considerable increase in the efficiency of hand-fired furnaces and boilers can be realized by regulating the air supply by means of the damper in the outlet instead of the ashpit damper. Use of the ashpit damper is required, of course, for low rates of combustion. The cold air check damper is to be used only when chimney draft is excessive. It is normally closed unless closing of the

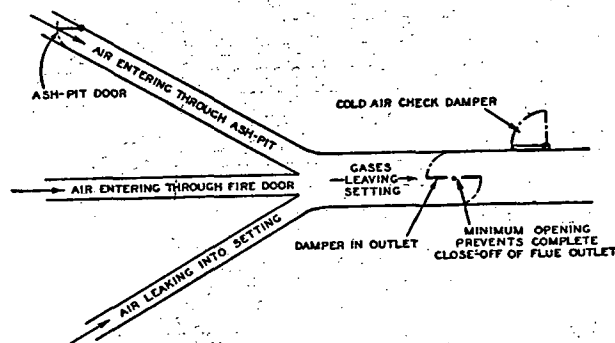


FIG. 2. METHODS OF DRAFT REGULATION IN A HAND-FIRED FURNACE

outlet damper and ashpit damper is unable to control the rate of combustion.

#### Furnace Volume for Coal and Coke

The principal requirements for a *hand-fired furnace* are that it shall have enough grate area and correctly proportioned combustion space. The amount of grate area required is dependent upon the desired combustion rate.

The furnace volume is influenced by the kind of coal used. Bituminous coals, on account of their long-flaming characteristic, require more space in which to burn the gases of combustion completely than do the coals low in volatile matter. For burning high volatile coals, provision should be made for mixing the combustible gases thoroughly, so that combustion is complete before the gases come in contact with the relatively cool heating surfaces. An abrupt change in the direction of flow tends to mix the gases of combustion more thoroughly. Anthracite requires comparatively little combustion space.

#### CLASSIFICATION OF FUEL OILS

Fuel oils are mixtures of hydrocarbons derived from crude petroleum by refining processes designed to produce suitable proportions of naphtha, gasoline, kerosene, fuel oil, and lubricating oil. The processes leave a residue of coke, asphalt, or paraffin depending on the source of the crude oil. In the past, refining processes have been directed toward producing the maximum amount of gasoline, because this product was in greatest demand. The relative proportions of gasoline and fuel oil produced, per unit volume

of crude oil could be varied considerably to suit seasonal changes in demand or gradual trends from year to year. At present gasoline represents about 43 percent and fuel oil (including kerosene) about 22 percent of the yield from crude oil.

Crude oil is distilled in towers at atmospheric pressure to produce gasoline, naphtha, kerosene distillates, and colored distillates, and leave straight-run residues. The colored distillates are distilled further to produce light distillate fuel oils, some lubricating oil, wax, etc., whereas the straight-run residues are distilled under vacuum to produce heavier distillates. The residual fuels remaining can then be passed through cracking plants to produce more gasoline, cracked kerosene, cracked distillates, and cracked residual fuel oils. The exact processes used depend on the proportions of the various end products desired, and to some extent upon the composition and characteristics of the crude oil.

Fuel oils may be described as straight-run fuels, thermally-cracked fuels, catalytically-cracked fuels, or blended fuels depending on the refining process used to produce them. Straight-run fuels are those produced by distillation under atmospheric pressure or a vacuum without decomposition of the hydrocarbons by cracking. Thermally-cracked fuels are those produced by a cracking process involving elevated temperatures (850-1100 F) to decompose some of the heavier hydrocarbons. Catalytically-cracked fuels are those produced with the aid of an alumina-silica catalyst in the cracking process at lower temperatures than those used for thermal cracking. Blended fuel oils are mixtures of any of the above three types. Over 90 percent of all No. 5 fuel oils are blended.

There is no particular problem involved with the burning of a blended oil providing it is blended from two oils which come from the same source. If the oils are not properly blended under heat or pressure, they will exhibit a degree of instability in storage, resulting in sludge formation and a tendency to plug filters and atomizing nozzles in high pressure burners. This is especially true when the oil burning rate is 1 gpm or less.

There is some evidence that the viscosity of blended oils is generally higher than for straight run fuels of the same grade. The viscosity of the oil can change the spray pattern such that smoking and pulsation may result. The adverse effects of high viscosity can be alleviated to a considerable degree in high pressure burners by the use of higher atomizing pressures. In all cases the pressure should be 100 psig or higher and in some cases pressures up to 150 psig have been used to correct difficulties attributed to high viscosity oil.

#### Analysis of Fuel Oils

Crude oil in its natural state contains primarily paraffin hydrocarbons (chemical formula  $C_nH_{2n+2}$ , naphthene hydrocarbons (formula  $C_nH_{2n}$ ), and aromatic hydrocarbons (formula  $C_nH_{2n-6}$ ) where  $n$  is a whole number. Fuel oils produced by pure distillation, that is the straight-run fuel oils contain essentially these same hydrocarbons. Those produced by cracking processes may contain generally all the hydrocarbon series from  $C_nH_{2n+2}$  to  $C_nH_{2n-14}$ , and especially do they contain appreciable percentages of the olefin hydrocarbons which are relatively less stable than the paraffin, naphthene, and aromatic hydrocarbons. The paraffin hydrocarbons are hydrogen-saturated, are among the most stable, and have the highest hydrogen-carbon ratio of any of the hydrocarbon series. The straight-run fuel oils have the highest paraffin content, the highest hydrogen-carbon ratio and are the most stable of the fuel oils. The thermally-cracked fuel

TABLE 4. DETAILED REQUIREMENTS FOR FUEL OILS<sup>a</sup>

| TABLE 4. DETAILED REQUIREMENTS FOR FUEL OILS <sup>a</sup>                                                                    |               |              |                              |                                            |              |                             |      |           |      |                           |      |                    |      |                                 |      |          |      |          |      |
|------------------------------------------------------------------------------------------------------------------------------|---------------|--------------|------------------------------|--------------------------------------------|--------------|-----------------------------|------|-----------|------|---------------------------|------|--------------------|------|---------------------------------|------|----------|------|----------|------|
| GRADE OF FUEL OIL <sup>b</sup>                                                                                               | FLASH POINT F | POUR POINT F | WATER AND SEDIMENT % by vol. | CARBON RESIDUE ON 10% RESIDUE <sup>c</sup> | ASH % by wt. | DISTILLATION TEMPERATURES F |      |           |      | SAYBOLT VISCOSITY seconds |      |                    |      | KINEMATIC VISCOSITY centistokes |      |          |      |          |      |
|                                                                                                                              |               |              |                              |                                            |              | 100% Point                  |      | 90% Point |      | End Point                 |      | Universal at 100 F |      | Fuel at 122 F                   |      | at 100 F |      | at 122 F |      |
|                                                                                                                              |               |              |                              |                                            |              | Max.                        | Min. | Max.      | Min. | Max.                      | Min. | Max.               | Min. | Max.                            | Min. | Max.     | Min. | Max.     | Min. |
| 1. A distillate oil intended for vaporizing pot-type burners and other burners requiring this grade A.P.I. gravity 33 (min.) | Min.          | Max.         | Max.                         | Max.                                       | Max.         | 420                         |      |           | 825  |                           |      |                    |      |                                 | 2.2  | 1.4      |      |          |      |
| 2. A distillate oil for general purpose domestic heating for use in burners not requiring No. 1 A.P.I. gravity 28 (min.)     | 100 or Legal  | 20°          | 0.10                         | 0.35                                       |              |                             |      | 875       |      | 40                        |      |                    |      | (4.3)                           |      |          |      |          |      |
| 3. An oil for burner installations not equipped with preheating facilities                                                   | 130 or Legal  | 20           | 0.50                         |                                            | 0.10         |                             |      |           |      | 125                       | 45   |                    |      | (26.4)                          | 5.8  |          |      |          |      |
| 4. A residual type oil for burner installations equipped with preheating facilities                                          | 130 or Legal  |              | 1.00                         |                                            | 0.10         |                             |      |           |      |                           | 150  | 40                 |      |                                 | 32.1 | (81)     |      |          |      |
| 5. An oil for use in burners equipped with preheaters permitting a high viscosity fuel                                       | 150           |              | 2.00 <sup>d</sup>            |                                            |              |                             |      |           |      |                           |      | 300                | 45   |                                 |      | (538)    | (92) |          |      |

<sup>a</sup> Recognizing the necessity for low sulfur fuel oils used in connection with heat-treatment, non-ferrous metal, glass, ceramic furnaces and other special uses, a sulfur requirement may be specified in accordance with the following table.

GRADE OF FUEL OIL

No. 1 ..... No Limit

No. 2 ..... No Limit

No. 3 ..... No Limit

No. 4, 5 and 6 ..... No Limit

Other sulfur limits may be specified only by mutual agreement between the buyer and seller.

<sup>b</sup> It is the intent of these classifications that failure to meet any requirement of a given grade does not automatically place an oil in the next lower grade unless in fact it meets all requirements of the lower grade.

<sup>c</sup> Lower or higher pour points may be specified whenever required by conditions of storage. However, these specifications shall not require a pour point lower than 0° F. under any condition.

<sup>d</sup> No. 1 oil shall pass test for corrosion made in accordance with paragraph 15 of ASTM Tentative Specifications for Fuel Oils, 3d ed., 1947.

<sup>e</sup> The 10 percent point may be specified at 40 F maximum for use in other than atomizing burners.

<sup>f</sup> The amount of water by distillation, plus the sediment by extraction, shall not exceed 2.00 percent.

<sup>g</sup> The amount of sediment by extraction, shall not exceed 0.10 percent.

<sup>h</sup> The amount of sediment in quantity shall be made for all water and sediment in excess of 1.0 percent.

oils have the lowest paraffin content while the catalytically-cracked fuel oils are intermediate in paraffin content and stability. The hydrogen-carbon ratio of straight-run fuel oils ranges from 0.155 to 0.170, and in catalytically-cracked fuel oils ranges from 0.133 to 0.156, while it is somewhat lower for thermally-cracked fuels. The blending of straight-run oils with cracked oils is common practice to improve the paraffin content, stability, and ignition characteristics of fuel oils. A high paraffin content and a high hydrogen-carbon ratio are generally desirable characteristics for domestic fuel oils and consequently, the straight-run distillates are better suited to this use than the fuel oils produced by the various cracking processes. On the other hand, thermally-cracked fuel oils often have a lower pour point and a lower viscosity than comparable straight-run fuel oils. The color and stability of cracked fuel oils can be much improved by treatment with sulfuric acid, by neutralization, and by redistillation.

### Grade Classification of Fuel Oils

Fuel oils are most commonly classified by dividing them into grades in accordance with the *Commercial Standard* (CS12-48) entitled *Fuel Oil* published by the U. S. Department of Commerce. These specifications, given in Table 4, conform to *ASTM Materials Tentative Specifications for Fuel Oils D 396-48 T*. Oils may be classified roughly by specific gravity but it is not an adequate index of the suitability of an oil for a given purpose. Other characteristics of fuel oils which determine their grade classification in the *Commercial Standard*, and their suitability for given uses are the flash point, pour point, water and sediment content, carbon residue, ash, sulfur content, distillation characteristics, and viscosity.

The flash point of an oil is important with regard to safety in storage and ease of ignition in systems employing automatic ignition. The distillation characteristics determine whether or not the oil can be completely evaporated in some types of burners, and whether cracking will be likely to occur prior to combustion. A low pour point and low water content are desirable for outdoor storage in cold climates. Sediment, carbon residue, and ash should be low to prevent clogging of strainers and the accumulation of unburned material in the burner. A low viscosity allows the fuel oil to flow through supply lines readily and to be broken up into small droplets in atomizing-type burners. The sulfur content is of importance because sulfur compounds corrode the burner and heating system or because undesirable compounds of sulfur may be formed in certain industrial processes. Some of these characteristics of a fuel oil are required to lie within certain limits for each of the grades of fuel oil listed in *Commercial Standard* CS12-48. Some fuel oils do not fall into any of the grade classifications of the *Commercial Standard* because failure to comply with all of the requirements of one grade does not automatically place the fuel oil in the next lower grade, unless it meets all of the requirements of the lower grade.

By ultimate analysis the No. 1 and No. 2 fuel oils contain 84 to 86 percent carbon, 12.0 to 13.5 percent hydrogen, one to three percent oxygen and nitrogen, and 0.5 percent or less of sulfur. The heavier grades of fuel oil, Nos. 4, 5 and 6, may contain as much as 88 percent carbon, as low as 11 percent hydrogen, and considerably more sulfur than is permissible in the domestic grades.

Due to variation in the constituents of different fuel oils and the different refining methods used, the *API* gravities and calorific values of the different grades of fuel oil cover a range in each grade with some overlapping

between domestic grades and between commercial and industrial grades. The relation between the API gravity of fuel oils and their calorific value is shown in Table 5. Grades No. 1 and No. 2 are used predominantly in domestic heating equipment whereas grades 5 and 6 are used in commercial and industrial burners. Grade 6 usually requires preheating to increase its fluidity and to permit atomization, whereas grade 5 is used in some burners without preheating. Grade 4 fuel oil does not require preheating and can be burned satisfactorily in a limited number of domestic burners.

### COMBUSTION OF FUEL OILS

Many theories have been advanced during the past century to explain the mechanism of combustion of hydrocarbons in oil burners and other devices used for producing heat or light. These theories have been modified from time to time to agree with new experimental evidence. Much

TABLE 5. APPROXIMATE GRAVITY AND CALORIFIC VALUE OF STANDARD GRADES OF FUEL OIL

| COMMERCIAL STANDARD NO. | APPROXIMATE GRAVITY A.P.I. | WEIGHT LB PER GALLON | CALORIFIC VALUE BTU PER GALLON |
|-------------------------|----------------------------|----------------------|--------------------------------|
| 1                       | 35-45                      | 7.076-6.675          | 138,800-132,900                |
| 2                       | 26-40                      | 7.481-6.870          | 144,300-135,800                |
| 4                       | 12-25                      | 8.212-7.529          | 153,000-145,000                |
| 5                       | 10-23                      | 8.328-7.627          | 154,600-146,200                |
| 6                       | 8-17.5                     | 8.448-7.909          | 156,000-149,700                |

still remains unknown about the process of decomposition and combustion of hydrocarbons.

Only three theories will be discussed here: (1) the carbonic combustion theory, (2) the aldehydeous combustion theory, and (3) the chain reaction theory.

The carbonic combustion theory postulates that thermal destruction of hydrocarbon molecules is likely to occur if (1) the oil is suddenly exposed to intense heat without allowing time for previous evaporation, (2) the oil and air are inadequately mixed, and (3) there is no preheating of the air or mixture. According to this theory the hydrocarbons would be thermally decomposed into hydrocarbons of lower molecular weight along with some free carbon atoms released under the conditions just described. The free carbon atoms may produce smoky combustion while those carbon atoms that are oxidized to carbon dioxide will produce a yellow luminous flame.

The aldehydeous combustion theory is based on the evidence that aldehydes, alcohols, and possibly peroxides are formed as intermediate products when hydrocarbons are decomposed and oxidized to the final products of combustion. The formation of formaldehyde is certain since it can be identified in the flue gases from blue flame oil burners when insufficient combustion air is provided. Alcohols have been identified by certain investigators during the oxidation of methane and ethane. Aldehydeous combustion is illustrated by the blue flame oil burner and the conditions conducive to this type of hydrocarbon decomposition consist of (1) allowing the oil time and opportunity to evaporate completely prior to combustion, (2) mixing the air and oil vapor thoroughly before combustion, and (3) preheating the air or the mixture.

Blue and yellow flame combustion can be demonstrated by the apparatus

illustrated in Fig. 3. If methane is burned in an atmosphere of air, as in burner A, a yellow flame will result, whereas the introduction of the air for combustion in the center of a stream of methane, as in burner B, will result in blue flame combustion. As the center of the flame in burner A is exposed to intense radiation the methane is thermally decomposed and liberates carbon particles which emit a yellow luminous flame during oxidation. In burner B the center of the flame cone is filled with air which cannot decompose under heat, the methane gas at the zone of contact with the air is only moderately heated because of outward radiation, and the air is preheated in the center as it approaches the flame; each of these conditions tend to produce aldehydeous combustion.

It is probable that the chain reaction theory is an extension of the aldehydeous combustion theory since most investigators who have studied the former have observed that the formation of aldehydes is one of the steps in the combustion process. It has been well established that fuel oils

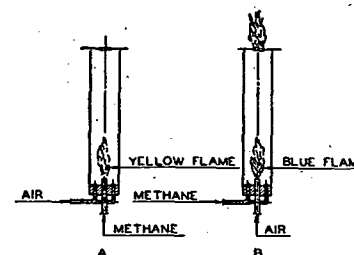


FIG. 3. ILLUSTRATION OF BLUE AND YELLOW FLAME COMBUSTION

must be gasified before combustion can occur, and that molecules of a hydrocarbon and oxygen do not combine directly with each other to form carbon dioxide and water vapor, but pass through intermediate reactions in the process.

Lewis and von Elbe,<sup>5</sup> Pease, and others<sup>6</sup> have advanced the theory that the reactions between hydrocarbons and oxygen are probably chain reactions. This theory postulates that a great many different reactions take place simultaneously or progressively between molecules, atoms, and radicals in a mixture of hydrocarbons and oxygen. Some of these reactions produce particles or substances that tend to accelerate the reactions while others tend to slow down the process. Also, temperature, pressure, light and certain catalytic agents all may affect the speed and nature of these processes. The kind of intermediate products formed before combustion is complete depends on the physical conditions mentioned, as well as the molecular structure of the particular hydrocarbon participating in the reaction. Aldehydes, methyl and ethyl alcohols, formic acid, and other substances, have all been identified as intermediate products in certain reactions. The chain reaction theory, in reality embraces and elaborates on the aldehydeous combustion theory.

### Oil Burning Indexes

A number of indexes have been used, or proposed, as an indication of the burning qualities of fuel oils based on one or more physical measurements made on the oil. These may be summarized as follows:

A. Indexes based on a single physical test: (1) *API* gravity<sup>7</sup>, (2) Aniline point<sup>8</sup>, (3) *Institute of Petroleum* smoke test, (4) Carbon-Hydrogen ratio based on flue gas analysis or ultimate analysis, and (5) Percent aromatics determined by sulfuric acid absorption tests<sup>9</sup>.

B. Indexes based on two or more physical tests: (1) Diesel index<sup>8</sup> based on *API* gravity and aniline point, (2) *Institute of Petroleum* cetane number<sup>10</sup> based on the *API* gravity and 50 percent distillation point, (3) *Universal Oil Products* characterization factor<sup>11</sup> based on specific gravity and average boiling point, (4) Burning index<sup>12</sup> based on *API* gravity and 50 percent distillation point, and (5) Estimated Carbon-Hydrogen ratio<sup>13</sup> based on *API* gravity aniline point, and boiling point.

Various investigators have shown correlation between one or more of these indexes and the performance of fuel oils in oil burners. Experiments

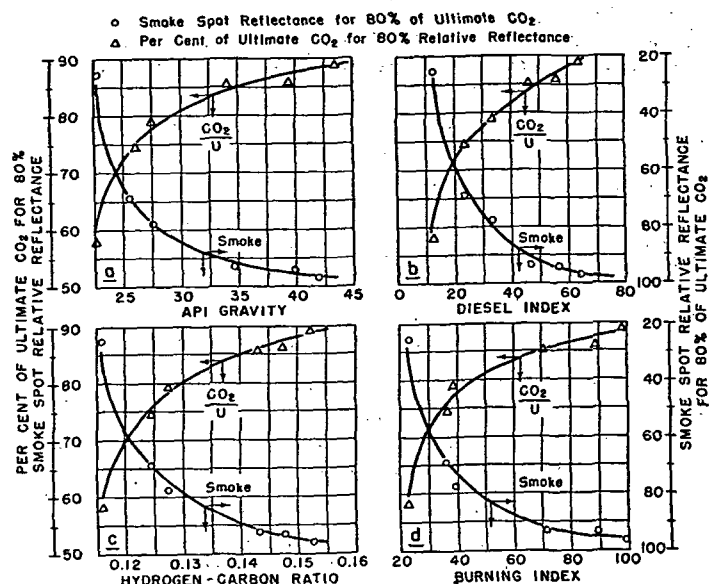


FIG. 4. CORRELATION OF BURNING QUALITIES OF FUEL OILS WITH FOUR COMBUSTION INDEXES

conducted with the *Oil Heat Institute* Reference Test Unit<sup>14</sup> indicated good correlation between the smoking tendency of fuel oils and *API* gravity, burning index, Diesel index, and hydrogen-carbon ratio for a limited number of oils in laboratory apparatus simulating a pressure-atomizing burner. These results are shown graphically in Fig. 4. Smoking tendency is given here in terms of smoke spot reflectance, the light reflectance of a smoke-soiled filter paper. A high reflectance, relative to a clean filter paper, indicates low smoking tendency.  $CO_2/U$  is the observed  $CO_2$  divided by the ultimate or maximum theoretical  $CO_2$  expressed as a percentage. Reid and Hersberger<sup>12</sup> have related burning qualities and burning index for various oils in a wall-flame burner. Cauley and Delgass<sup>13</sup> cite test results on combustion indexes obtained with vaporizing burners. The present experimental data are probably too meager as yet to correlate adequately any one of these indexes with burning qualities of oil fuel for all types of burners. Few attempts have been made to suggest limits for any of these

fuel oil indexes for particular applications, even though correlations between them and burning qualities have been observed. In other words, none of the above mentioned indexes has yet gained sufficiently wide usage to replace the grading of oils by *Commercial Standard* CS12-48.

Experiments have shown that thermal decomposition or cracking of hydrocarbons begins at a temperature of approximately 680 F at atmospheric pressure, although the temperature of cracking varies somewhat above and below this value. Thus pure distillate fuel oils, whose end point does not exceed this temperature, can usually be completely evaporated in vaporizing-type oil burners at atmospheric pressure without leaving a residue or without cracking of the hydrocarbons. Fuel oils that cannot be completely evaporated below 680 F are likely to undergo cracking in vaporizing type burners, with the resulting possibilities of smoky combustion and residues in the oil burner. A complete distillation curve cannot usually be determined for fuel oils containing fractions that evaporate above 680 F.

Since No. 1 grade fuel oil in *Commercial Standard* CS12-48 has a maximum end point of 625 F, it can in most cases be completely evaporated in atmospheric vaporizing burners without cracking, although occasionally an oil is found that undergoes cracking at temperatures below 625 F. By the same criterion, No. 2 grade fuel oil in the *Commercial Standard*, which can have a maximum distillation temperature of 675 F at the 90 percent point, would frequently be cracked in a vaporizing burner. However some No. 2 fuel oils do not crack before complete evaporation takes place. Vaporizing-type burners can generally use only No. 1 fuel oil with assurance that thermal decomposition will not occur during combustion. On the other hand either No. 1 or No. 2 fuel oils may be employed in high or low pressure atomizing burners when the temperatures developed in the combustion chamber are high enough to assure complete combustion, even if the fuel oil is thermally decomposed.

In vaporizing burners, preheating of the combustion air and fuel, complete evaporation of fuel before it is exposed to intense heat, and thorough mixing of the air and gasified fuel promote complete combustion without smoke and with a minimum of excess air. In pressure-type burners preheating of the combustion air, a maximum of air turbulence, good atomization of the fuel, and high combustion chamber temperatures (preferably red hot) promote smokeless combustion with a minimum of excess air.

Natural draft burners depend on the motivating force of a chimney to induce enough air into the burner for complete combustion. Forced draft burners are supplied with combustion air by means of a blower or fan; the chimney merely conducts the flue gases outdoors and prevents leakage of flue gases inside the building. More details on the operation of the different kinds of oil burners and on chimneys and draft will be found in Chapters 15 and 17 respectively.

### FUEL GASES

Fuel gases employed for various heating and air conditioning processes throughout the United States fall into three broad classifications: natural, manufactured, and liquefied petroleum. Natural gas is a mixture of several combustible gases and, usually, a small percentage of inert gases obtained from geologic formations. Natural gas is produced in significant amounts in 20 states. Texas is by far the largest producer, followed by Louisiana, Oklahoma, California, Kansas, and West Virginia. Manufactured gas is made by the distillation or cracking of oil or coal, by the steam carbon



TABLE 6. TYPICAL GAS ANALYSES  
Constituents of Gas—Percent by Volume

| No. Type                 | Source                       | CO <sub>2</sub> | O <sub>2</sub> | N <sub>2</sub> | CO   | H <sub>2</sub> | CH <sub>4</sub> | C <sub>2</sub> H <sub>6</sub> | C <sub>3</sub> H <sub>8</sub> | C <sub>4</sub> H <sub>10</sub> | Spec.<br>Grav.<br>Air | Btu per<br>Cu Ft. <sup>a</sup> |      |
|--------------------------|------------------------------|-----------------|----------------|----------------|------|----------------|-----------------|-------------------------------|-------------------------------|--------------------------------|-----------------------|--------------------------------|------|
|                          |                              |                 |                |                |      |                |                 |                               |                               |                                |                       | Gross                          | Net  |
| 1 Natural gas            | Typical                      | 2.1             | 0.3            | 1.5            | 13.6 | 83.4           | 15.8            |                               |                               |                                | 0.61                  | 1129                           | 1021 |
| 2 Propane                | Commercial (natural gas)     | 0.2             | 0.2            | 0.5            | 1.2  | 1.2            | 3.2             | 1.9                           |                               |                                | 1.55                  | 2558                           | 2358 |
| 3 Propane                | Commercial (refinery gas)    | 1.2             | 0.5            | 2.4            | 7.7  | 54.2           | 30.1            |                               |                               |                                | 1.77                  | 2504                           | 2316 |
| 4 Butane                 | Commercial (natural gas)     | 3.0             | 0.2            | 4.4            | 10.9 | 84.5           | 24.2            |                               |                               |                                | 2.04                  | 3210                           | 2961 |
| 5 Butane                 | Commercial (refinery gas)    | 2.0             | 0.3            | 4.8            | 5.5  | 51.9           | 32.3            |                               |                               |                                | 2.00                  | 3184                           | 2935 |
| 6 Butane-air             |                              | 4.5             | 0.6            | 50.9           | 27.0 | 14.0           | 3.0             |                               |                               |                                | 1.16                  | 550                            | 516  |
| 7 Reformed natural       | Straight shot generator      | 11.5            | 0.6            | 60.0           | 27.5 | 1.0            |                 |                               |                               |                                |                       |                                |      |
| 8 Refinery oil           | Vapor phase crack            | 5.3             | 0.9            | 27.6           | 28.2 | 5.4            |                 |                               |                               |                                |                       |                                |      |
| 9 Oil gas                | Portland, Ore.               | 6.0             | 0.9            | 12.4           | 26.8 | 2.1            |                 |                               |                               |                                |                       |                                |      |
| 10 Coal gas              | Contin. Vert.                | 0.7             | 0.3            | 5.8            | 11.7 | 28.0           | 36.1            |                               |                               |                                |                       |                                |      |
| 11 Coke oven gas         | By-product                   | 3.9             | 0.1            | 15.5           | 10.3 | 17.8           | 46.9            |                               |                               |                                |                       |                                |      |
| 12 Producer gas          | Bituminous                   | 11.1            | 0.4            | 6.6            | 4.0  | 35.8           | 45.7            |                               |                               |                                |                       |                                |      |
| 13 Blast furnace gas     | Heavy oil with blow run      | 6.0             | 0.9            | 12.4           | 26.8 | 2.1            |                 |                               |                               |                                |                       |                                |      |
| 14 Blue gas              | High Btu                     | 0.7             | 0.3            | 5.8            | 11.7 | 28.0           | 36.1            |                               |                               |                                |                       |                                |      |
| 15 Carburetted water gas | Natural, Blue, Producer, Re- |                 |                |                |      |                |                 |                               |                               |                                |                       |                                |      |
| 16 Carburetted water gas | formed Natural               |                 |                |                |      |                |                 |                               |                               |                                |                       |                                |      |
| 17 Mixed Gas             | Coal, Natural                |                 |                |                |      |                |                 |                               |                               |                                |                       |                                |      |
| 18 Mixed Gas             | Natural, Coke Oven           |                 |                |                |      |                |                 |                               |                               |                                |                       |                                |      |
| 19 Mixed Gas             | Decatur, Ill.                |                 |                |                |      |                |                 |                               |                               |                                |                       |                                |      |
| 20 Sewage Gas            |                              |                 |                |                |      |                |                 |                               |                               |                                |                       |                                |      |

<sup>a</sup> This table abstracted from *Gaseous Fuels*, American Gas Association, and from A.G.A. Laboratories Data.  
<sup>b</sup> At 60°F and 30 in. mercury, absolute pressure.

reaction, or by combinations of these processes. Liquefied petroleum gases (propane and butane) are higher hydrocarbon gases normally obtained as a by-product of oil refineries or by stripping natural gas. These two compounds are generally gaseous under usual atmospheric conditions although they can be liquefied by the application of moderate pressures at normal temperatures.

The demand for gaseous fuels has increased so tremendously during the past 25 years that few cities now can be said to depend solely on one source of supply. During peak load periods, heating demands on natural gas distribution systems may necessitate augmenting the base supply with supplemental fuels such as high Btu oil gas or liquefied petroleum gas-air mixtures. The supply of manufactured gases may be similarly increased by adding natural gas, reformed refinery gases, or relatively low heating value mixtures of liquefied petroleum gas and air.

In American gas practice the heating value of a gas and appliance efficiencies are based on the gross heating value. This value is the number of Btu liberated by complete combustion, at constant pressure, of one cubic foot of gas saturated with water vapor and measured at 60 F and 30 in. of mercury, with air at the same temperature and pressure. Products of combustion are cooled to the initial temperature of the gas and air and the water formed by combustion of free and combined hydrogen is condensed to the liquid state.

### Classification of Gases

Representative properties of gaseous fuels commonly employed for domestic heating processes are shown in Table 6.<sup>15, 16, 17, 18</sup>

Natural gas contains from 55 to 98 percent methane with various percentages of higher hydrocarbons, chiefly ethane. In addition to these components, small quantities of non-combustible gases such as carbon dioxide, nitrogen, and helium are sometimes present. Percentages of the different components vary with the area from which natural gas is withdrawn. They may even vary slightly from any given well during its lifetime but these variations are inconsequential insofar as the utilization of the gas is concerned. Heating values of natural gases vary from 900 to 1400 Btu per cu ft but the usual range for use is from 1000 to 1050 Btu (gross) per cu ft. A typical analysis is given in Table 6.

Manufactured gases commonly produced are listed in Table 6. Gross, or higher, calorific values of typical send-out gases made from these manufactured gases generally range from 500 to 600 Btu per cu ft. Due largely to the greatly increased demand for city gases the tendency during recent years has been to increase rather than to decrease heat content of manufactured gases, thus making it possible to serve more customers through the existing distribution system.

Mixed gases are a result of increased distribution of natural gas, through transcontinental transmission lines, into areas having existing manufactured gas facilities. In such instances some gas companies supply a 600 to 800 Btu mixture (See Table 6). In some territories these mixtures are distributed as an intermediate step in changing over from manufactured gas to natural gas. Although the burden of adjusting installed heating and air conditioning equipment and supplying new orifices and burner equipment is generally assumed by the gas companies when the gas is changed, it is advisable to consult the local gas company to insure that equipment is provided with proper orifices and burners when installed.

Most states enforce legislation through their public service commissions



to require delivery of a gas of specified average or minimum heating value within their respective limits. Any given heating value within reason fortunately may be maintained and yet permit considerable latitude in the composition of the gas distributed. Hence the constituents of city gases are not necessarily the same in different districts nor even at successive stations in the same district. In every community, however, the objective is to maintain variations in composition and gas pressure within limits which will provide satisfactory operation and performance of all common types of gas burning equipment.

*Liquefied petroleum gases*, such as propane and butane or mixtures thereof have calorific values ranging from 2500 to 3200 Btu per cu ft. These fuels are often supplied as liquids under pressure in tanks or bottles. In such cases the liquid evaporates when pressure is relieved, the heat necessary for vaporization being obtained from the surrounding air or ground. As butane boils at 32 F some provision is necessary, for maintaining the gas above this temperature or for lowering the partial pressure by dilution if the gas is utilized in colder climates. Propane, with a boiling point of -40 F, may be served in localities where temperatures substantially below freezing are encountered. When employed for heating purposes, these gases are usually stored in high pressure tanks and delivered by tank truck in much the same manner as fuel oil. Both gases, mixed with air, or in undiluted form, are also extensively employed by gas companies to augment their base load supplies during peak load periods. In some smaller communities, where gas manufacturing plants are not economically feasible and natural gas is unavailable, liquefied petroleum gases or liquefied petroleum gas-air mixtures are supplied through mains in much the same manner as manufactured or natural gas.

### COMBUSTION OF GASEOUS FUELS

Gas burners employed in domestic heating appliances are generally of the non-luminous flame or Bunsen type. Part of the air required for combustion is inspirated as *primary air* into the burner mixing tube where it mixes with gas, and then takes part in combustion at the burner ports. As the amount of primary air is seldom sufficient to support complete combustion, additional air is supplied to the burner flames around the periphery of its ports. This *secondary air* is induced into the appliance and around the base of each separate burner flame by force of the issuing mixture of gas and primary air and by draft inspiration inherent in the heat of the flames. If a Bunsen type burner is properly adjusted, its flames will generally have a clear, blue appearance. Yellow flames are indicative of insufficient primary air supply, and possibly of incomplete combustion. An appreciable updraft is seldom, if ever, present even in flue-connected gas heating appliances, because most appliances of this kind are equipped with a draft hood which reduces the chimney draft at the appliance. It is important to note that gas furnaces and boilers, as well as most other classes of heating equipment, are designed to create their own draft.

The air-to-gas ratio in a Bunsen burner head has a decided effect on the rate of flame propagation. The gas-air mixture must flow from the burner ports faster than the flame burns, otherwise flashback will occur. The flashback condition normally results either from an excess amount of primary air or insufficient gas or both. Conversely, the velocity of the issuing mixture must not be so high that the flame will be blown from the ports, a condition known as *lifting*. Fortunately, contemporary types of such burners have a rather wide range of flexibility in capacity and adjust-

ment. In addition to this characteristic, gas supply is normally so uniform that if a gas heating appliance is properly adjusted when it is installed, its burners, with occasional cleaning, should provide trouble-free service for years. When problems incident to changeover of the gas supply are involved, they are generally assumed by the local utility providing the supply of gas. It should be recognized that a change in fuel gas will change the operating  $CO_2$  value. For example, an appliance operating on carburetted water gas at 20 percent excess air will have 14.2 percent  $CO_2$  in the flue gases. If a change is made to coke oven gas at the same gas input rate, with the excess air maintained at 20 percent, the operating  $CO_2$  would drop to 9.2 percent.

Luminous flame burners are occasionally used in central heating gas appliances. With these devices all air required for complete combustion is supplied to the flames as secondary air. Two fundamental advantages of this type of burner are that the possibilities of flashback are eliminated, and that a much higher gas velocity is needed to blow the flames off the ports. On the other hand, if there is any appreciable amount of flame impingement on any portion of the heating surface, or if secondary air is not effectively supplied to the flames, soot may be formed and also combustion may be incomplete.

In some types of gas burners radiant baffles are used to convert part of the energy formed during the process of combustion to radiant heat. These baffles may also serve to direct the flow of products of combustion along the heat-absorbing surface.

Gas designed furnaces and boilers approved by the *American Gas Association* are certified for operation at the rating shown on the nameplate. Considerations relating to safety, performance, and service life, require that such appliances be adjusted at inputs which do not exceed the nameplate input rating. These appliances normally draw in from 20 to 50 percent excess air, depending on the type and general design. As has been indicated, some excess air is necessary to insure complete combustion at all times and also to provide a reasonable degree of flexibility in performance.

Various types of appliances used for gas space heating purposes are described in Chapter 15.

Care must be exercised to insure adequate air supply for combustion equipment installed in buildings or other structures. Where the equipment is closely confined, as in closets or small furnace or boiler rooms, the air supply must also provide for ventilation. Current recommended practices are:

1. Where the equipment is not closely confined (typical cellar installation or equivalent) provide not less than 1 sq in. of free access to outside air for each 1000 Btu per hr heat release of fuel consumed. Infiltration into conventional frame or brick construction, unless unusually tight with storm windows and tight doors, provides adequate air.
2. Where the equipment is closely confined, provide two openings to outside air or from spaces freely communicating to the outside. One opening should be near the top of the equipment enclosure and the other near the bottom. Each opening should have not less than  $\frac{1}{4}$  sq in. of free area for each 1000 Btu per hr heat release of fuel burned, and should communicate to air source or outside by suitable ducts. Where the enclosure is in a building of otherwise conventional construction, and the air source will be the normal infiltration into building, each opening shall have not less than 1 sq in. of free area for each 1000 Btu per hr heat release.
3. Clearances from equipment to closely confining enclosures should conform to local codes and to standards listed by recognized agencies such as *AGA Testing Laboratories*<sup>19</sup> and *Underwriters' Laboratories*.<sup>20</sup> See Fig. 5 for details concerning installa-

tion of gas burning equipment.<sup>13</sup> For installation of equipment burning other types of fuel, refer to the *National Building Code of the N.B.F.U.*

4. Certain additional precautions may be required for certain fuels (such as undiluted liquefied petroleum gas) and consequently provisions of local codes and other authoritative agencies should be followed.

### FUNDAMENTAL PRINCIPLES OF COMBUSTION

Regardless of the type of fuel under consideration, its combustion results in the production of gaseous products. Many kinds of solid fuels contain minerals which cannot be burned and are therefore left as a residue commonly called ash. Moreover, unless sufficiently high temperatures are employed and an ample supply of oxygen properly distributed is present,

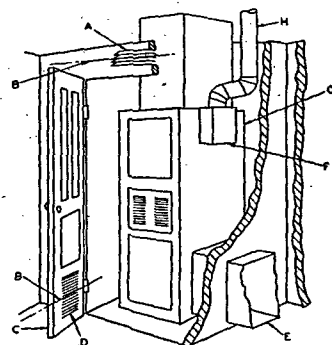


FIG. 5. ILLUSTRATION SHOWING AIR OPENINGS NECESSARY TO SUPPLY AIR FOR COMBUSTION WHEN APPLIANCE IS INSTALLED IN CONFINED SPACE

- A. Ventilating air outlet register for furnace room, 1 sq. in. free area for each 1000 Btu per hr furnace input located above relief opening of draft hood. Register must not be blocked by drapes or other furnishings.
- B. Both registers must either face same large ventilated interior space or extend to such space by means of ducts. Vertical distance C/L to C/L of registers should be not less than 3 1/4 ft.
- C. Suggest room access door be not less than 6 ft high by a width sufficient to provide for installation or removal of furnace. At least 2 ft horizontal clearance should be provided in front of furnace when closet door is open, or 18 in. when door is closed.
- D. Combustion and ventilation air inlet register for furnace room, 1 sq. in. free area for each 1000 Btu per hr furnace input, located at or below combustion air inlet to furnace. Register must not be blocked by drapes or other furnishings.
- E. Air circulated by furnace must be handled by ducts which are sealed to furnace casing and are entirely separate from means provided for supplying combustion and ventilation air.
- F. Spacing between draft hood and wall at least 6 in. (unless approved for closer spacing). If flue products may be directed toward wall, 12 in. spacing recommended.
- G. No part of furnace casing closer than 6 in. to wall (unless approved for closer spacing).
- H. Flue should terminate above peak of roof and above nearby walls to assure satisfactory flue performance. In installations where the flue terminal is below nearby walls or roof peaks, an effective vent cowl should be used.

the combustible constituents of solid, liquid, and even gaseous fuels cannot be completely burned. Incomplete or partial combustion of all fuels produces toxic gases, such as carbon monoxide, with smaller quantities of aldehydes, ketones, and other hydroxylated hydrocarbon compounds. This fact indicates that, while combustion processes involving common types of fuel may be regulated by experienced operators to produce the most efficient results, normal combustion processes can be so unbalanced as to create hazards unless both design and operation are planned with a knowledge of the fundamental principles of combustion.

Combustion may be defined as the chemical combination of a substance with oxygen resulting in the evolution of heat, and usually some light. The rate of combustion depends upon the rate of reaction of the substance with oxygen, upon the rate at which oxygen is supplied, and upon the tempera-

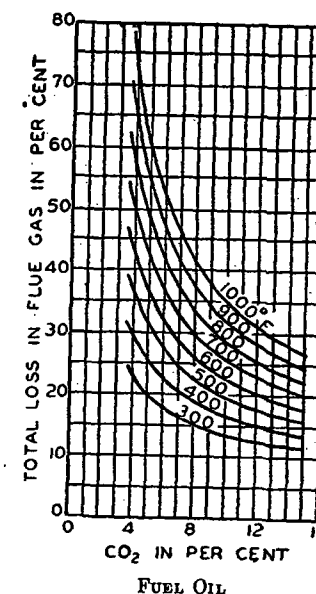
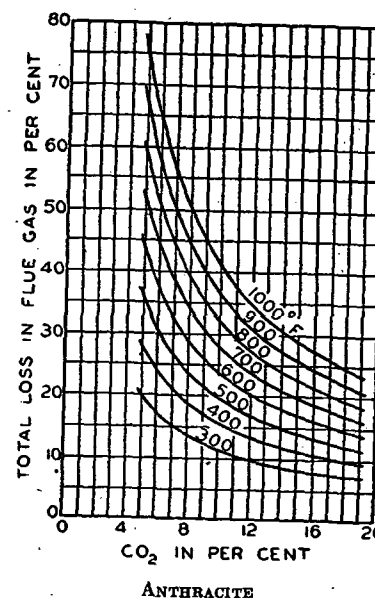
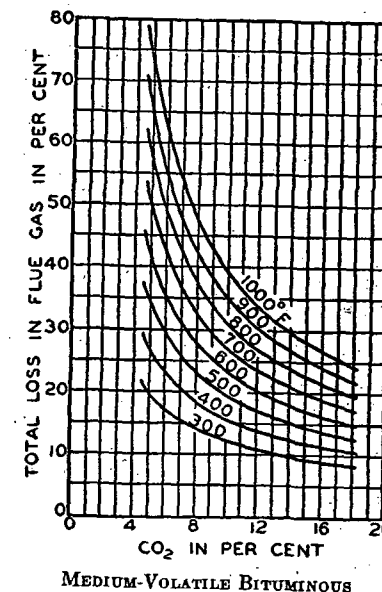
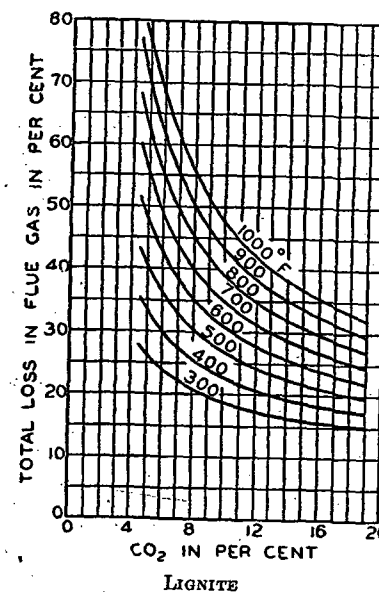


FIG. 6. FLUE GAS LOSSES WITH VARIOUS FUELS<sup>1</sup>

Flue Gas Temperature Shown. Loss is Based on 65 F Room Temperature.

ture obtained due to surrounding conditions. This is combustion in its simplest form. All solid, as well as liquid and even gaseous fuels generally contain several combustible elements in combination with others which, depending on their nature, affect oxygen requirements and thus govern the combustion process. For a continuous reaction, as in heating processes, it is necessary to establish an effective balance between rates of removing heat and of supplying fuel and air or oxygen to keep the reaction going. In establishing such a balance, consideration must be given to the removal or venting of products of combustion, so that the entire process is one of flow wherein draft conditions in the combustion space are important.

*Complete combustion* is obtained when all combustible elements in a fuel are oxidized by all of the oxygen with which they will combine. All oxygen or air supplied is generally not utilized, and this excess portion is commonly referred to as *excess oxygen* or *excess air*. Excess air is usually expressed as a percentage of the air required for perfect combustion.

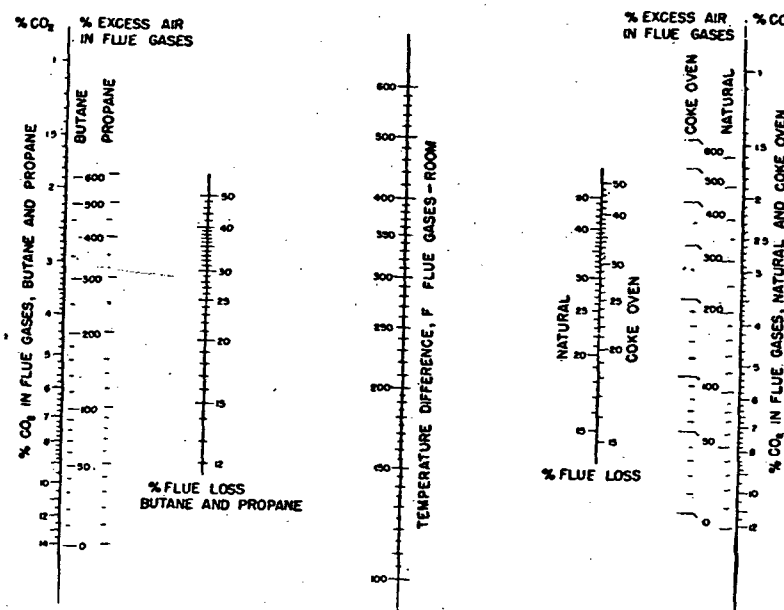
*Perfect combustion* results when the exact amount of oxygen required for complete combustion of all elements of a fuel is supplied and utilized. The percentage of carbon dioxide contained in the products of combustion from such a reaction is obviously the maximum attainable and is referred to as the ultimate  $CO_2$  or *maximum theoretical percentage of carbon dioxide*. This condition of perfect combustion, without having excess air or oxygen left from the reaction, is seldom, if ever, realized in practice. Most types of heating equipment must be sufficiently flexible in performance to provide complete combustion with not only variations in the quality of a fuel but also changes in the rate at which it is supplied. This situation makes it advisable, from a practical standpoint, to insure *complete combustion* but not *perfect combustion* in the sense expressed above. To attempt to do so would undoubtedly result eventually in unsatisfactory performance especially from a safety standpoint. Consequently, common types of heating equipment are usually designed, installed, and adjusted to operate with some excess air. The exact percentage of such air depends on the type of fuel being utilized, as well as anticipated variations in its quantity and quality. Despite these practical limitations, however, it should not be inferred that common types of fuels cannot be utilized economically. Reference to flue loss charts such as Figs. 6 and 7 for gas burning equipment and to the air requirements discussion in Chapter 15 shows that reasonable quantities of excess air can be used without appreciable reductions in operating efficiencies.

Oxygen combines with the combustible elements and compounds of any fuel in accordance with fixed laws. The reactions and resultant products of perfect combustion of common fuel constituents are set forth in Table 7. All of the oxygen required for combustion is normally obtained from the surrounding air, which is a mechanical mixture of nitrogen and oxygen with small amounts of carbon dioxide, water vapor and inert gases. For practical combustion calculations, air is considered to consist of 20.9 percent oxygen and 79.1 percent nitrogen by volume, and 23.15 percent oxygen and 76.85 percent nitrogen by weight. The nitrogen, being inert, passes through the reaction without change. Table 7 gives the air quantities corresponding to the oxygen required for perfect combustion.

Air supplied to the combustion reaction is in most instances introduced in two ways. *Primary air* is introduced through or with the fuel, and *secondary air* is supplied to the flames issuing from the fuel.

*Incomplete combustion* is obtained when any of the combustible elements are not completely oxidized in the combustion reaction. This condition

not only represents inefficient use of the fuel but also presents a hazard because carbon monoxide is usually one of the products of incomplete combustion. For example, a hydrocarbon may not oxidize completely to carbon dioxide and water, as indicated in Table 7, but may also form alcohols, ketones, aldehydes, or carbon monoxide depending on where and how the reaction is interrupted. Too low a temperature (such as may be caused by flame impingement on a cold surface), a poor oxygen supply to the flames (due to insufficient or poorly located air supply, or smothering



Adapted from American Gas Association Laboratories Flue Loss Charts.

FIG. 7. ALIGNMENT CHART FOR CALCULATION OF FLUE LOSSES FOR BUTANE, PROPANE, COKE OVEN, AND NATURAL GASES

by products of combustion not properly vented), or insufficient mixing of the air and fuel, are the primary causes of incomplete combustion.

### Heat of Combustion

As previously stated, the process of combustion results in the evolution of heat. The heat generated by the complete combustion of a unit of fuel is constant for a given combination of combustible elements and compounds, and is known as the *heat of combustion*, *calorific value*, or *heating value* of the fuel. The heat of combustion of the several substances found in the more common fuels is given in Table 7.

The calorific value of a fuel may be determined either by direct measurement of the heat evolved during combustion in a calorimeter, or it may be computed from the ultimate analysis and the heat of combustion of the several chemical elements in the fuel. When the heating value of a fuel is determined in a calorimeter, the water vapor is condensed and the latent heat of vaporization is included in the heating value of the fuel. The heat-

TABLE 7. GENERAL DATA OF COMBUSTIBLE ELEMENTS AND COMPOUNDS\*

| SUBSTANCE                    | MOLECULAR SYMBOL               | CHEMICAL REACTION OF COMBUSTION                                                            | IGNITION TEMPERATURE <sup>b</sup> , F Deg | CALORIFIC VALUE    |                    |                            | THEORETICAL OXYGEN AND AIR REQUIREMENTS |       |                 |       |
|------------------------------|--------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------|--------------------|--------------------|----------------------------|-----------------------------------------|-------|-----------------|-------|
|                              |                                |                                                                                            |                                           | Btu per Lb         |                    | Btu per Cu Ft <sup>b</sup> | Lb per Lb                               |       | Cu Ft per Cu Ft |       |
|                              |                                |                                                                                            |                                           | Gross              | Net                |                            | O <sub>2</sub>                          | Air   | O <sub>2</sub>  | Air   |
| Carbon (to CO)               | —                              | 2C + O <sub>2</sub> = 2CO                                                                  | —                                         | 3950               | —                  | —                          | 1.33                                    | 5.76  | —               | —     |
| Carbon (to CO <sub>2</sub> ) | —                              | 2C + 2O <sub>2</sub> = 2CO <sub>2</sub>                                                    | —                                         | 14093              | —                  | —                          | 2.66                                    | 11.53 | —               | —     |
| Sulfur (to SO <sub>2</sub> ) | —                              | S + O <sub>2</sub> = SO <sub>2</sub>                                                       | —                                         | 3983               | —                  | —                          | 1.00                                    | 4.29  | —               | —     |
| Sulfur (to SO <sub>3</sub> ) | —                              | 2S + 3O <sub>2</sub> = 2SO <sub>3</sub>                                                    | —                                         | 5940               | —                  | —                          | 1.50                                    | 6.43  | —               | —     |
| Carbon Monoxide              | CO                             | 2CO + O <sub>2</sub> = 2CO <sub>2</sub>                                                    | 1166-1319                                 | 4347               | —                  | —                          | 0.57                                    | 2.47  | 0.5             | 2.39  |
| Methane                      | CH <sub>4</sub>                | CH <sub>4</sub> + 2O <sub>2</sub> = CO <sub>2</sub> + 2H <sub>2</sub> O                    | 1260-1380                                 | 23879              | 21520              | —                          | 3.99                                    | 17.27 | 2.0             | 9.53  |
| Acetylene                    | C <sub>2</sub> H <sub>2</sub>  | 2C <sub>2</sub> H <sub>2</sub> + 5O <sub>2</sub> = 4CO <sub>2</sub> + 2H <sub>2</sub> O    | 763-824                                   | 21500              | 20776              | —                          | 3.07                                    | 13.30 | 2.5             | 11.91 |
| Ethylene                     | C <sub>2</sub> H <sub>4</sub>  | C <sub>2</sub> H <sub>4</sub> + 3O <sub>2</sub> = 2CO <sub>2</sub> + 2H <sub>2</sub> O     | 986-1123                                  | 21644              | 20295              | —                          | 3.42                                    | 14.81 | 3.0             | 14.29 |
| Ethane                       | C <sub>2</sub> H <sub>6</sub>  | 2C <sub>2</sub> H <sub>6</sub> + 7O <sub>2</sub> = 4CO <sub>2</sub> + 6H <sub>2</sub> O    | 990-1120                                  | 22320              | 20432              | —                          | 3.73                                    | 16.12 | 3.5             | 16.68 |
| Hydrogen                     | H <sub>2</sub>                 | 2H <sub>2</sub> + O <sub>2</sub> = 2H <sub>2</sub> O                                       | 1063-1166                                 | 60958 <sup>c</sup> | 51571 <sup>c</sup> | —                          | 7.94                                    | 34.34 | 0.5             | 2.39  |
| Hydrogen Sulfide             | H <sub>2</sub> S               | 2H <sub>2</sub> S + 3O <sub>2</sub> = 2H <sub>2</sub> O + 2SO <sub>2</sub>                 | 599-608                                   | 7100               | 6545               | —                          | 1.41                                    | 6.10  | 1.5             | 7.15  |
| Propane                      | C <sub>3</sub> H <sub>8</sub>  | C <sub>3</sub> H <sub>8</sub> + 5O <sub>2</sub> = 3CO <sub>2</sub> + 4H <sub>2</sub> O     | 950-1080                                  | 21661              | 19944              | —                          | 3.63                                    | 15.70 | 5.0             | 23.82 |
| n-Butane                     | C <sub>4</sub> H <sub>10</sub> | 2C <sub>4</sub> H <sub>10</sub> + 13O <sub>2</sub> = 8CO <sub>2</sub> + 10H <sub>2</sub> O | 890-1020                                  | 21308              | 19680              | —                          | 3.58                                    | 15.49 | 6.5             | 30.97 |
| Commercial Propane           | —                              | —                                                                                          | 920-1020                                  | 21560              | 19865              | —                          | 3.60                                    | 15.58 | 4.9             | 23.4  |
| Commercial Butane            | —                              | —                                                                                          | 900-1000                                  | 21180              | 19591              | —                          | 3.54                                    | 15.3  | 6.3             | 30.0  |

\* Values in table taken chiefly from page 51 of Fuel Plus Gases published by American Gas Association.

<sup>b</sup> Gas measured at 60 F and 30 in. Hg.<sup>c</sup> Value from National Bureau of Standards.

ing value so-determined is termed the *gross* or *higher* heating value, and this is what is ordinarily meant when the heating value of a fuel is specified. In burning the fuel, however, the products of combustion are not cooled to the dew-point and the higher heating value cannot be utilized.

When combustion is complete, the carbon in the fuel unites with oxygen to form carbon dioxide, CO<sub>2</sub>, the hydrogen unites with oxygen to form water vapor, H<sub>2</sub>O, and the nitrogen, being inert, passes through the reaction without change. When combustion is incomplete, some of the carbon may unite with oxygen to form carbon monoxide, CO, and some of the hydrogen and hydrocarbon gases may not be burned at all. When carbon monoxide or other combustible gases are present in the flue gases, there is a loss of heat produced per unit of fuel consumed, and a lower combustion efficiency is obtained. Incomplete combustion may result from any or all of the following three conditions: (1) inadequate air supply, (2) insufficient mixing of air and gases, and (3) a temperature too low to produce ignition or maintain combustion.

### AIR REQUIRED FOR PERFECT COMBUSTION

Air requirements for combustion of solid and liquid fuels are ordinarily expressed in pounds. On the other hand similar requirements for gaseous fuels are usually stated on a cubic foot basis. For solid and gaseous fuels this method of treatment corresponds to the standards of measurement commonly employed by these two industries.

The weight of air required for perfect combustion per pound of solid or liquid fuel may be calculated after substitution of the proper percentages by weight of the various elements obtained from an ultimate analysis of the fuel in Equation 2. For gaseous fuels see Equation 3 for volume of air required.

#### Solid or Liquid Fuels:

$$\text{Pounds air required per pound fuel} = \frac{34.56}{100} \left[ \frac{C}{8} + \left( H - \frac{O}{8} \right) + \frac{S}{8} \right] \quad (2)$$

#### For Gaseous Fuels:

$$\begin{aligned} \text{Cubic feet air required per cubic foot gas} = & 2.39 (CO + H_2) + 9.53 CH_4 + \\ & 16.68 C_2H_6 + 23.82 C_3H_8 + 30.97 C_4H_{10} + 11.91 C_2H_2 + 14.29 C_2H_4 + \\ & 7.15 H_2S - 4.78 O_2 + 30.47 \text{ Illuminants} \end{aligned} \quad (3)$$

Gaseous fuels may contain a wide variety of components classified as *illuminants*, which are not separated by the usual methods of gas analysis. The principal ones in addition to ethylene and acetylene which are included in Equation 3, with the air required per cubic foot of gas are: propylene, 21.44; butylene, 28.58; pentene, 35.73; benzene, 35.73; toluene, 42.88; and xylene, 50.02. Since toluene and xylene are normally scrubbed from the gas before distribution, they may be disregarded in computing air required for a fuel gas. An approximate value of 30.47 (as shown in Equation 3) may, therefore, be employed. If ethylene and acetylene are included as *illuminants*, it is suggested that the value 19.65 be used.

If it is desired to make the gas calculations on a weight basis the equation is expressed as follows:

$$\begin{aligned} \text{Pounds air required per pound fuel} = & 2.47 CO + 34.34 H_2 + 17.27 CH_4 + \\ & + 16.12 C_2H_6 + 15.70 C_3H_8 + 15.49 C_4H_{10} + 13.30 C_2H_2 + \\ & 14.81 C_2H_4 + 6.10 H_2S - 4.32 O_2 \end{aligned} \quad (4)$$

Where approximate results only are desired, values appearing in Table 8 may be substituted for Equations 2, 3, and 4; or the air required for perfect combustion may be estimated by assuming that 0.9 cu ft air is required per 100 Btu of fuel.

Where extreme precision is involved it is suggested that the reader refer to scientific literature published on the subject of combustion and related topics by the various industries concerned. If approximate values for theoretical air requirements suffice, or if complete information on the fuel is not available, the following values should also be found helpful:

1. *Solid Fuels* (Pounds air per pound fuel). Anthracite, 9.6; Semi-Bituminous, 11.2; Bituminous 10.3; Lignite 6.2; and Coke 11.2.

TABLE 8. APPROXIMATE AIR REQUIREMENTS FOR THEORETICALLY PERFECT COMBUSTION OF FUELS\*

| TYPE OF FUEL | AIR REQUIRED FOR PERFECT COMBUSTION |                                  | APPROXIMATE PRECISION, PER CENT | EXCEPTIONS                            |
|--------------|-------------------------------------|----------------------------------|---------------------------------|---------------------------------------|
|              | Lbs per Lb Fuel                     | Cu Ft per Unit <sup>b</sup> Fuel |                                 |                                       |
| Solid        | Btu per lb $\times 0.00073$         | Btu per lb $\times 0.0097$       | 3                               | Fuels containing more than 30% water  |
| Liquid       | Btu per lb $\times 0.00071$         | Btu per lb $\times 0.0094$       | 3                               | Results low for gasoline and kerosene |
| Gas          | Btu per lb $\times 0.00067$         | Btu per cu ft $\times 0.0089$    | 5                               | Gases of 300 Btu per cu ft or less    |

\* Values in table taken from page 276 of *Gaseous Fuels*, 1948, published by American Gas Association.

<sup>b</sup> Units for solid and liquid fuels in pounds, for gas in cubic feet.

2. *Fuel Oil* (Pounds air per gallon): Commercial Standard No. 1, 102.6; No. 2, 105.5; No. 5, 112; No. 6, 114.2.

3. *Gaseous Fuels* (Cubic feet of air per cubic foot): Natural, 10.0; Mixed Natural and Manufactured, 8.0; Manufactured, 4.7, Propane, 23.8, Butane, 31.0.

### COMBUSTION EFFICIENCY FROM THE FLUE GAS ANALYSIS

#### Excess Air

A commonly employed index of efficiency of combustion is the relation existing between the amount of air theoretically required for perfect combustion and the amount of air actually supplied. Since the difference between air supplied for combustion and theoretical air required is characterized as excess air, its percentage may be calculated by use of the following equation,

$$\text{Percent excess air} = \left( \frac{\text{Air supplied} - \text{Theoretical air}}{\text{Theoretical air}} \right) \times 100 \quad (5)$$

The amount of dry air supplied per pound of fuel burned may be obtained from Equation 6 which has reasonable precision for most solid and liquid fuels. Values for  $CO_2$ ,  $CO$  and  $N_2$  are percentages by volume from the flue gas analysis, and  $C$  is the weight of carbon burned per pound of fuel, corrected for carbon in the ash.

$$\text{Pounds dry air supplied per pound of fuel} = \frac{3.04N_2}{(CO_2 + CO)} \times C \quad (6)$$

Because excess air calculations are almost invariably made from Orsat

analysis results, and theoretical air requirements are not always known, another convenient method of expressing the relation of Equation 5 is as follows:

$$\text{Percent excess air} = \frac{100(O_2 - CO/2)}{N_2 \times 0.264 - (O_2 - CO/2)} \quad (7)$$

As measurement standards for gaseous fuels are almost universally expressed in cubic feet, Equation 8 may be employed for computing excess air on a percentage basis for gases.<sup>21</sup>

$$\text{Percent excess air} = \frac{(U - CO_2)}{CO_2} \times 100 \frac{P}{A} \quad (8)$$

where

$U$  = ultimate carbon dioxide, percent of flue gases resulting from perfect combustion.

$CO_2$  = carbon dioxide content of flue gases, percent.

$P$  = dry products from perfect combustion, cubic feet per cubic foot of gas burned.

$A$  = air theoretically required for complete combustion, cubic feet per cubic foot of gas burned.

As the ratio of  $P/A$  is approximately 0.9 for most city gases, a value of 90 may be substituted for  $100 \frac{P}{A}$  in Equation 8 for rough calculation.

Carbon-hydrogen ratios of different fuels vary considerably, hence the maximum or ultimate  $CO_2$  attainable also varies. Where they are unknown, theoretical maximum  $CO_2$  values may be calculated from a flue gas analysis by use of Equation 9.

$$\text{Maximum theoretical \% } CO_2 = \frac{\% CO_2 \text{ in flue gas sample} \times 100}{100 - \left( \frac{O_2 \text{ in same sample}}{0.21} \right)} \quad (9)$$

Approximate maximum  $CO_2$  values for perfect combustion of several common types of fuel are shown in Table 9 together with values of  $CO_2$  that will be attained with different amounts of excess air. Desirable values to be attained in practice depend upon the fuel, the method of firing, and other considerations. In general, fuels burned in suspension, such as gas, oil, and pulverized coal, can be burned with a lower amount of excess air than fuels burned on grates.

To produce heat efficiently by burning any common fuel a number of basic requirements must be met: (1) adequate heat absorbing surface of proper shape and construction is necessary in the appliance, (2) heat transfer surfaces must be clean, (3) a minimum amount of excess air must be present, (4) air employed for combustion and combustible gases must be properly mixed, and (5) flue gas losses must be reduced to a safe minimum.

If insufficient heating surface is employed, or if heat transfer surfaces are covered with soot, ash, or scale, flue losses will generally be excessive due to the large amount of sensible heat escaping to the chimney. Too much excess air dilutes flue gases excessively and increases sensible flue gas loss. On the other hand, a deficiency of excess air will in all probability cause incomplete combustion, and some of the combustible gases will pass from the appliance without being completely burned. Highest combus-

tion efficiency is not always obtained when sufficient excess air is supplied to eliminate incomplete combustion entirely, because the air supply must not only be adequate but also be properly mixed with the combustible gases. Even with appliances connected to an effective flue every reasonable precaution should be taken to insure as complete combustion as possible at all times. This is of vital importance in unvented equipment such as a gas space heater, for example. It is considered good practice to supply from 20 to 50 percent excess air, the exact amount depending on the kind of fuel burned and especially on the type of equipment in which it is utilized.

### Flue Gas Analysis

As radiation, convection, and conduction losses from common types of central heating appliances are largely employed in heating occupied spaces, flue gas losses logically become the item of principal concern. Another reason for their importance is the fact that they are usually larger than all other heat losses combined. These important considerations and others indicate not only the desirability but absolute necessity of a reasonably accurate method for determining flue losses if it is desired to compute even approximate operating efficiencies.

Customary procedure in arriving at flue gas losses is to make an analysis of a representative sample of flue gases and to measure their temperature. This information will enable the observer to compute the amount of flue gases produced, the excess air, the actual quantity of air supplied for combustion, and the flue losses. While the analysis of flue gases has been well described in several governmental and other scientific publications, the subject is of such importance that it warrants brief repetition here. Carbon dioxide and oxygen content are of principal interest in determining flue losses. Either or both of these values may be employed in such calculations. While the former constituent is probably most commonly employed, special considerations may make the latter of greater interest. Fortunately, both can be determined readily by use of an Orsat gas analysis apparatus, a device of reasonably simple construction and design. For field testing and burner adjustment, simple portable devices are available for determining carbon dioxide only. See Chapter 52 for details regarding the operation of the Orsat apparatus.

The weight of dry flue gas per pound of fuel burned is widely used in combustion loss calculations. For solid fuels this item may be determined by application of Equation 10.

$$\text{Pounds dry flue gas per pound fuel} = \frac{11 \text{ CO}_2 + 8 \text{ O}_2 + 7 (\text{CO} + \text{N}_2)}{3 (\text{CO}_2 + \text{CO})} \times C \quad (10)$$

Values for  $\text{CO}_2$ ,  $\text{O}_2$ ,  $\text{CO}$ , and  $\text{N}_2$  are percentages by volume from the flue gas analysis, and  $C$  is the weight of carbon burned per pound of fuel, corrected for carbon in the ash.

Total dry gas volumes of flue gases resulting from the combustion of one cubic foot of gaseous fuels for various percentages of  $\text{CO}_2$  may be determined by application of Equation 11:

$$\text{Cubic feet dry flue gases per cubic foot fuel gas} = \frac{\text{Cubic feet CO}_2 \text{ produced per cubic foot of gas burned} \times 100}{\text{Percent CO}_2 \text{ by analysis}} \quad (11)$$

After obtaining the quantity of flue gases from Equations 10 or 11, the excess air quantity may be determined by subtracting the quantity of dry

### Fuels and Combustion

flue gases which would result from perfect combustion. Computations of flue losses are described in the next section on Heat Balance.

Application of the preceding equations and tables are illustrated by Examples 1 and 2.

**Example 1:** The analysis of the flue gases resulting from the burning of a natural gas is 10.0 percent  $\text{CO}_2$ , 3.1 percent  $\text{O}_2$ , and 86.9 percent  $\text{N}_2$  by volume. The analysis of the fuel is 90 percent  $\text{CH}_4$ , 5 percent  $\text{N}_2$ , and 5 percent  $\text{C}_2\text{H}_6$  by volume. Find  $U$  the maximum theoretical percent  $\text{CO}_2$  and the percent excess air.

**Solution:** From Equation 9:

$$U = \frac{(10.0)(100)}{100 - \left(\frac{3.1}{0.21}\right)} = 11.8\% \text{ CO}_2$$

From Equation 8,

$$\text{Percent Excess Air} = \frac{(11.8 - 10.0) \times 90}{10} = 16.2$$

**Example 2:** For the analyses in Example 1 find, per cubic foot of fuel gas, the cubic feet of dry air required for combustion, the cubic feet of each constituent in the flue gases, and the total volume of dry and wet flue gases.

**Solution:** From Equation 3 (or Table 7) the volume of dry air required for combustion is:  $(9.53)(\text{CH}_4) + (16.68)(\text{C}_2\text{H}_6) = 9.53 \times 0.90 + 16.68 \times 0.05 = 9.41 \text{ cu ft/cu. ft gas.}$

From Table 7, the constituents per cubic foot of gas are:

$$\begin{aligned} \text{Nitrogen, N}_2: \\ \text{From methane} &= (0.9 \text{ CH}_4)(9.53 - 2.0) = 6.78 \\ \text{From ethane} &= (0.05 \text{ C}_2\text{H}_6)(16.68 - 3.0) = 0.68 \\ \text{Nitrogen in fuel} &= 0.05 \\ \text{Nitrogen in excess air} &= 0.791 \times .162 \times 9.41 = 1.20 \\ \hline \text{Total Nitrogen} &= 8.71 \text{ cu ft} \end{aligned}$$

$$\begin{aligned} \text{Oxygen, O}_2: \\ \text{Oxygen in excess air} &= 0.209 \times .162 \times 9.41 = 0.32 \text{ cu ft} \\ \text{Carbon dioxide, CO}_2: \\ \text{From methane} &= (0.9 \text{ CH}_4)(1.0) = 0.90 \\ \text{From ethane} &= (0.05 \text{ C}_2\text{H}_6)(4.0/2.0) = 0.10 \end{aligned}$$

$$\begin{aligned} \text{Total Carbon Dioxide} &= 1.00 \text{ cu ft} \\ \text{Water vapor, H}_2\text{O (does not appear in Orsat analysis):} \\ (0.9 \text{ CH}_4)(2.0) &= 1.8 \\ (0.05 \text{ C}_2\text{H}_6)(6.0/2.0) &= .15 \end{aligned}$$

$$\text{Total water vapor} = 1.95 \text{ cu ft}$$

$$\begin{aligned} \text{Total volume of dry gas per cubic foot of gas:} \\ 8.71 + 0.32 + 1.00 &= 10.03 \text{ cu ft} \end{aligned}$$

Total volume of wet gases per cubic foot of gas (neglecting water vapor in combustion air):

$$10.03 + 1.95 = 11.98 \text{ cu ft}$$

The cubic feet of dry flue gas per cubic foot of fuel gas may also be computed from Equation 11 as follows:

$$\frac{(1.00)(100)}{10.0} = 10.0 \text{ cu ft}$$

### HEAT BALANCE

The usual practice in analyzing the performance of heating appliances is to make an accounting, insofar as possible, of the disposition of all heat units available in the quantity of fuel burned. This accounting is called

TABLE 9. APPROXIMATE MAXIMUM THEORETICAL  $CO_2$  VALUES, AND  $CO_2$  VALUES FOR VARIOUS FUELS WITH DIFFERENT PERCENTAGES OF EXCESS AIR

| TYPE OF FUEL                                  | MAXIMUM THEORETICAL OR ULTIMATE PERCENT $CO_2$ | PERCENT $CO_2$ AT GIVEN EXCESS AIR VALUES |      |      |
|-----------------------------------------------|------------------------------------------------|-------------------------------------------|------|------|
|                                               |                                                | 20%                                       | 40%  | 60%  |
| Coke                                          | 21.0                                           | 17.5                                      | 15.0 | 13.0 |
| Anthracite                                    | 20.2                                           | 16.8                                      | 14.4 | 12.6 |
| Bituminous Coal                               | 18.2                                           | 15.1                                      | 12.9 | 11.3 |
| No. 1 and 2 Fuel Oil                          | 15.0                                           | 12.3                                      | 10.5 | 9.1  |
| No. 6 Fuel Oil                                | 16.5                                           | 13.6                                      | 11.6 | 10.1 |
| Natural Gas                                   | 12.1                                           | 9.9                                       | 8.4  | 7.3  |
| Carburetted Water Gas                         | 17.2                                           | 14.2                                      | 12.1 | 10.6 |
| Coke Oven Gas                                 | 11.2                                           | 9.2                                       | 7.8  | 6.8  |
| Mixed Gas (Natural and Carburetted Water Gas) | 15.3                                           | 12.5                                      | 10.5 | 9.1  |
| Propane Gas (Commercial)                      | 13.9                                           | 11.4                                      | 9.6  | 8.4  |
| Butane Gas (Commercial)                       | 14.1                                           | 11.6                                      | 9.8  | 8.5  |

a heat balance. Various components of this balance are generally expressed in terms of Btu per pound of fuel burned, or as a percentage of its calorific value. Components of special interest are listed as items 1 to 7 inclusive.

1. Useful heat transferred to heating medium, usually computed by determining the rate of flow of the heating fluid through the heating device, and the change in enthalpy of the fluid (heat added) between the inlet and outlet.

2. Heat loss in the dry chimney gases.

$$h_1 = w_g c_p (t_g - t_a) \quad (12)$$

3. Heat loss in water vapor formed by the combustion of hydrogen.

$$h_2 = \frac{9H_2}{100} (1089 - t_a + 0.455 t_g) \quad (13)$$

4. Heat loss in water vapor in the air supplied for combustion.

$$h_3 = 0.455 M w_a (t_g - t_a) \quad (14)$$

5. Heat loss from incomplete combustion.

$$h_4 = 10143 C \left( \frac{CO}{CO_2 + CO} \right) \quad (15)$$

6. Heat loss from unburned carbon in the ash or refuse.

$$h_5 = 14600 \left( \frac{C_u}{100} - C \right) \quad (16)$$

7. Radiation and all other unaccounted for losses.

Radiation and convection losses from a heating appliance are not usually determined by direct measurement. For this reason they, together with any other losses not measured, are determined by subtracting the total of items 1 to 6 from the heat of combustion of the fuel. If the heating appliance is located within the heated space, however, radiation and convection losses may be considered as useful heat rather than lost heat. They may, therefore, be omitted from calculations of heat

\* A value of 14600 applies in calculating ash pit loss; in calculating heat of formation of carbon compounds use 14093 Btu per lb.

losses, or added to item 1. If there is  $CO$  in the flue gases, small amounts of unburned hydrogen and hydrocarbons will probably also be present. The small losses due to incomplete combustion of these latter gases would also be included in item 7.

Symbols used in Equations 12 to 16 inclusive are:

$h_1$  = heat loss in the dry chimney gases, Btu per pound of fuel.

$h_2$  = heat loss in water vapor from combustion of hydrogen, Btu per pound of fuel.

$h_3$  = heat loss in water vapor in combustion air, Btu per pound of fuel.

$h_4$  = heat loss from incomplete combustion of carbon, Btu per pound of fuel.

$h_5$  = heat loss from unburned carbon in the ash, Btu per pound of fuel.

$w_g$  = weight of dry flue gas per pound of fuel (from Equation 10), pounds.

$c_p$  = mean specific heat of flue gases at constant pressure ( $c_p$  ranges from 0.242 to 0.254 for flue gas temperatures from 300 F to 1000 F), Btu per pound.

$t_g$  = temperature of flue gases at exit of heating device, Fahrenheit.

$t_a$  = temperature of combustion air, Fahrenheit.

$H_2$  = percentage of hydrogen in fuel by weight from ultimate analysis of fuel burned.

1091.8 = enthalpy of saturated water vapor at a temperature of 70 F, Btu per pound.

$M$  = humidity ratio of combustion air, pounds of water vapor per pound of dry air.

$w_a$  = weight of combustion air per pound of fuel used, pounds, from Equations 2, 4, 5, 6, 7 and 8.

$CO, CO_2$  = percentages of  $CO, CO_2$  in flue gases by volume.

$C$  = weight of carbon burned per pound of fuel corrected for carbon in ash, pounds.

$$C = \frac{WC_u - W_a C_a}{100 W} \quad (17)$$

where

$C_u$  = percentage of carbon in the fuel by weight from the ultimate analysis.

$W_a$  = weight of ash and refuse, pounds.

$C_a$  = percent of combustible in ash by weight (combustible in ash is usually considered to be carbon).

$W$  = weight of fuel used, pounds.

Flue gas losses for solid and liquid fuels, listed as items 2, 3 and 4 of the heat balance, may be determined with sufficient precision for most purposes from curves shown in Fig. 6<sup>2</sup>, if  $CO_2$  content and temperature of flue gases are known. Values of the losses plotted for fuel oil were computed from the ultimate analysis of a typical fuel oil used in domestic burners, while those presented for the several ranks of coal were computed from the typical ultimate analyses shown in Table 1. The curves for medium volatile bituminous coal may be used for high volatile bituminous coal with negligible error.

Utilization of gaseous fuels, for numerous reasons, is generally a more simple process than is the case with either solid or liquid fuels. Accordingly, the determination of a practical heat balance is also a more simple procedure in that items 5 and 6 do not generally apply to gas installations. A series of typical alignment charts has been combined in Fig. 7 for use in determining flue losses of items 2, 3 and 4 from common types of gas burning appliances. To determine flue losses place a straight edge extending from the corrected temperature reading to the percent  $CO_2$  recorded. Percent flue loss is indicated where the straight edge intersects the flue loss column.



The operating efficiency of a gas appliance can then be computed with sufficient precision by application of Equation 18.

Percent Combustion Efficiency =

$$\frac{(\text{Gross Btu of fuel}) - (\text{total flue losses per cubic foot fuel gas})}{\text{Gross Btu of fuel gas per cubic foot}} \times 100 \quad (18)$$

Reference to Table 9 will show that ultimate  $\text{CO}_2$  percentage values of fuel gases vary. While personal errors involved in  $\text{CO}_2$ , temperature, and chart determinations, would doubtless more than offset any inaccuracies due to universal use of the alignment charts shown, precise laboratory work may require a more exact method. For more complete information the reader is referred to *Combustion*, 3rd Edition, and *Gaseous Fuels*, (published by American Gas Association) and particularly to tables covering various properties of different commercial gases included in these publications.

#### CONDENSATION AND CORROSION

Sulfur dioxide or sulfur trioxide, formed by the combustion of sulfur in fuels, are the principal corroding substances in flue gases. They become active whenever sufficient moisture is present for the formation of sulfurous or sulfuric acid,<sup>22</sup> and they lower the dew points of flue gases appreciably. Therefore, unless heating equipment is designed for operation at flue gas temperatures below the dewpoint, which is seldom the case, it is always advisable to maintain temperatures above this value in all parts of the appliance. Excessive spot temperatures in the combustion chamber or elsewhere, on the other hand, are also destructive in that they may result in rapid oxidation of ordinary heating surfaces. American Standard Requirements for gas furnaces, floor furnaces, and recessed heaters, for example, specify that minimum spot heating surface temperatures during normal operation must neither fall below 178 F (50 F above average dewpoint) nor exceed 875 F on any portion of the heating surface. In any event it is usually desirable to maintain flue temperatures within the limits indicated not only throughout the appliance, but in its connecting vent, flue, or chimney as well. Otherwise, excessive condensation and corrosion problems, with resultant customer dissatisfaction, will in all probability be the result. Average dewpoint temperatures of flue gases resulting from the combustion of various fuels, when burned with the amount of excess air normally supplied to insure complete combustion, are shown in Table 10.

#### SOOT

The deposit of soot on the flue surfaces of a boiler or heater acts as an insulating layer over the surface, and reduces the heat transmission to the water or air. The Bureau of Mines Report of Investigations No. 3272<sup>23</sup> shows that the loss of seasonal efficiency is not so great as has been believed, and usually is not over 6 percent because the greater part of the heat is transmitted through the combustion chamber surfaces. The Bureau of Standards Report BMS 54<sup>24</sup> points out that, although the decrease in efficiency of an oil fired boiler, due to soot deposits, is relatively small, the attendant increase in stack temperature may be considerable.

The soot accumulation clogs the flues, reduces the draft, and may prevent proper combustion. Soot can probably be most effectively removed by a jet of compressed air, by means of a brush, or a vacuum cleaner. However, it has been found that copper chloride, lead chloride, tin chloride, zinc chloride, common salt and some other salts are partially effective in

TABLE 10. AVERAGE FLUE GAS DEW-POINT FOR VARIOUS FUELS<sup>a</sup>

| TYPE OF FUEL                                | AVERAGE DEW-POINT TEMPERATURE, F |
|---------------------------------------------|----------------------------------|
| Anthracite.....                             | 68                               |
| Semi-Bituminous Coal.....                   | 84                               |
| Bituminous Coal.....                        | 93                               |
| Oil.....                                    | 111                              |
| Natural Gas.....                            | 127                              |
| Manufactured Gas.....                       | 137                              |
| Propane Gas (2500 Btu/cu ft).....           | 119                              |
| Butane Gas (3200 Btu/cu ft).....            | 124                              |
| Butane-Air Gas Mixture (535 Btu/cu ft)..... | 121                              |

removing soot from furnaces and boilers when properly used.<sup>25</sup> A discussion of instruments and methods of evaluating smoke will be found in Chapter 52.

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## CHAPTER 15

## AUTOMATIC FUEL BURNING EQUIPMENT

Classification of Stokers, Combustion Process and Adjustments, Furnace Design, Rating; Classification of Oil Burners, Combustion Process, Combustion Chamber Design; Commercial and Industrial Oil Burners, Types of Burners; Oil Storage Tanks and Piping; Classification of Gas-Fired Heating Equipment, Combustion Process, Ratings; Sizing of Gas Piping, Fuel Burning Rates

AUTOMATIC mechanical equipment for the combustion of solid, liquid, and gaseous fuels is considered in this chapter.

## MECHANICAL STOKERS

A mechanical stoker is a device that feeds a solid fuel into a combustion chamber, provides a supply of air for burning the fuel under automatic control and, in some cases, incorporates a means of removing the ash and refuse of combustion automatically. Coal can be burned more efficiently by a mechanical stoker than by hand firing because the stoker provides a uniform rate of fuel feed, better distribution in the fuel bed and positive control of the air supplied for combustion.

## Classification of Stokers According to Capacity

Stokers may be classified according to their coal feeding rates. The following classification has been made by the *U. S. Department of Commerce*, in cooperation with the *Stoker Manufacturers Association*.

- Class 1. Capacity under 61 lb of coal per hour.
- Class 2. Capacity 61 to 100 lb of coal per hour.
- Class 3. Capacity 101 to 300 lb of coal per hour.
- Class 4. Capacity 300 to 1200 lb of coal per hour.
- Class 5. Capacity 1200 lb of coal per hour and over.

## Class 1 Stokers

These stokers are used primarily for home heating and are designed for quiet, automatic operation. Simple, trouble-free construction and attractive appearance are desirable characteristics of these small units.

A common stoker in this class (Fig. 1) consists essentially of a coal hopper, a screw for conveying the coal from the hopper to the retort, a fan which supplies the air for combustion, a transmission for driving the coal feed worm, and an electric motor for supplying power for coal feed and air supply.

Air for combustion is admitted to the fuel through tuyeres at the top of the retort which may be either round or rectangular. Stokers in this class are made for burning anthracite, bituminous, semi-bituminous, and lignite coals, and coke. The *U. S. Department of Commerce* has issued commercial standards for household anthracite stokers.<sup>1</sup>

Units are available in either the hopper type, as shown in Fig. 1, or in the bin-feed type as shown in Figs. 2 and 3. Some stokers, particularly those designed for use with anthracite, automatically remove ash from the ash pit and deposit it in an ash receptacle as shown in Fig. 3. Most

of the bituminous models, however, require removal of the ash from the fuel bed after it is fused into a clinker.

Stokers in this class feed coal to the furnace intermittently in accordance with temperature or pressure demands. A special control is used to insure sufficient stoker operation to maintain a fire during periods when no heat is required. Where year-round domestic hot water is supplied by a boiler and indirect water heater connected to a storage tank, the stoker will usually be called on to operate often enough to maintain the fire.

#### Stoker-Fired Boiler and Furnace Units

Boilers, air conditioners, and space heaters especially designed for stokers are available having design features closely coordinating the heat absorber and the stoker. Although efficient and satisfactory performance can be obtained from the application of stokers to existing boilers and

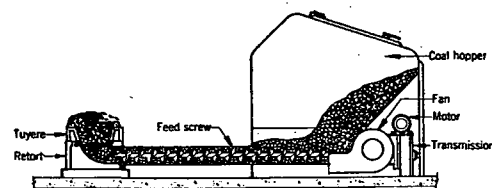


FIG. 1. UNDERFEED STOKER, HOPPER TYPE, CLASS 1

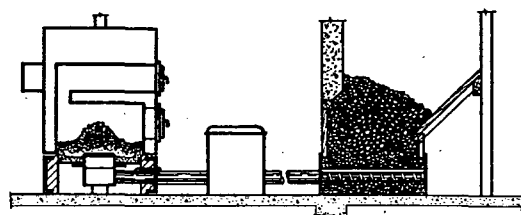


FIG. 2. UNDERFEED STOKER, BIN FEED TYPE, CLASS 1

furnaces, some of the combination stoker-fired units (Fig. 4) are more compact and attractive in appearance.

#### Class 2 and 3 Stokers

Stokers in this class are usually of the screw feed type without auxiliary plungers or other means of distributing the coal. They are used extensively for heating plants in apartments and hotels, also, for industrial plants. They are of the underfeed type and are available in both the hopper type, as illustrated in Fig. 5, and the bin feed type, shown in Fig. 6. These units also are built in plunger feed type with an electric motor or a steam or hydraulic cylinder coal feed drive.

Stokers in this class are available for burning all types of anthracite, bituminous and lignite coals. The tuyere and retort design varies according to the fuel and load conditions. Stationary type grates are used on bituminous models, and the clinkers formed from the ash accumulate on the grates surrounding the retort.

Anthracite stokers in this class are equipped with moving grates which

discharge the ash into a pit below the grate. This ash pit may be located on one or both sides of the grate and, in some installations, is of sufficient capacity to hold the ash for several weeks' operation.

#### Class 4 Stokers

Stokers in this group vary widely in details of design, and several methods of feeding coal are employed. The underfeed stoker is widely used, although a number of the overfeed types are used in the larger sizes. Bin-feed, as well as hopper models, are available in both underfeed and overfeed types.

#### Class 5 Stokers

The prevalent stokers in this field are: (1) underfeed side cleaning, (2) underfeed rear cleaning, (3) overfeed flat grate, and (4) overfeed inclined grate.

Underfeed side cleaning stokers are made in sizes up to approximately 500 boiler horsepower. They are not so varied in design as those in the smaller classes, although the principle of operation is similar. A stoker of this type is illustrated in Fig. 7.

The rear cleaning underfeed stoker is usually of the multiple retort design, and is used in some of the largest industrial plants and central power stations. Zoned air control has been applied to these stokers, both longitudinally and transversely of the grate surface.

The overfeed flat grate stoker is represented by the various chain—or traveling-grate stokers. A typical traveling-grate stoker is illustrated in Fig. 8.

Another distinct type of overfeed flat-grate stoker is the spreader (Figs. 9 and 10) type in which coal is distributed either by rotating paddles or by air over the entire grate surface. This type of stoker is adapted to a wide range of fuels and has a wide application on small sized fuels, and on fuels such as lignites, high-ash coals, and coke breeze.

The overfeed inclined-grate stoker operates on the same general combustion principle as the flat-grate stoker, the main difference being that rocking grates, set on an incline, are provided in the former to advance the fuel during combustion.

#### Combustion Process

In anthracite stokers of the Class 1 underfeed type, burning takes place entirely within the stoker retort. The refuse of combustion spills over the edge of the retort into an ash pit or receptacle from which it may be removed either manually or automatically.

Larger underfeed anthracite stokers operate on the same principle, except that the retort is rectangular and the refuse spills over only one or two sides of the grate. Anthracite for stoker firing is usually the No. 1 buckwheat or No. 2 buckwheat size.

Because the majority of the small bituminous coal stokers operate on the underfeed principle, a general description of their operation is given. When the coal is fed into the retort, it moves upward toward the zone of combustion and is heated by conduction and radiation from the burning fuel in the combustion zone. As the temperature of the coal rises, it gives off moisture and occluded gases, which are largely non-combustibles. When the temperature increases to around 700 or 800 F the coal particles become plastic, the degree of plasticity varying with the type of coal.

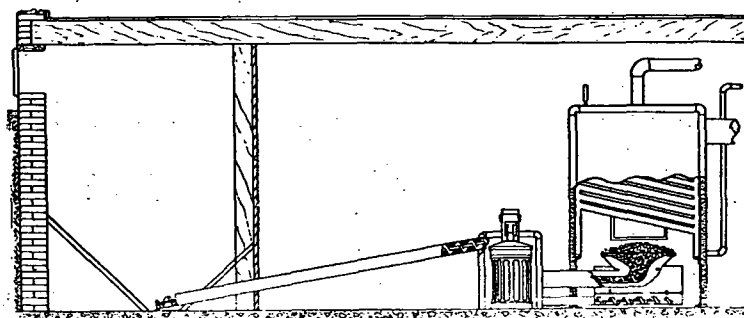


FIG. 3. UNDERFEED ANTHRACITE STOKER WITH AUTOMATIC ASH REMOVAL, BIN TYPE

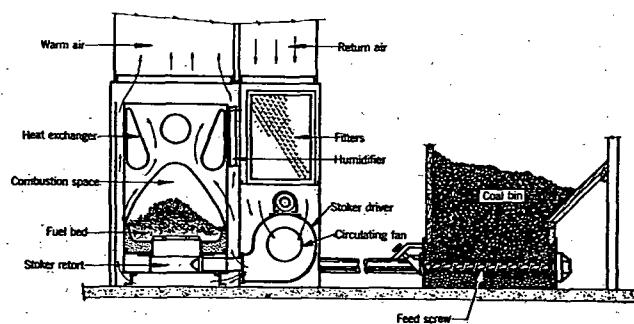


FIG. 4. STOKER-FIRED WINTER AIR CONDITIONING UNIT

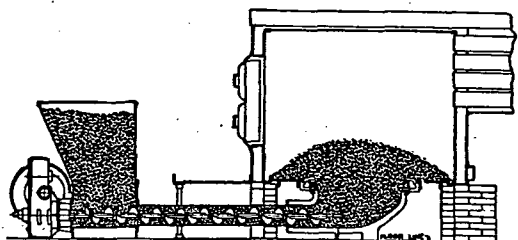


FIG. 5. UNDERFEED SCREW STOKER, HOPPER TYPE, CLASS 2, 3 OR 4

A rapid evolution of the combustible volatile matter occurs during and directly after the plastic stage. The distillation of volatile matter continues above the plastic zone where the coal is coked. The strength and porosity of the coke formed will vary according to the size and characteristics of the coal. While some of the ash fuses into particles on the surface of the coke as it is released, most of it remains on the hearth or grates and, as this ash layer becomes thicker with time, that portion exposed to the higher temperatures surrounding the retort fuses into a clinker. The

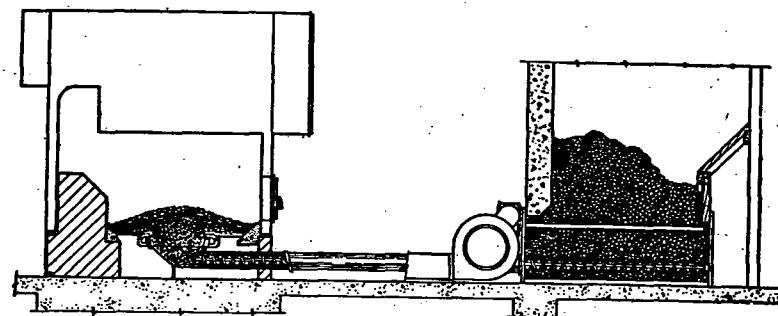


FIG. 6. UNDERFEED SCREW STOKER, BIN TYPE, CLASS 2, 3 OR 4

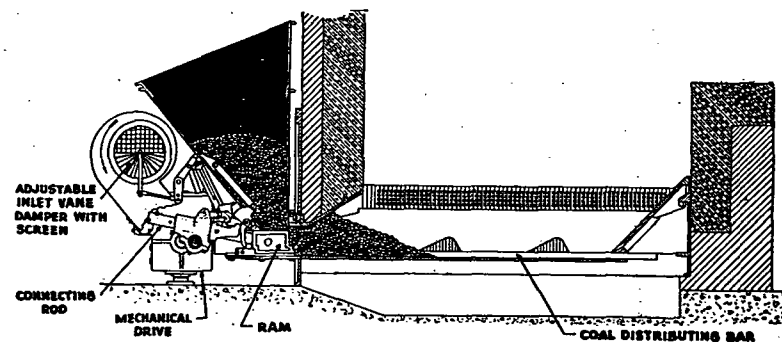


FIG. 7. UNDERFEED SIDE CLEANING STOKER

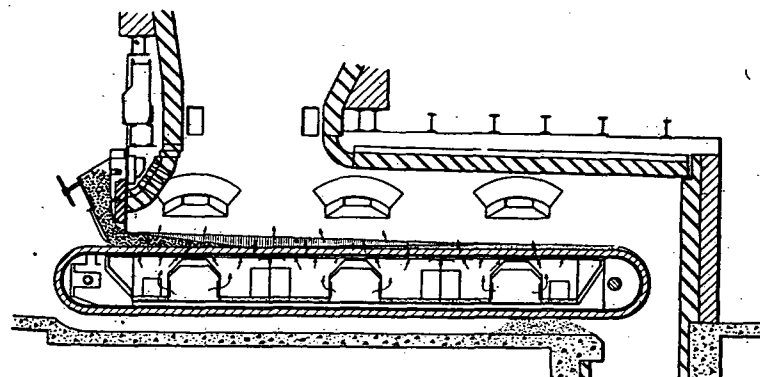


FIG. 8. OVERFEED TRAVELING-GRADE STOKER

temperature in the fuel bed, the chemical composition and homogeneity of the ash, and the time of heating govern the degree of fusion.

Most bituminous coal stokers of Classes 1, 2, 3 and 4 require manual removal of the ash in clinker form.

In the underfeed side-cleaning stokers the fuel is introduced at the front of the furnace to one or more retorts, and is advanced away from the retort as combustion progresses, while finally the ash is disposed of at the sides. This type of stoker is suitable for all bituminous coals, while in the smaller sizes it is suitable for small sizes of anthracite. In this type of stoker the fuel is delivered to a retort beneath the fire and is raised into the fire. During this process the volatile gases are released, are mixed with air, and pass through the fire where they are burned. The ash may be continuously or periodically discharged at the sides.

The underfeed rear-cleaning stoker accomplishes combustion in much the same manner as the side-cleaning type, but consists of several retorts placed side by side and filling up the furnace width, while the ash disposal is at the rear. In principle, its operation is the same as the side-cleaning underfeed type.

Overfeed flat-grate stokers receive fuel at the front of the grate in a

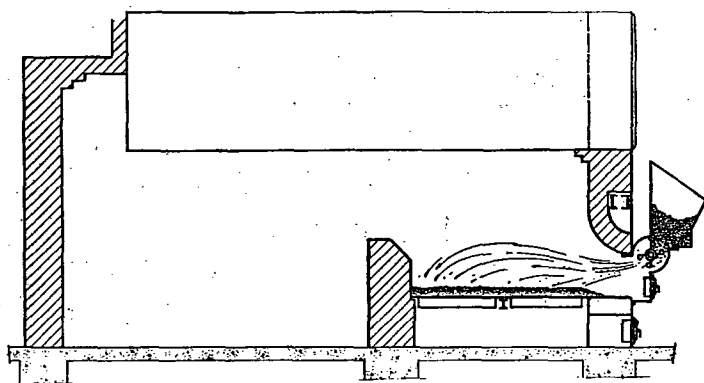


FIG. 9. OVERFEED SPREADER STOKER (ROTOR TYPE)

layer of uniform thickness and move it horizontally to the rear of the furnace. Air is supplied under the moving grate to carry on combustion at a sufficient rate to complete the burning of the coal near the rear of the furnace. The ash is carried over the back end of the stoker into an ash pit beneath. This type of stoker is suitable for small sizes of anthracite or coke breeze, and also for bituminous coals; the characteristics of which make it desirable to burn the fuel without disturbing it. This type of stoker requires an arch over the front of the fuel bed to maintain ignition of the incoming fuel, and frequently a rear combustion arch.

In addition to the use of rocking grates, the overfeed inclined-grate stoker is provided with an ash plate on which ash is accumulated and dumped periodically. This type of stoker is suitable for all types of coking fuels, but preferably for those of low volatile content. Its grate action keeps the fuel bed broken up, thereby allowing free passage of air. Because of its agitating effect on the fuel, it is not desirable for badly clinkering coals. It usually should be provided with a front arch to ignite the volatile gases.

#### Combustion Adjustments.

The coal feeding rate and air supply to the stoker should be regulated so

as to maintain a balance between the load demand and the heat liberated by the fuel. Under such conditions, no manual attention to the fuel bed should be required other than the removal of clinker in stokers which operate on this principle of ash removal.

As in all combustion processes, the maintenance of the correct proportions of air and fuel is essential. It is desirable to supply the minimum amount of air required to properly burn the fuel at the rate of feed.

While there may be only slight variations in the rate at which the coal is being fed, due to variations in the size or density of the coal, there may be wide variations in the rate of air flow as the result of changes in fuel bed resistance. These changes in resistance may be caused by changes in the porosity of the fuel bed due to variations in size or friability of the coal, ash and clinker accumulation, and variations in depth of the fuel bed. Because of this variable fuel bed resistance, many bituminous stokers, even in the smaller domestic sizes, incorporate air controls which automatically com-

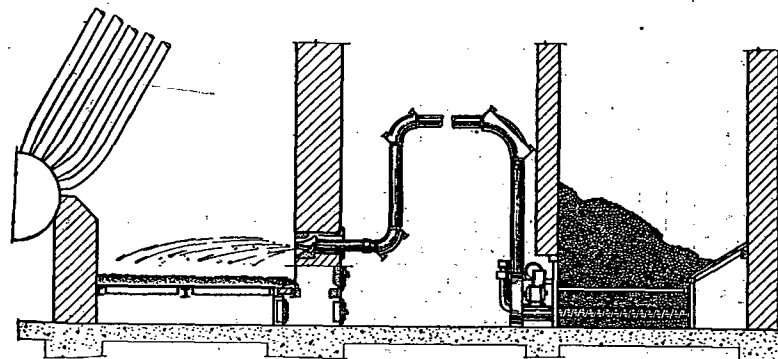


FIG. 10. OVERFEED SPREADER STOKER (PNEUMATIC TYPE)

pensate for these changes in resistance and maintain a constant air fuel ratio. The efficiency of combustion may be determined by analyzing the flue gases, as explained in Chapters 14 and 52.

It is desirable on most stoker installations to provide automatic draft regulation in order to reduce air infiltration and provide better control during the banking, or off, periods of the stoker.

#### Furnace Design

Although there is considerable variation in stoker, boiler, and furnace design, the stoker industry, from long-time experience, has established certain rules for the proportioning of furnaces for domestic and commercial stokers. The stoker installer and designer of stoker-fired equipment should give careful consideration to these factors.

The *Stoker Manufacturers Association* has published standard recommendations on setting heights for stokers having capacities up to 1200 lb of coal per hour.<sup>2</sup>

The empirical formulas for determining these setting heights are:

For burning rates up to 100 lb coal per hour

$$H = 0.1125 B + 15.75 \quad (1)$$

For burning rates from 100 to 1200 lb coal per hour

$$H = 0.03 B + 24$$

where

$H$  = minimum setting height, inches, measured from dead plates to crown sheet for steel boilers. For cast-iron boilers height may be  $\frac{1}{2} H$ .

$B$  = burning rate coal per hour, pounds.

Standards for minimum firebox dimensions and base heights have been formulated by the *Stoker Manufacturers Association* as shown in Fig. 11.<sup>2</sup>

In considering these recommendations, it should be understood that they show the average recommended minimum. There are many factors affecting the proper application of stokers to various types of boilers and furnaces, and, in certain instances, setting height or firebox dimensions shown in the standards may be modified without impairing performance. Such modification will depend upon the experience of the installer or de-

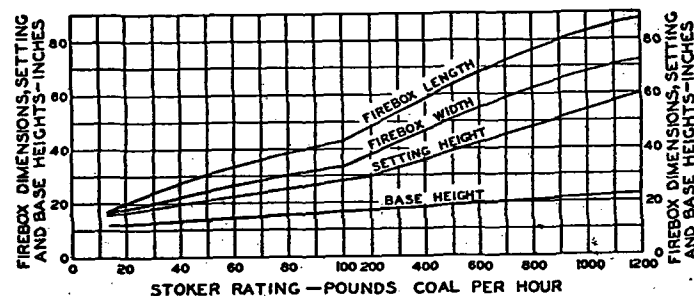


FIG. 11. SUGGESTED MINIMUM FIREBOX DIMENSIONS AND BASE HEIGHTS<sup>a</sup>

<sup>a</sup> For reference in selecting or designing boilers and furnaces for stoker firing. Dimensions shown are for net inside clearance at grate level using coal with heating value of not less than 12,000 Btu per pound. Under certain conditions smaller fireboxes will permit satisfactory performance but these dimensions are preferred normal minimums.

signer with a particular stoker, the type of fuel used, and the construction of the boiler or furnace.

Installation of stokers (particularly smaller sizes) on the side of the boiler or furnace will sometimes facilitate clinker removal.

### Rating and Sizing Stokers

The capacity or rating of small underfeed stokers is usually stated as the burning rate in pounds of coal per hour. Codes for establishing uniform methods of rating anthracite and bituminous coal stokers have been adopted by the *Stoker Manufacturers Association*.<sup>3</sup>

The Association also has adopted a uniform method of selecting stokers that is published in convenient tables and charts.<sup>3</sup> The required capacity of the stoker is calculated as follows:

$$\frac{\text{Load (Btu per hour)}}{\text{Heating value of coal (Btu per pound)} \times \text{overall efficiency of stoker and boiler or furnace}} = \text{Stoker burning rate required (pounds of coal per hour)}$$

In determining the total load placed on a stoker-fired boiler by a steam

or hot water heating system, a piping and pick-up factor of 1.33 is commonly used in sizing the stoker, but this factor should be increased at times due to unusual conditions.

### Controls

The heat delivery from the stoker of the smallest household type to the largest industrial unit can be regulated accurately with fully automatic controls. The smaller heating applications are controlled normally by a thermostat placed in the building to be heated. Limit controls are supplied to prevent excessive temperature or pressure from being developed in the furnace or boiler, and refueling controls are used to maintain ignition during periods of low heat demand. Automatic low water cut-outs are recommended for use with all automatically-fired steam boilers. (See Chapter 39.)

### DOMESTIC OIL BURNERS

An oil burner is a mechanical device for producing heat automatically from liquid fuels. Two methods are employed for the preparation of the

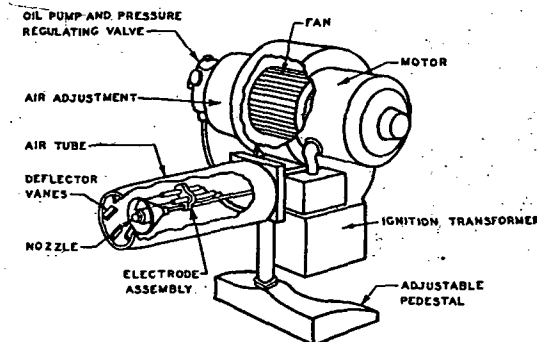


FIG. 12. HIGH-PRESSURE ATOMIZING OIL BURNER

oil for the combustion process; atomization, and vaporization. The simpler types of burners depend upon the natural chimney draft for supplying the air for combustion. Other burners provide mechanical air supply or a combination of atmospheric, and mechanical. Ignition is accomplished by an electrical spark or hot wire, or by an oil or gas pilot. Some burners utilize a combination of these methods. Continuously operating burners may use manual ignition. Burners of different types operate with luminous or non-luminous flame. Operation may be intermittent, continuous with high-low flame, or continuous with graduated flame.

### Classification of Burners

Domestic oil burners may be classified by type of design or operation into the following groups: pressure atomizing or gun, rotary, and vaporizing or pot. These are further classified as mechanical draft, and natural draft.

### Pressure Atomizing (Gun Type) Burner

Gun type burners are usually designed to burn No. 1 or 2 grade fuel oil. They may be divided into two classes: high-pressure and low-pressure

atomization. The high-pressure atomizing type, illustrated in Fig. 12, is characterized by an air tube, usually horizontal, with oil supply pipe centrally located in the tube and arranged so that a spray of atomized oil is introduced at about 100 psi, and mixed in the combustion chamber with the air stream emerging from the air tube. A variety of patented shapes is employed at the end of the air tube to influence the direction and speed of the air, and thus the effectiveness of the mixing process.

A fan is used to supply the air for combustion. Ignition is established by a high-voltage electric spark that may be operative continuously while the burner is running, or just at the beginning of the running period. The burner operates on the intermittent *on-off* principle, and with a luminous flame.

The combustion process is completed in a chamber constructed of refractory material, or stainless steel, this being a part of the installation.

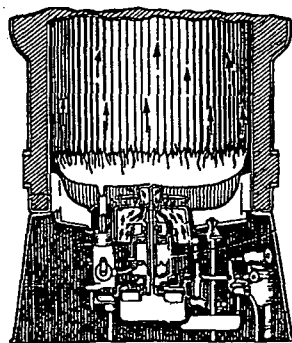


FIG. 13. CENTER FLAME VERTICAL ROTARY BURNER

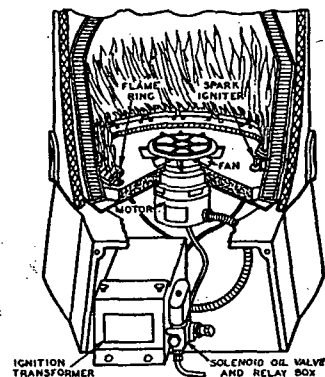


FIG. 14. WALL FLAME VERTICAL ROTARY BURNER

The *low pressure atomizing* type differs from the high pressure type mainly by having means for supplying a mixture of oil and primary air to the burner nozzle. The air pressure before mixing and the pressure of the oil-air mixture at the nozzle vary with different makes of burners, but are in a low range of 1 to 15 psig for the air and 2 to 7 psig for the mixture, respectively. The various parts of the burner, except for oil and air mixing parts, are the same as shown in Fig. 12.

#### Rotary Type Burner

This class of burners may be divided into two groups: vertical and horizontal. Most of the smaller rotary burners are of the vertical type, and use a fuel oil of No. 1 or 2 grade.

The most distinguishing feature of vertical rotary burners is the principle of flame application. These burners are of two general types: the center flame and wall flame. In the former type (Fig. 13), the oil is atomized by being thrown from the rim of a revolving disc or cup, and the flame burns in suspension with a characteristic yellow color. Combustion is supported by means of a bowl-shaped chamber or hearth. The wall flame burner (Fig. 14) differs in that combustion takes place in a ring of stainless steel

or refractory material which is placed around the hearth. Dependent upon combustion adjustment, these burners may operate with either a semi-luminous or non-luminous flame.

Both types of vertical rotary burners are further characterized by their installation within the ash pit of the boiler or furnace. Various types of ignition are utilized, gas and electric, either spark or hot wire. The air for combustion is supplied partially by natural draft, and partially by fan effect of the central spinner element.

#### Vaporizing Burner

In the vaporizing burner, fuel oil is ignited (manually or electrically) and vaporized in a vessel or pot which is open at the top or one side. Heat for vaporization is supplied by the combustion process. Openings in the side walls of the burner admit primary air which forms a rich mixture of air and oil vapors in the burner. Adjacent to the outlet opening, sufficient additional or secondary air is admitted to complete combustion. The openings

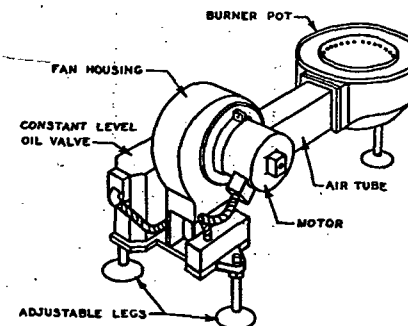


FIG. 15. VAPORIZING FORCED-DRAFT POT-TYPE BURNER

for admitting air are arranged to obtain gradual and intimate mixing of air and oil vapor for combustion, with a minimum amount of excess air and resulting high combustion efficiency.

Fuel is fed by gravity from a constant level control valve, and the flow is either *on* (at rated capacity) or *off* (at pilot flow), according to the demand of the thermostat. However, the high fire can be reduced and the pilot fire can be increased to give almost any desired control characteristic within the range of the burner. The majority of vaporizing burners are manufactured in sizes up to one gallon per hour input. Most vaporizing burners are limited to use with No. 1 fuel oil having a maximum end point of 625 F and a minimum A.P.I. gravity of 35 deg.

A barometric draft regulator is required to maintain the recommended draft. A draft of not more than 0.06 in. of water column is recommended for most natural draft burners. When burners are equipped with mechanical forced draft, a slightly lower chimney draft can be used. A burner of this type is illustrated in Fig. 15. A gravity type is shown in Fig. 16.

Vaporizing burners are adaptable to water heaters, space heaters, and furnaces. Some types have also been applied successfully to conversion



installations. The heat output is in the range of requirements for the average or small home.

The modulating flame allows simple manual control by regulation of a metering valve, and simplifies the control equipment. Quiet combustion and the absence of moving parts contribute to quiet operation when the heating device is located in the living quarters.

The ability to operate on natural draft and gravity feed of the fuel, makes possible the use of these burners where electric current is not available or is unreliable. However, most furnaces are thermostatically controlled, and many are provided with mechanical draft.

#### Oil-Fired Boiler and Furnace Units

A number of types of specially designed oil-fired boiler-burner and furnace-burner units are available. Various locations of burners will be noted in such units; some having the combustion chamber and burner

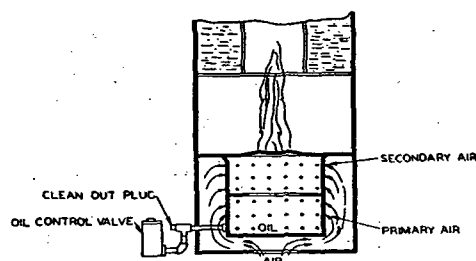


FIG. 16. VAPORIZING GRAVITY POT-TYPE BURNER

at the top, some at the bottom, and some at the center of the appliance. Typical combination units are shown in Figs. 17 and 18. The coordinated design of boiler (or furnace) and burner elements insures the optimum in operating characteristics, and the maintenance of balanced performance. This type of equipment usually has more heating surface, and better flue proportions and gas travel than conventional boilers or furnaces. Some of the better conversion installations, however, may equal the unit type in performance.

#### Operating Requirements for Oil Burners

The U. S. Department of Commerce, in conjunction with the oil burner and heating appliance industries, has established commercial standards for conversion burners and burner-appliance units which cover installation, construction and performance tests.<sup>4</sup>

#### Combustion Process

Efficient combustion must produce a clean flame and use a relatively small excess of air, i.e., between 25 and 50 percent. This can be done only by vaporizing the oil quickly and completely, and mixing it vigorously with air in a combustion chamber hot enough to support the combustion.

A vaporizing burner prepares the oil for combustion by transforming the liquid fuel to the gaseous state by the application of heat.

In an atomizing burner, the oil is mechanically separated into very fine particles so that the surface exposure of the liquid to the radiant heat of the combustion chamber is vastly increased and vaporization thereby promoted. The result is the ability to burn more and heavier oil within a given combustion space. Because the air enters the combustion chamber with the liquid fuel particles, mixing, vaporization and burning occur all at once in the same space. This produces a luminous flame. A deficient amount of air is indicated by a dull red or dark orange flame with smoky tips.

An excessive supply of air may produce a brilliant white flame or a short ragged flame with incandescent sparks flashing through the combustion space. While extreme cases may be detected, it is not possible

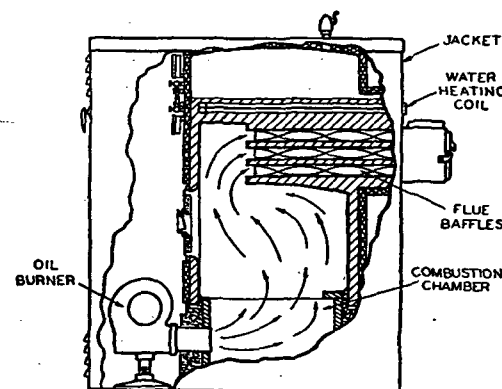


FIG. 17. TYPICAL BOILER-BURNER UNIT

to distinguish, by eye, the effect of the finer adjustment which competent installation requires.

#### Combustion Adjustments

The present-day oil burner with mechanical oil and air supply, properly installed and equipped with an automatic draft regulator, is capable of maintaining efficient combustion for a considerable period following the initial adjustments of oil and air. Eventually, certain changes will occur, and may be such that the amount of excess air will decrease below allowable limits. A decrease in air supply while the oil delivery remains constant, or an increase in oil delivery while the air supply remains constant, will make the mixture of oil and air too rich for clean combustion. The more efficient the adjustment, the more critical it will be. The oil and air supply rates must remain constant.

The following factors may influence the oil delivery rate: (1) changes in oil viscosity due to temperature change or variations in grade of oil delivered; (2) erosion of atomizing nozzle; (3) fluctuations in by-pass relief pressures; and (4) possible variations in methods of atomization. Any change due to partial stoppage of oil delivery will increase the proportion

of excess air. This will result in less heat, reduced economy; and possibly a complete interruption of service.

The following factors may influence the air supply: (1) changes in combustion draft due to a variety of causes (i.e., changes in chimney draft because of weather changes, seasonal changes, back drafts, failure or inadequacy of automatic draft regulator, use of chimney for other purposes, possible stoppage of the chimney, and changes in draft resistance of boiler due to partial stoppage of the flues); and (2) changes in air inlet adjustments at the fan.

Air leakage into the boiler or furnace setting should be reduced to a minimum. The amount of air leakage will be determined by the draft in the combustion chamber. It is important that this draft should be reduced as low as is consistent with the proper disposal of the gases of combustion. When using mechanical draft burners with average condi-

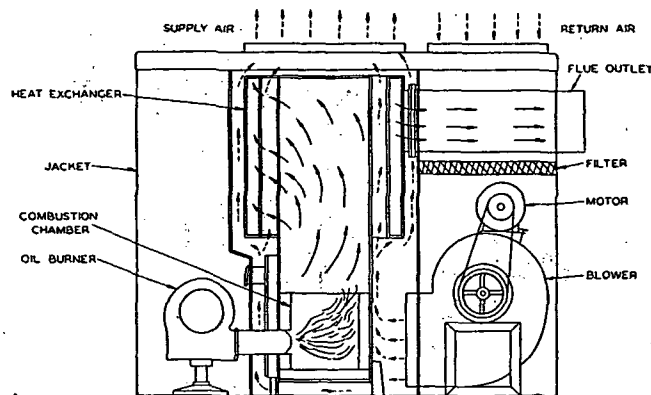


FIG. 18. TYPICAL OIL-FIRED FURNACE UNIT

tions, the combustion chamber draft should not be allowed to exceed 0.02-0.05 in. water. An automatic draft regulator is necessary in order to maintain constant draft conditions which, in turn, improve efficiency of operation. The draft regulator should be adjusted in accordance with the manufacturer's instructions.

Even though a fan is generally used to supply the air for combustion, in most oil burners, the importance of a proper chimney should not be overlooked. The chimney should have sufficient height and size to insure that the draft will be uniform within the limits given, if maximum efficiency throughout the heating season is to be maintained.

#### Measurement of the Efficiency of Combustion

Since efficient combustion is based upon a clean flame and definite proportions of oil and air employed, it is possible to determine the results by analyzing the combustion gases. It is usually sufficient to analyze only for carbon dioxide ( $\text{CO}_2$ ) and to obtain the temperature of the stack gas. A showing of 10 to 12 percent indicates the best adjustment, if the flame is clean. Most of the good installations show from 8 to 10 percent

$\text{CO}_2$ . Taking into account the potential hazard of low excess air (high  $\text{CO}_2$ ), a setting to give 10 percent  $\text{CO}_2$  constitutes a reasonable standard for most oil burners. *Commercial Standard CS-75* requires that oil burners labeled as complying with the standard shall obtain smoke-free combustion at 10 percent  $\text{CO}_2$ . In all cases smokeless combustion is a requirement for oil burners.

#### Combustion Chamber Design

With burners requiring a refractory combustion chamber, the size and shape should be in accordance with the manufacturer's instructions. It is important that the chamber be as nearly air tight as is possible, except when the particular burner requires a secondary supply of air for combustion.

The atomizing burner is dependent upon the surrounding heated combustion chamber surfaces to vaporize the oil and support combustion. Unsatisfactory combustion may be due to inadequate atomization and mixing. A combustion chamber can only compensate for these things to a limited extent. If liquid fuel continually reaches some part of the fire-brick surface, a carbon deposit will result. The combustion chamber should enclose a space having a shape similar to the flame, but large enough to avoid flame contact. The nearest approach in practice is to have the bottom of the combustion chamber flat, but far enough below the nozzle to avoid flame contact, the sides tapering from the air tube at the same angle as the nozzle spray, and the back wall rounded. A plan view of the combustion chamber resembles in shape the outline of the flame. This insures quick vaporization, rapid combustion and better mixing by eliminating dead spaces in the combustion chamber. An overhanging arch at the back of the fire pot is sometimes used to increase the flame travel and give more time for mixing and burning, and sometimes to prevent the gases from going too directly into the boiler flues. When good atomization and vigorous mixing are achieved by the burner, combustion chamber design becomes a less critical matter. Where secondary air is used, combustion chamber design is quite important. When installing some of the vertical rotary burners, the manufacturer's instructions must be followed carefully when installing the hearth, as in this class successful performance depends upon this factor.

#### Boiler Settings

As the volume of space available for combustion is a determining factor in oil consumption, it is general practice to remove grates and extend the combustion chamber downward to include or even exceed the ash pit volume; in new installations the boiler may be raised to make added volume available. Approximately 1 cu ft of combustion volume should be provided for every developed boiler horsepower, and in this volume from 1.5 to 2.5 lb of oil per hour can properly be burned. This corresponds to an average liberation of about 38,000 Btu per cubic foot per hour. At times much higher fuel rates may be satisfactory. For best results, care should be taken to keep the gas velocity below 40 fps. Where checkerwork of brick is used to provide secondary air, good practice calls for about 1 sq in. of opening for each pound of oil fired per hour. Such checkerwork is best adapted to flat flames, or to conical flames that can be spread over the floor of the combustion chamber. The proper bricking of a large or even medium sized boiler for oil firing is important, and frequently it is advisable to consult an authority on this subject. The essential in combustion

chamber design is to provide against flame impingement upon either metallic or firebrick surfaces. Manufacturers of oil burners usually have available detailed plans for adapting their burners to various types of boilers, and such information should be utilized.

*Controls* for oil burner operation, including devices for the safety and protection of a boiler or furnace, are fully described in Chapter 39.

### COMMERCIAL AND INDUSTRIAL OIL BURNERS

Oil burning equipment for commercial and industrial applications is usually designed for burning the lower cost heavy fuel oils such as U. S. Commercial Standard Grades Nos. 4, 5, and 6. The viscosity of these oils is much greater than that of the lighter domestic grades and, therefore, the equipment required for satisfactory storage, pumping, and combustion differs greatly from that used in the typical domestic oil burning system.

Both the initial cost and the operating cost of an oil burning system may be affected materially by the characteristics of the industrial fuel oil to be used. These characteristics should, therefore, be given careful consideration when setting up the specifications of the fuel oil for which the system is to be designed.

#### Classification of Burners

These burners are usually classified according to the method used for atomizing the oil as (1) horizontal rotary cup atomizing, (2) mechanical pressure atomizing, (3) steam atomizing, and (4) air atomizing.

#### Horizontal Rotary Cup Burner

In this type of burner, oil is delivered into a horizontal cup that is rotated at high speed. As the thin film of oil is spun from the rim of the cup, it enters a cone of high velocity primary air and very effective atomization is obtained. In most applications secondary air for combustion is supplied by natural draft through checkered openings in the floor of the combustion chamber. In some applications, however, the secondary air is admitted through openings surrounding the burner nozzle and may be supplied by forced draft.

The rotary cup burner has been the most popular type in the capacity range from approximately 25 to 500 boiler horsepower. Its principal advantages are that it is a self-contained integral unit; it is readily adaptable to manual, semi-automatic, or fully-automatic control; and the firing rate may be easily modulated through a wide range while maintaining high combustion efficiencies. These burners are frequently used for firing packaged steam generator units.

#### Mechanical Pressure Atomizing Burner

In this burner oil is atomized by passing it through a specially designed nozzle under pressures of approximately 100 to 250 psig. The air for combustion may be supplied by either natural or forced draft, and is usually admitted through an air register surrounding the burner nozzle or through checkered openings in the floor of the combustion chamber. This burner is popular for marine service and for large capacity multiple installations. It is not readily adapted to fully automatic operation.

#### Steam Atomizing Burner

High pressure steam is used in this burner for atomizing the oil. Oil is delivered to the nozzle at pressures ranging from approximately 5 to 50 psig, and steam at approximately 50 to 150 psig is admitted to the nozzle by various methods to assist in the atomization. Combustion air is usually supplied by natural draft through checkered openings in the floor of the combustion chamber or through an air register surrounding the nozzle.

This burner is relatively low in first cost but is not adapted to fully automatic operation or wide variations in firing rate.

#### Air Atomizing Burner

The air atomizing burner is similar to the steam atomizing type, except that air under pressure instead of steam is used for atomization. The performance characteristics of the two burners are also similar but higher temperature oil is usually required when using air for atomization.

#### Heating the Oil

Commercial Standard No. 4 fuel oil is intended for use in burners that are not equipped with preheating facilities. Nos. 5 and 6 oils usually require preheating equipment to reduce their viscosity sufficiently for satisfactory pumping and atomization. Some oils in the lower viscosity range of No. 5 specification may at times be handled without preheating, but definite viscosity limitations should be specified if this is attempted. In northern climates, the *pour point* of oil may affect the preheating requirements and should be included in the oil specifications.

The common heat sources employed in the heating of fuel oil are steam, hot water and electricity. Shell and tube type heaters connected to the oil fired boiler are normally used for steam or hot water heating. It is extremely important in many plants to provide oil heating equipment that will readily permit starting the burner after a prolonged shutdown during cold weather. While the initial cost of this heating system may be higher, it is necessary where a plant shutdown may cause the oil in the tank and oil lines to congeal to a point where circulation cannot be re-established unless the oil preheating system is designed for this type of service.

### OIL STORAGE TANKS AND PIPING

Storage tanks, also the piping and pumping facilities for delivering the oil from the tank to the burner, are very important considerations in the design of an industrial oil burning system. The construction and location of the tank and oil piping are usually subject to local regulations which should always be consulted, and to the standards of the *National Board of Fire Underwriters*, such as *NFBU Pamphlet No. 31*.

The size of the storage tank is usually based on the rate at which oil is to be consumed, the space available, method of oil delivery (truck or tank car) and the ease with which deliveries can be made under all weather conditions. A minimum capacity of at least the maximum weekly usage is desirable. If deliveries are to be made by tank car, the capacity should not be less than 15,000 gal.

The 275 gal oil storage tank is commonly used for domestic installations.

In most localities it may be installed in basements without being enclosed. Where a greater storage capacity is necessary, local regulations usually permit inside installation of two tanks of 275 gal each in accordance with *NBFU Standards Pamphlet No. 31*.

### GAS-FIRED HEATING EQUIPMENT

A gas burner is defined by the *American Gas Association* as "a device for the final conveyance of the gas, or a mixture of gas and air, to the combustion zone." Burners used for domestic heating are of the atmospheric injection, luminous flame, or power burner types.

Because of the ease with which gas fuel may be controlled, automatic gas-fired heating equipment has become very widely used, and is available

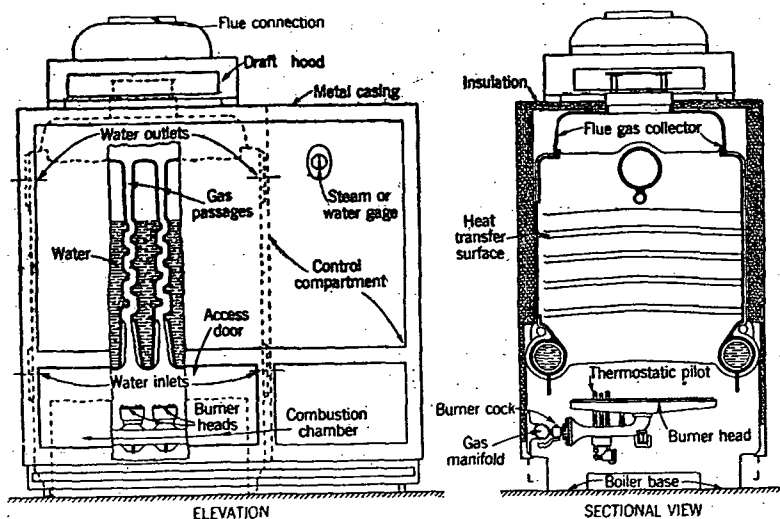


FIG. 19. GAS-FIRED BOILER

in a number of types of domestic gas heating appliances and systems. These may be classified in types designed for central heating plants and those for unit application. Gas designed units and conversion burners are available for the several kinds of central systems in which gravity and forced warm air furnaces or steam and hot water boilers are used, and for other applications where warm air floor furnaces and room heaters are installed in the space being heated.

### Central Heating Systems

Boilers and furnaces specially designed for gas-firing incorporate design features for obtaining maximum efficiency and performance. Small flue passes to secure good heat transfer, the use of materials resistant to the corrosive effects of products of combustion, and draft hoods are notable features. Control equipment includes gas pressure regulators, automatic pilots, and limit controls designed to protect the appliance and to insure safety of operation. A boiler designed for gas-burning is illustrated in Fig. 19.

Gas designed boilers for hot water or steam heating are available in

cast-iron, steel, and non-ferrous metals. The burners are located beneath the sections, and the flue gases pass upwards between the sections to the flue collector. Some boilers are designed to provide domestic hot water through the use of tankless or instantaneous heaters.

Warm air furnaces are of two types, gravity and forced air. The former depends upon a thermal head to provide circulation of air over the heat exchanger and thence directly to the space to be heated, usually through ducts. Most gravity furnaces can be equipped with humidifiers. Forced warm air furnaces utilize a motor-driven blower to circulate air over the heat exchanger and through the ducts. A common type is quite similar to Fig. 18 except that gas burners, pilots, controls, and gas pressure regulator are substituted for the oil burner, and a draft hood is attached to the outlet of the furnace. Due to the pressure developed by the blower, ductwork becomes smaller and the location of the furnace less critical than in gravity systems. Designs of forced air furnaces vary from the conventional types that deliver heated air to overhead ductwork to the downblow types wherein the heated air is delivered at the bottom of the furnace, this

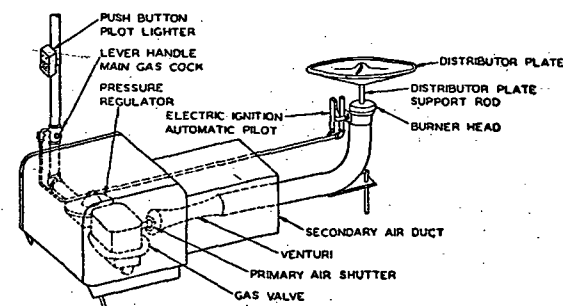


FIG. 20. TYPICAL SINGLE PORT GAS CONVERSION BURNER

latter type being designed for perimeter or radiant panel heating. Several types of low height horizontal furnaces are available for installation in attics or under floors of unexcavated houses. These furnaces are designed for compactness. The *A.G.A.* listed output at the boiler nozzle or at the bonnet for forced air and gravity furnaces is 80 and 75 percent, respectively, of the approved input to the burners.

### Conversion Burners

Conversion burners are usually complete burner and control units designed for installation in existing boilers and furnaces. A typical gas conversion burner is shown in Fig. 20. Atmospheric conversion burners may have drilled port, slotted port, or single port burner heads. Single port types have become increasingly popular in the last few years due to their simplicity of construction and ease of installation. In rectangular or round, drilled and slotted port burners baffles of clay or metal are usually used to direct the products of combustion toward the side walls of the combustion chamber. In single port burners the flame usually impinges against a horizontal cast-iron, stainless steel, or ceramic distributor plate which directs the products of combustion toward the side walls. For certain applications, particularly wet base boilers, a horizontal single port burner

is utilized. This design produces a horizontal flame which strikes a curved baffle that spreads the flame in a fan shape.

Several power burners in domestic sizes are available. These are of gun burner design and feature small mechanical blowers for supplying all the air required for combustion. These are particularly desirable for handling restricted flue boilers or furnaces where an atmospheric burner cannot obtain the desired output.

Conversion burners for domestic application are available in sizes ranging from 50,000 to 400,000 Btu per hr capacity. It should be noted that the American Standard Approval Requirements are limited at present to conversion burners of capacities up to 400,000 Btu per input hr. Burners of larger capacity, for use in large steel boilers, are usually engineered by a contractor specializing in this type of work, or by the local utility company. They are available in a large number of sizes and types. In some cases the burner may be an assembly of multiple burner heads filling the entire firebox. For conversion burner installation in boilers requiring more than 400,000 Btu per hr input, reference should be made to the American Standard Requirements for Installation of Gas Equipment in Large Boilers, ASA Z21.33-1950.

Domestic sizes of conversion burners should conform to American Standard Listing Requirements of Conversion Burners, ASA Z21.17-1948. As the successful and safe performance of a gas conversion burner depends on numerous factors other than those incorporated in such equipment, installations of this kind must be made in strict accordance with American Standard Requirements for Installation of Domestic Gas Conversion Burners, ASA Z21.8-1948. Also, draft hoods conforming to American Standard Listing Requirements for Draft Hoods, ASA Z21.12-1937, R 1950, should be installed (in place of the dampers used with a solid fuel) on all boilers and furnaces intended to operate without chimney draft. The A.G.A. lists the output efficiency of conversion burners at 72 percent. This value is based on average installations and average heating equipment performance.

One form of central heating system is the warm air floor furnace.<sup>5</sup> The use of these furnaces is adaptable to mild climates, or for auxiliary heating or heating of single rooms in colder climates. They are used for heating first floors, or where heat is required in only one or two rooms. A number may be used to provide heat for the entire building where all rooms are on the ground floor, thus giving the heating system flexibility.

In floor-furnace applications, the heating element, gas piping, and flue vent piping are suspended below the floor, and the only part in the room being heated is the circulating air register which may be of the single-type installed in the floor, or of the dual-type installed in a partition, and heating two rooms. The A.G.A. rating of floor furnaces is based on an efficiency of 70 percent.

A recent type of central heating, used in mild climates, is the recessed heater which is either a gravity or forced-air furnace designed for installation in the interior partition of a building, and having stub ducts conducting air to two or more rooms. This type of heater is usually installed in new homes, and is plastered into the wall, becoming a permanent part of the building.

#### Space Heaters

Space heaters are defined as heating units that take the air for combustion from the space being heated. They may be broadly classified as room heaters and unit heaters.

*Room heaters* are used for heating single rooms or connecting rooms with good circulation between them and, except for wall-type heaters, they are semi-portable. Unvented-type room heaters should not be used unless space is properly ventilated to prevent excess moisture and to provide sufficient combustion air to prevent formation of carbon monoxide. All types of room heaters are capable of automatic control, although they are generally controlled manually. When equipped for automatic control, they must have an automatic pilot as part of the control equipment. Room heaters may be classified as follows:

*Circulators*, vented and unvented, are small warm air furnaces that heat the room mainly by convection, although some have radiants over the burner, with windows in the front to allow some heat by radiation.

*Radiant heaters*, usually unvented, although some vented types are available, have a refractory directly above the burners which is heated to incandescence, and gives off at least 30 percent of its heat in the form of radiant energy.

*Gas-fired steam and hot water radiators*, vented and unvented, are similar in appearance to an ordinary steam or hot water radiator, but are self-contained, and the gas input is controlled by steam pressure or water temperature within the radiator.

*Warm air radiators* are vented or unvented circulators whose heating elements are constructed in the form of a steam radiator.

*Wall heaters*, vented or unvented, are usually a type of radiant heater constructed with sufficient insulation (either solid or circulating air) to prevent overheating of the casing, and are built into a wall with the front flush with the wall surface.

The A.G.A. rating of room-type heaters is based on an efficiency of 70 percent.

*Unit heaters* are used extensively for heating large spaces such as stores, garages, and factories. These heaters consist of a burner, heat exchanger, fan for distributing the air, draft hood, automatic pilot, and controls for burners and fan. They are usually mounted in an elevated position from which the heated air is directed downward by louvers. Some unit heaters are suspended from the ceiling, and others are free-standing floor units of the heat tower type. Unit heaters are classified for use with, or without, ducts depending on specific A.G.A. approval. When connected to ducts they must have sufficient blower capacity to deliver an adequate air quantity against the duct resistance.

*Duct furnaces* are usually of the unit heater type without the fan, and are used for heating air in existing duct systems where blowers are provided for moving the air through the system. Duct furnaces are tested for operation at much higher static pressures than are obtained in unit heaters.

#### Combustion Process and Adjustments

Most domestic gas burners are of the atmospheric injection (Bunsen) type in which primary air is introduced and mixed with the gas in the throat of the mixing tube. For normal operation of most atmospheric type burners, 40 to 60 percent of the theoretical air as primary air will give best operation. Slotted port and ribbon burners may require from 50 to 80 percent primary air for proper operation. The amount of excess air required in practice depends upon several factors, notably: uniformity of air distribution and mixing, direction of gas travel from burner, and the height and temperature of combustion chamber. With power type burners utilizing motor driven blowers to provide both primary and secondary air, the excess air can be closely controlled while securing proper combustion.

Secondary air is drawn into gas appliances by natural draft. As with other fuels, excess secondary air constitutes a loss, and should be reduced to a proper minimum, which usually cannot be less than 25 to 35 percent, if the appliance is to meet ASA approval requirements. Yellow flame burners depend upon secondary air, alone, for combustion.

The flame produced by atmospheric injection burners is non-luminous. Air shutter adjustments for manufactured gas should be made by closing the air shutter until yellow flame tips appear, and then by opening the air shutter to a final position at which the yellow tips just disappear. This type of flame obtains ready ignition from port to port, and also favors quiet flame extinction. When burning natural gas, the air adjustment is generally made to secure as blue a flame as is obtainable without lifting of flames from burner ports. Manufacturers' instructions for burner adjustment should be followed.

Gas designed equipment does not usually incorporate any means for varying the secondary air supply (and hence the  $\text{CO}_2$ ). The amount of effective opening and baffling is determined by A.G.A. tests and cannot be varied. Gas conversion burners, however, do incorporate means for controlling secondary air to permit adjustment over a wide range of inputs according to the type of installation encountered. The manufacturer's specific instructions contained in the installation manual required to be supplied with each burner should be followed. It is possible through the use of suitable indicators to determine whether carbon monoxide is present in flue gases. Carbon monoxide should not exceed 0.04 percent when operating at the maximum gas input to the burners.

During recent years, the use of fuel gas (natural, manufactured, and liquified petroleum) has become increasingly popular for heating tourist cabins and motels. Due largely to the intermittent use of such equipment and the fact that so many of the users are entirely unfamiliar with the fundamentals governing its operation, many special and unusual problems arise. The importance of safe-guarding the public interest has prompted some state and city officials to adopt and enforce legislation governing not only the manner in which these appliances are installed but the extent to which they must be equipped with reliable safety devices, for example, connection to an effective flue is mandatory. Furthermore, all such heating equipment must incorporate an automatic ignition pilot which will shut off gas supply to the main burner or burners in the event of pilot outage. If liquified petroleum gas is used, the automatic pilot must cut off all gas supply to the appliance, including the pilot burner, in case the pilot flame becomes extinguished.

#### Ratings for Gas Appliances

Input rating for a gas appliance is established by demonstrating that the appliance can meet the Approval Requirements of the ASA. The tests are conducted at the A.G.A. Laboratories. Output rating is determined from the approved input and an average efficiency stated in the Approval Requirements, and is the heat available at the outlet.

#### Sizing Gas-Fired Heating Plants

Although gas-burning equipment usually is completely automatic, maintaining the temperature of rooms at a predetermined figure, there are some manually controlled installations. In order to overcome effectively the starting load and losses in piping, a manually-controlled gas

boiler should have an output as much as 100 per cent greater than the equivalent standard radiation which it is expected to serve.

Boilers under thermostatic control, however, are not subject to such severe pick-up loads and consequently, it is possible to use a lower selection factor. For a gas-fired boiler or furnace under thermostatic control, a factor of 20 to 25 percent is usually sufficient for pick-up allowance.

In those installations, in mild climates where 100 per cent outside air is used, furnaces should be of larger size in order to provide adequate capacity and quick pick-up under intermittent heating conditions.

The factor to be allowed for loss of heat from piping will vary somewhat, the proportionate amount of piping installed being greater for small installations than for large ones. For selection factors to be added to installed radiation under thermostatic control, see Chapter 16.

TABLE 1. CAPACITY OF GAS PIPING

| Length of Pipe<br>in Feet | Nominal Diameter of Pipe in Inches                                                |     |                 |     |     |
|---------------------------|-----------------------------------------------------------------------------------|-----|-----------------|-----|-----|
|                           | $\frac{1}{2}$                                                                     | 1   | 1 $\frac{1}{2}$ | 2   | 2   |
|                           | Capacity—Cu Ft Per Hr with a 0.5 Sp Gr Gas and Pressure Drop of 0.3" Water Column |     |                 |     |     |
| 15                        | 172                                                                               | 345 | 750             |     |     |
| 30                        | 120                                                                               | 241 | 535             | 850 |     |
| 45                        | 99                                                                                | 199 | 435             | 700 |     |
| 60                        | 86                                                                                | 173 | 380             | 610 |     |
| 75                        | 77                                                                                | 155 | 345             | 545 |     |
| 90                        | 70                                                                                | 141 | 310             | 490 |     |
| 105                       | 65                                                                                | 131 | 285             | 450 | 920 |
| 120                       |                                                                                   | 120 | 270             | 420 | 860 |
| 150                       |                                                                                   | 109 | 242             | 380 | 780 |
| 180                       |                                                                                   | 100 | 225             | 350 | 720 |

Appliances used for heating with gas should bear the approval seal of the A.G.A. Laboratories on the manufacturer's nameplate, together with the official input and output ratings. It is not permissible to operate a gas heating unit above its stated rating. It may be necessary to operate below this rating at elevations above 2000 ft, unless the appliance has been tested and approved for operation at altitudes up to 5200 ft, in which case such approval will be shown on the manufacturer's nameplate. Installations should be made in accordance with recommendations shown in the publications of the American Gas Association.

#### Controls

Temperature controls for gas burners are described in Chapter 39. Some central heating plants are equipped with push-button or other manual control. The main gas valve may be of either the snap action or throttling type. Automatic electric ignition is available.

#### Sizing of Gas Piping

Piping for gas appliances should be of adequate size, and so installed as to provide a supply of gas sufficient to meet the maximum demand without undue loss of pressure between the point of supply (the meter) and the burner. The size of gas pipe required depends upon the following:

1. Maximum gas consumption to be provided.



2. Length of pipe and number of fittings.
3. Allowable loss in pressure from the outlet of the meter to the burner.
4. Specific gravity of the gas.

To obtain the cubic feet per hour of gas required by the burner, divide the Btu input at which the burner will be adjusted, by the average Btu heating value per cubic foot of the gas.

Capacities of different sizes and lengths of pipe, in cubic feet per hour, with a pressure drop of 0.3 in. of water column for a gas of 0.60 sp gr, are shown in Table 1. In adopting a 0.3 in. pressure drop, due allowance for an ordinary number of fittings was made.

To convert the figures given in Table 1 to capacities for another gas of different specific gravity, multiply the tabular values by the multipliers shown in Table 2.

TABLE 2. MULTIPLIERS FOR VARIOUS SPECIFIC GRAVITIES  
For Use With Table 1

| Specific Gravity | Multiplier | Specific Gravity | Multiplier |
|------------------|------------|------------------|------------|
| .35              | 1.31       | 1.00             | .775       |
| .40              | 1.23       | 1.10             | .740       |
| .45              | 1.16       | 1.20             | .707       |
| .50              | 1.10       | 1.30             | .680       |
| .55              | 1.04       | 1.40             | .655       |
| .60              | 1.00       | 1.50             | .633       |
| .65              | .962       | 1.60             | .612       |
| .70              | .926       | 1.70             | .594       |
| .75              | .895       | 1.80             | .577       |
| .80              | .867       | 1.90             | .565       |
| .85              | .841       | 2.00             | .547       |
| .90              | .817       | 2.10             | .535       |

### COMMERCIAL AND INDUSTRIAL GAS EQUIPMENT

No attempt can be made, due to space limitation, to describe or classify the varied types of equipment used for commercial and industrial applications. Much of the equipment utilized is custom built to suit a particular process. Certain standard parts such as venturi and burner head sets, ring burners, proportional mixers, or compressors, are purchased for assembly in existing equipment, usually by the installer. Furnaces to provide particular atmospheres or for annealing, soaking pits, metal melting, etc. are usually engineered by industrial gas equipment manufacturers.

Burners utilized in industrial equipment often operate at gas pressures higher than encountered in domestic usage. High pressure gas provides flexibility of control required in the production of constant temperatures. In addition, air-gas ratios can be closely maintained under throttling conditions, and heat liberation per cubic foot of combustion space is considerably greater than can be achieved with lower pressures.

A few of the many basic types of burners used are as follows: single-pipe high pressure, proportional mixing, pre-mix, two-pipe high pressure, and atmospheric.

The *single-pipe high pressure burner* system utilizes gas delivered to the orifice of a venturi at pressures from 10 to 50 psig. A constant pressure compressor, sometimes remotely placed, is occasionally used to increase the

gas pressure. The velocity of the gas issuing from the orifice entrains primary air which is controlled by an air shutter on the venturi tube. An advantage of this system is that when the gas pressure is reduced (lowering the input) the air-gas ratio will remain constant over a fairly wide range.

In the *proportional mixing burner*, an enclosed type venturi is used and high pressure air is delivered through an orifice. The resulting partial vacuum entrains the gas which is supplied through a zero pressure governor. When the air pressure is reduced, the amount of gas entrained is similarly reduced, thus maintaining a constant air-gas ratio over a wide fuel capacity range.

The *pre-mix burner* system embodies a compressor which mixes air and gas intimately and discharges the mixture through pipes to the burners

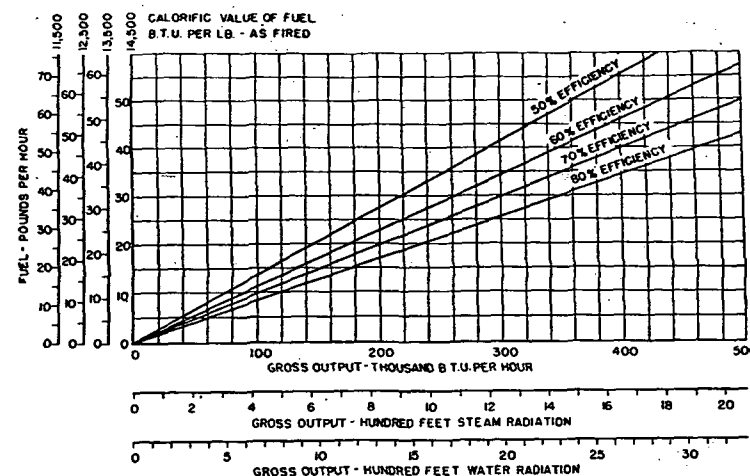


FIG. 21. COAL FUEL BURNING RATE CHART

where it is discharged through orifices and burned. The pre-mix compressor can be remotely installed and the mixture can be closely controlled.

The *two-pipe high pressure burner* system utilizes both air and gas under pressure, both being delivered through orifices and mixed prior to delivery to the burner.

The *atmospheric burner* system is not commonly used. It consists of a burner supplied with gas at a pressure of 2 to 12 in. water. A portion of the air or primary air required for combustion is entrained from the atmosphere by the stream of gas issuing from an orifice, and the air-gas mixture is delivered through a venturi mixing tube to the burner head and parts. About 40 to 60 percent of the air required for combustion is in the form of primary air and the remainder, known as secondary air, is supplied from the air surrounding the flame.

Each system embodies characteristics essential for certain applications. It is strongly recommended that proper and qualified engineering authorities be consulted prior to the purchase, installation, or operation of industrial gas equipment.



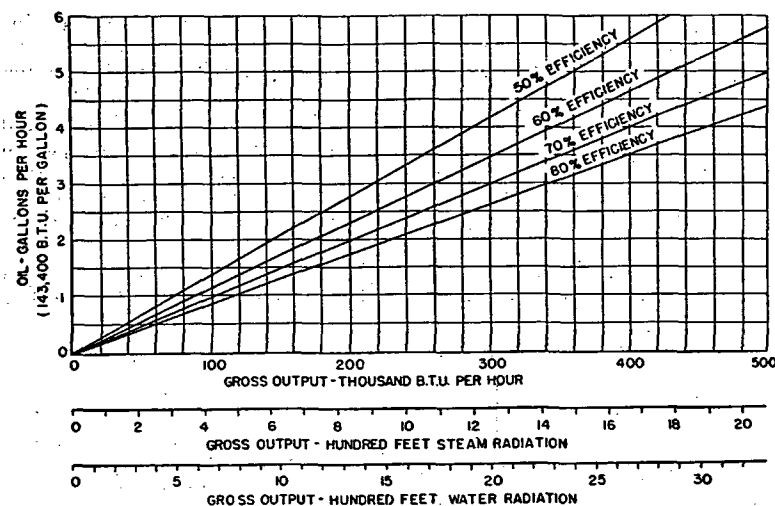


FIG. 22. OIL FUEL BURNING RATE CHART\*

\* This chart is based upon No. 2 oil having a heat content of 143,400 Btu per gallon. If other grades of oil are used multiply the value obtained from this chart by the following factors: No. 1 oil (139,000 Btu per gallon) 1.032; No. 4 oil (144,500 Btu per gallon) 0.992; No. 5 oil (146,000 Btu per gallon) 0.982; and No. 6 oil (150,000 Btu per gallon) 0.956.

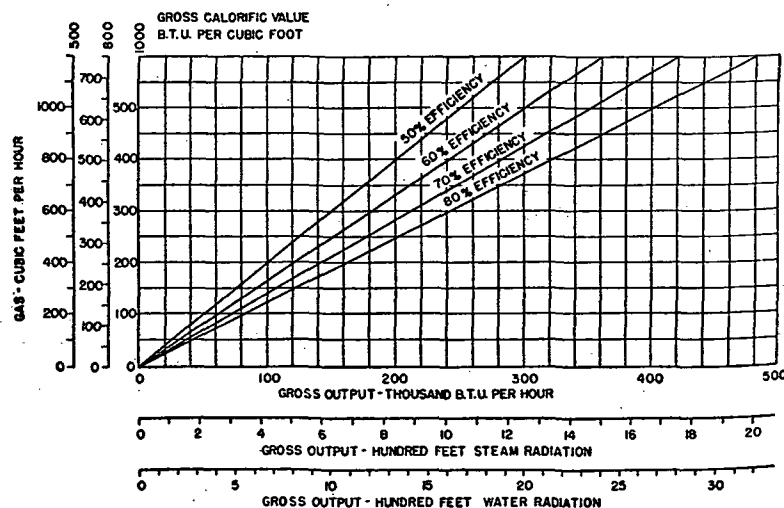


FIG. 23. GAS FUEL BURNING RATE CHART

## FUEL BURNING RATES

The burning rate for automatic fuel burning devices is determined by the gross heat output required of the boiler, or furnace, to carry the net heating load, plus allowances for system losses and pick-up. General values for these allowances have been given in preceding text. Detailed information for piping and pick-up allowances for steam and hot water systems, is given in Chapter 16, and for warm air systems, in Chapters 19 and 20.

When the gross output, operating efficiency, and heat value of the fuel are known, the required rate of burning can be determined by means of Figs. 21, 22 and 23 for the several fuels.

As the rate of fuel burning is directly proportional to the load for a given efficiency, these charts can be extended by moving the decimal points the same number of digits in both vertical and horizontal scales.

The correct fuel burning rate can be determined directly from the several charts for oil or gas burning installations, as these customarily operate on a strictly intermittent basis. These fuel burning devices usually introduce the fuel at a single fixed rate during the on periods, and this rate should be sufficient to carry the gross load. In the case of coal stokers, which are usually capable of variable rates of firing, it is desirable to operate at as low a rate as weather conditions will permit, but the maximum firing rate of the stoker should be sufficient to carry the gross load. This rate may be determined by the same method as used for oil or gas.

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<sup>2</sup> Stoker Manufacturers Association Manual: Industry Standards, Recommended Practices, Technical Information. Published by Stoker Manufacturers Association, 307 N. Michigan Ave., Chicago 1, Ill.

<sup>3</sup> Code for Determination of Rated Capacities of Anthracite Underfeed Stokers, adopted June 1, 1944, and a Code for Determination of Rated Capacities of Bituminous Underfeed Stokers, adopted May 3, 1944. See Stoker Manufacturers Association Manual.

<sup>4</sup> Automatic Mechanical Draft Oil Burners Designed for Domestic Installations (U. S. Department of Commerce, National Bureau of Standards, Commercial Standard No. CS75-42). Flue Connected Oil Burning Space Heaters Equipped with Vaporizing Pot Type Burners (U. S. Department of Commerce, National Bureau of Standards, Commercial Standard No. CS101-43). Warm-Air Furnaces Equipped with Vaporizing Pot-Type Oil Burners (U. S. Department of Commerce, National Bureau of Standards, Commercial Standard No. CS104-46). Oil-Burning Floor Furnaces Equipped with Vaporizing Pot-Type Burners (U. S. Department of Commerce, National Bureau of Standards, Commercial Standard No. CS113-44).

<sup>5</sup> Gas Floor Furnaces, Gravity Circulating Type (U. S. Department of Commerce, National Bureau of Standards, Commercial Standard No. CS99-42).

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## CHAPTER 16

### HEATING BOILERS, FURNACES, SPACE HEATERS

**BOILERS:** Construction, Types, Design Considerations, Rating and Testing Codes, Efficiency, Rating, Selection, Space Limitations, Connections and Fittings, Erection, Operation and Maintenance. **FURNACES:** Types, Materials and Construction, Ratings, Testing and Rating Codes, Efficiency, Design Considerations, Humidification Equipment. **SPACE HEATERS:** Types: Solid Fuel, Oil, Gas; Materials and Construction, Testing and Rating, Design Considerations, Installation.

IN presenting the subject of Boilers, Furnaces and Space Heaters this chapter is divided into three parts; the first dealing with boilers, the second treating warm air furnaces, and the third covering space heaters.

#### HEATING BOILERS

Steam and hot water boilers for low pressure heating are built of steel or cast-iron in a wide variety of types and sizes, many of which are illustrated in the *Catalog Data Section*.

The nationally recognized code governing the construction of low-pressure steel and cast-iron heating boilers is the *ASME Boiler Construction Code for Low Pressure Heating Boilers*. Some states and municipalities have their own codes which apply locally, but these are usually patterned after the *ASME Code*.

The maximum allowable working pressures are limited by the *ASME Code for Low Pressure Heating Boilers* to 15 psi for steam and 160 psi for hot water heating boilers, with a maximum temperature limitation of 250 F. Hot water boilers are generally designed for a working pressure of 30 psi and may be supplied for higher working pressures, for either heating purposes or for hot water supply, only when designed, tested and stamped for the higher pressure.

#### TYPES OF HEATING BOILERS

Heating boilers are classified in a number of different ways, such as:

1. According to materials of construction. These are steel and cast-iron. Very few non-ferrous boilers are made.
2. According to the fuels for which the boilers are designed. These are coal, hand-fired or stoker-fired; oil; gas; or wood. Some boilers are designed specifically for one fuel, but many boilers are designed for more than one fuel.
3. According to the specific purpose or application for which the boiler is used, such as space heating or domestic hot water supply.
4. According to the design or construction of the boiler such as sectional, round, fire-tube, water-tube, magazine feed, Scotch, etc.

#### Cast-Iron Boilers

Cast-iron boilers are generally classified as:

1. Square or rectangular boilers with vertical sections and rectangular grates, commonly known as sectional boilers.
2. Round boilers with horizontal pancake sections and circular grates.

Cast-iron boilers are usually shipped in sections, and assembled at the place of installation. However some small boilers are shipped factory assembled. In the majority of boilers the sections are assembled with push nipples and tie rods but external headers and screw nipples are also used successfully. Many sectional boilers are provided with large push nipples at top to permit the circulation of water between adjacent sections at both the water line and bottom of the boiler, which is necessary to enable the use of an indirect water heater with the boiler for summer-winter hot water supply. Round and sectional boilers may be increased in size by the addition of sections and corresponding plate work.

Small sectional type boilers are available with *wet-base* construction, wherein the ashpit or combustion chamber sides and bottom are surrounded by extensions of the water legs of the boiler sections, and thus no separate base is required. This type of construction permits the boiler to be set directly on a wood or composition floor without danger of fire. The *wet-base* also provides some additional heating surface.

Capacities of cast-iron boilers range generally from capacities required for small residences up to about 12,000 sq ft of steam radiation but boilers are made with capacities up to approximately 32,000 sq ft E.D.R.

### Steel Boilers

Steel boilers may be of the fire-tube type, in which the gases of combustion pass through the tubes and the boiler water circulates around them, or of the water-tube type, in which the gases circulate around the tubes and the water passes through them. Either the fire-tube or water-tube type may be designed with integral water jacketed furnaces, or arranged for refractory lined brick or refractory lined jacketed furnaces. Those with integral water jacketed furnaces are called portable firebox boilers, and are the most commonly used type. They are usually shipped in one piece, ready for piping connections. Refractory furnaces are usually installed in refractory lined furnace boilers after they are set in place.

Capacities of steel boilers range from those required for small residences up to about 50,000 sq ft E.D.R. (steam).

### Boilers for Special Applications

One of these is known as the *magazine feed boiler* developed for the burning of small sizes of anthracite and coke, and has a large fuel carrying capacity, which results in longer firing periods than would be the case with the standard types burning coal of buckwheat size. Special attention must be given to proper chimney sizes and connections in order to insure adequate draft.

Boilers for *hot water supply* are classified as direct, if the water heated passes through the boiler, and as indirect, if the water heated does not come in contact with the water or steam in the boiler.

*Direct heaters* are built to operate at the pressures found in city supply mains, and are tested at pressures from 200 to 300 lb per square inch. The life of direct heaters depends almost entirely on the scale-forming properties of the water supplied and the temperatures maintained. If low water temperatures are maintained, the life of the heater will be much longer due to decreased scale formation and minimized corrosion. Direct water heaters in some cases are designed to burn refuse and garbage.

*Indirect heaters* generally consist of steam boilers in connection with heat exchangers of the coil or tube types which transmit the heat from the

steam to the water. This type of installation has the following advantages:

1. The boiler operates at low pressure.
2. The boiler is protected from scale and corrosion.
3. The scale is formed in the heat exchanger in which the parts to which the scale is attached, can be cleaned or replaced. The accumulation of scale does not affect efficiency, although it will affect the capacity of heat exchanger.
4. Discoloration of water may be prevented if the water supply comes in contact with only non-ferrous metal.

Where a steam or a forced circulation hot water heating system is installed, the domestic hot water may be heated by an indirect heater attached to the boiler. For most satisfactory performance in the steam system, this heater is placed just below the water line of the boiler. In a forced circulation hot water system, it should be located as high as possible with respect to the boiler.

## BOILER DESIGN CONSIDERATIONS

### Furnace Design

Good efficiency and proper boiler performance are dependent on correct furnace design. There must be sufficient volume for burning the particular fuel which is used, and means to obtain a thorough mixing of air and gases at a high temperature and at a velocity low enough to permit complete combustion of all the volatiles. For hand-fired boilers, the furnace volume should be large enough to hold sufficient fuel for reasonably long firing periods. (See Chapters 14 and 15.)

### Heating Surface

Boiler heating surface is that portion of the surface of the heat transfer apparatus in contact with the fluid being heated on one side and the gas or refractory being cooled on the other side. Heating surface on which the fire shines, is known as *direct* or radiant surface, and that in contact with hot gases only, as *indirect* or convection surface. The amount of heating surface, its distribution, and the temperatures on either side thereof, influence the capacity of any boiler.

Direct heating surface is more valuable than indirect per square foot because it is subjected to a higher temperature and also, in the case of solid fuel, because it is in position to receive the full radiant energy of the fuel bed.

The effectiveness of the heating surface depends on its cleanliness, its location in the boiler, and the shape of the gas passages. The area of the gas passages must not be so small as to cause excessive resistance to the flow of gases, where natural draft is employed. Inserting baffles so that the heating surface is arranged in series with respect to the gas flow, increases boiler efficiency and reduces stack temperature, but increases the draft loss through the boiler.

### Heat Transfer Rate

Practical average overall heat transfer rates, expressed in Btu absorbed per square foot of surface per hour, will average about 3300 for hand-fired boilers, and 4000 for mechanically-fired boilers when operating at *design load*. When mechanically-fired boilers are operating at *maximum load*, as defined in this chapter under heading *Selection of Boilers*, these values will run between 5000 and 6000. Boilers operating under favorable conditions at these heat transfer rates, will give exit gas temperatures that

are considered consistent with good practice, although there are boilers which have high efficiencies and also operate at higher transmission rates.

### RATING AND TESTING CODES

Heating boilers are usually rated according to codes developed by the *Steel Boiler Institute*, the *Institute of Boiler and Radiator Manufacturers*, the *American Gas Association*, and the *Heating, Piping and Air Conditioning Contractors National Association*, whose test codes have been prepared specifically for the purpose of obtaining information required for establishing acceptable ratings. In view of the preference of industry for the above codes, consideration is being given to the withdrawal of the following five Society codes for determining efficiency and performance characteristics:

ASHVE Standard and Short Form Heat Balance Codes for Testing Low-Pressure Steam Heating Solid Fuel Boilers—Codes 1 and 2—(Revision of June, 1929).<sup>1</sup>

ASHVE Performance Test Code for Steam Heating Solid Fuel Boilers—Code No. 3—(Edition of 1929).<sup>2</sup>

The ASHVE Standard Code for Testing Steam Heating Boilers Burning Oil Fuel, (Adopted June, 1938).<sup>3</sup>

The ASHVE Standard Code for Testing Stoker-Fired Steam Heating Boilers, (Adopted June 1938;<sup>4</sup> also adopted by the Stoker Manufacturers Association, 1938).

The various current rating and testing codes will be discussed in following paragraphs in which limitations, methods of application, and resulting ratings will be described.

The *Steel Boiler Institute* has adopted a rating code for boilers designated *Table 1 Steel Boilers* and *Table 2 Steel Boilers* and a testing code for *Oil-fired Table 2 Steel Boilers* (*SBI Rating Code*, Sixth Edition, July 1954). Tables 1 and 2 of this chapter show the *SBI* ratings of these two classes of boilers. The *Table 1* boilers (defined as those having 129 to 3571 sq ft of heating surface and formerly designated as *Commercial* boilers) are rated in square feet E.D.R. (steam) on the basis of heating surface with limitations set for grate area, furnace volume, and furnace height. The *Table 2* boilers (defined as those having not more than 294 sq ft of heating surface and formerly designated as *Residential* boilers) are rated from tests of oil-fired boilers, with limitations in relation to heating surface and testing conditions. Stoker-fired and gas-fired *Table 2* boilers are rated (*SBI* Net Rating) not in excess of the oil-fired rating. Hand-fired *Table 2* boilers are rated (*SBI* Net Rating) not greater than fourteen times the heating surface.

The *Institute of Boiler and Radiator Manufacturers* has adopted a code<sup>5</sup> for rating cast-iron heating boilers, based upon performance obtained under controlled test conditions. This code applies to all sectional cast-iron heating boiler except those of magazine-feed type.

The *Gross I=B=R Output* is obtained by test, and is subject to certain limiting factors. For hand-fired boilers, the number of boilers of a series to be tested, the minimum overall efficiency, the minimum time limit (the time an *Available Fuel Charge* will last when burned at a rate which will produce the *Gross I=B=R Output*), the chimney area and height, and the draft in the stack are all subject to the limits established in the code. Tests are run using anthracite coal of standard specification. Bituminous coal and coke ratings are the same as for anthracite.

For automatically-fired boilers, the number of boilers of a series to be

TABLE 1. SBI RATINGS FOR Table 1 STEEL BOILERS

| MECHANICALLY-FIRED |                 |                |                 |                 |                |                  |                  |                 |                                   | HAND-FIRED       |                  |                 |                                   | (c) TAPPINGS             |                              |
|--------------------|-----------------|----------------|-----------------|-----------------|----------------|------------------|------------------|-----------------|-----------------------------------|------------------|------------------|-----------------|-----------------------------------|--------------------------|------------------------------|
| SBI Rating         |                 |                | SBI Net Rating  |                 |                | SBI Rating       |                  |                 | MINIMUM HEATING SURFACE Sq Ft (9) | SBI Net Rating   |                  |                 | (d) Minimum Grate Area Sq Ft (16) | Steam Output I.P.S. (17) | (a) Steam Return I.P.S. (18) |
| Sq Ft Steam (1)    | Sq Ft Water (2) | Btu Per Hr (3) | Sq Ft Steam (4) | Sq Ft Water (5) | Btu Per Hr (6) | Sq Ft Steam (10) | Sq Ft Water (11) | Btu Per Hr (12) |                                   | Sq Ft Steam (13) | Sq Ft Water (14) | Btu Per Hr (15) |                                   |                          |                              |
| 2,190              | 3,500           | 526,000        | 1,800           | 2,880           | 432,000        | 1,800            | 2,880            | 432,000         | 129                               | 1,500            | 2,400            | 360,000         | 7.9                               | 6                        | 3*                           |
| 2,680              | 4,280           | 643,000        | 2,000           | 3,200           | 480,000        | 2,000            | 3,200            | 480,000         | 188                               | 1,830            | 2,930            | 439,000         | 8.9                               | 6                        | 3*                           |
| 3,160              | 5,050           | 758,000        | 2,600           | 4,160           | 624,000        | 2,600            | 4,160            | 624,000         | 234                               | 2,170            | 3,470            | 521,000         | 9.7                               | 6                        | 3*                           |
| 3,650              | 5,840           | 876,000        | 3,000           | 4,800           | 720,000        | 3,000            | 4,800            | 720,000         | 294                               | 2,500            | 4,000            | 600,000         | 10.5                              | 6                        | 4*                           |
| 4,250              | 6,800           | 1,020,000      | 3,500           | 5,600           | 840,000        | 3,500            | 5,600            | 840,000         | 304                               | 2,920            | 4,670            | 700,000         | 11.4                              | 6                        | 4*                           |
| 4,860              | 7,770           | 1,166,000      | 4,000           | 6,400           | 960,000        | 4,000            | 6,400            | 960,000         | 320                               | 3,350            | 5,350            | 800,000         | 12.2                              | 6                        | 4*                           |
| 5,470              | 8,750           | 1,313,000      | 4,500           | 7,200           | 1,080,000      | 4,500            | 7,200            | 1,080,000       | 332                               | 3,780            | 6,000            | 900,000         | 13.4                              | 6                        | 4*                           |
| 6,080              | 9,720           | 1,460,000      | 5,000           | 8,000           | 1,200,000      | 5,000            | 8,000            | 1,200,000       | 338                               | 4,170            | 6,970            | 1,000,000       | 14.3                              | 6                        | 4*                           |
| 7,290              | 11,660          | 1,750,000      | 6,000           | 9,600           | 1,440,000      | 6,000            | 9,600            | 1,440,000       | 429                               | 5,000            | 8,000            | 1,200,000       | 16.4                              | 8                        | 4*                           |
| 8,500              | 13,600          | 2,040,000      | 7,000           | 11,200          | 1,680,000      | 7,000            | 11,200           | 1,680,000       | 500                               | 5,830            | 9,330            | 1,400,000       | 18.1                              | 8                        | 4*                           |
| 10,330             | 16,520          | 2,476,000      | 8,500           | 13,600          | 2,040,000      | 8,500            | 13,600           | 2,040,000       | 608                               | 7,080            | 11,330           | 1,700,000       | 20.5                              | 8                        | 4*                           |
| 12,150             | 19,440          | 2,912,000      | 10,000          | 16,000          | 2,400,000      | 10,000           | 16,000           | 2,400,000       | 715                               | 8,330            | 13,330           | 2,000,000       | 22.5                              | 8                        | 4*                           |
| 15,180             | 24,260          | 3,643,000      | 12,500          | 20,000          | 3,000,000      | 12,500           | 20,000           | 3,000,000       | 893                               | 10,430           | 16,700           | 2,800,000       | 25.6                              | 8                        | 4*                           |
| 18,210             | 29,150          | 4,373,000      | 15,000          | 24,000          | 3,600,000      | 15,000           | 24,000           | 3,600,000       | 1,072                             | 12,430           | 20,000           | 3,500,000       | 28.4                              | 8                        | 4*                           |
| 21,250             | 34,000          | 5,100,000      | 17,500          | 28,000          | 4,200,000      | 17,500           | 28,000           | 4,200,000       | 1,250                             | 14,580           | 23,330           | 4,300,000       | 30.9                              | 8                        | 4*                           |
| 24,290             | 38,860          | 5,830,000      | 20,000          | 32,000          | 4,800,000      | 20,000           | 32,000           | 4,800,000       | 1,429                             | 16,670           | 26,670           | 5,000,000       | 33.2                              | 8                        | 4*                           |
| 27,330             | 43,720          | 6,560,000      | 22,500          | 36,000          | 5,400,000      | 22,500           | 36,000           | 5,400,000       | 1,608                             | 18,700           | 29,330           | 5,800,000       | 35.7                              | 10                       | 6                            |
| 30,360             | 48,570          | 7,288,000      | 25,000          | 40,000          | 6,000,000      | 25,000           | 40,000           | 6,000,000       | 1,788                             | 20,830           | 32,000           | 6,600,000       | 38.2                              | 10                       | 6                            |
| 33,400             | 53,430          | 8,016,000      | 27,500          | 44,000          | 6,600,000      | 27,500           | 44,000           | 6,600,000       | 2,143                             | 23,000           | 35,000           | 7,400,000       | 40.7                              | 10                       | 6                            |
| 36,430             | 58,290          | 8,744,000      | 30,000          | 48,000          | 7,200,000      | 30,000           | 48,000           | 7,200,000       | 2,500                             | 25,170           | 38,000           | 8,200,000       | 43.2                              | 10                       | 6                            |
| 42,500             | 68,000          | 10,200,000     | 35,000          | 56,000          | 8,400,000      | 35,000           | 56,000           | 8,400,000       | 3,571                             | 29,170           | 46,070           | 10,000,000      | 44.7                              | 12                       | 6                            |
| 48,570             | 77,710          | 11,657,000     | 40,000          | 64,000          | 9,600,000      | 40,000           | 64,000           | 9,600,000       | 3,857                             | 33,330           | 53,330           | 11,600,000      | 48.0                              | 12                       | 6                            |
| 54,640             | 87,420          | 13,110,000     | 45,000          | 72,000          | 10,800,000     | 45,000           | 72,000           | 10,800,000      | 4,143                             | 37,500           | 60,000           | 13,200,000      | 51.0                              | 12                       | 6                            |
| 60,710             | 97,140          | 14,570,000     | 50,000          | 80,000          | 12,000,000     | 50,000           | 80,000           | 12,000,000      | 4,619                             | 41,670           | 66,700           | 14,800,000      | 54.0                              | 12                       | 6                            |

(a) The return tapping sizes shown for boilers having 129 to 500 sq ft heating surface, inclusive, are adequate for forced hot water.

(b) Bituminous Stoker-Fired. Does not apply to Scotch Type Boilers.

(c) Oil, gas or bituminous stoker-fired coal. Minimum furnace volumes for anthracite, stoker-fired, are not specified in this code.

(d) Does not apply to Scotch Type Boilers.

(e) Does not apply to high pressure boilers.

Note: Scotch Type Boilers may be cataloged in sizes having 50 sq ft minimum heating surface with 7.2 cu ft minimum furnace volume, and 90 sq ft minimum heating surface with 11.9 cu ft minimum furnace volume.

ciency, the draft loss through the boiler, and the heat release in the combustion chamber are subjected to limitation by the code.<sup>5</sup> Oil-fired boiler ratings are established by tests using gun-type oil burners and commercial grade No. 2 fuel oil. Stoker-fired ratings are based on the *Gross I=B=R Output* obtained by oil-fired tests. Gas-fired ratings for boilers having gross outputs greater than 300,000 Btu per hour, where no *A.G.A. Rating* is published, are based on the *Gross I=B=R Output* obtained by oil-fired tests. Gas-fired ratings for boilers having gross outputs less than 300,000 Btu per hour, where no *A.G.A. Rating* is published, are established by gas-fired tests with atmospheric, single-port-type burners using natural or manufactured gas or a mixture of these two

TABLE 2. SBI NET RATING DATA FOR Table 2 STEEL BOILERS—OIL-FIRED<sup>a</sup>

| SBI NET RATING |             | MINIMUM FURNACE<br>VOLUME Cu Ft | MINIMUM HEATING<br>SURFACE Sq Ft |
|----------------|-------------|---------------------------------|----------------------------------|
| Steam          | Water Btuh  |                                 |                                  |
| Sq Ft<br>(1)   | Btuh<br>(2) | (3)                             | (4)                              |
| 275            | 66,000      | 74,000                          | 2.5                              |
| 320            | 77,000      | 87,000                          | 2.9                              |
| 400            | 96,000      | 108,000                         | 3.6                              |
| 550            | 132,000     | 149,000                         | 5.0                              |
| 700            | 168,000     | 189,000                         | 6.4                              |
| 900            | 216,000     | 243,000                         | 8.2                              |
| 1100           | 264,000     | 297,000                         | 10.0                             |
| 1300           | 312,000     | 351,000                         | 11.8                             |
| 1500           | 360,000     | 405,000                         | 13.6                             |
| 1800           | 432,000     | 486,000                         | 16.4                             |
| 2200           | 528,000     | 594,000                         | 20.0                             |
| 2600           | 624,000     | 702,000                         | 23.6                             |
| 3000           | 720,000     | 810,000                         | 27.3                             |
| 3500           | 840,000     | 945,000                         | 31.8                             |
| 4000           | 960,000     | 1,080,000                       | 36.3                             |
| 4500           | 1,080,000   | 1,215,000                       | 40.9                             |
| 5000           | 1,200,000   | 1,350,000                       | 45.4                             |

<sup>a</sup> Stoker-Fired and Gas-Fired SBI Net Rating not greater than oil-fired ratings. Hand-Fired Net SBI Rating (Steam) not greater than 14 times the square feet of heating surface.

gases. The *A.G.A. Output Rating* of a gas-designed boiler may be used in determining the *Net I=B=R Rating*.

The *Net I=B=R Rating* is determined from the *Gross I=B=R Output* by applying specified *Piping and Pickup Factors* which range from 2.36 to 1.40 for hand-fired boilers, and from 1.56 to 1.288 for automatically-fired steam boilers, and from 1.333 to 1.288 for automatically-fired hot water boilers. In all cases, the factor decreases as the boiler size increases. Table 3 is abstracted from the 1951 *I=B=R Boiler Rating Tables* in the code and illustrates the relationship between *Net I=B=R Rating* and *Gross I=B=R Output*.

The *American Gas Association* rates gas-designed boilers at 80 percent of the *A.G.A. Input Rating*. These ratings are determined by performance tests described in the *A.G.A. Approval Requirements for Central Heating Appliances*.

The *Heating, Piping and Air Conditioning Contractors National Association* has adopted a method, based on their physical characteristics for

TABLE 3. I=B=R BOILER RATING TABLE<sup>a</sup>

| HAND-FIRED                                  |                                |                |                   |                                   |                                               |                                               |                                                 |                                             |                         | AUTOMATIC-FIRED |             |                             |       |                                                 |                                                |  |  |  |  |
|---------------------------------------------|--------------------------------|----------------|-------------------|-----------------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------------|---------------------------------------------|-------------------------|-----------------|-------------|-----------------------------|-------|-------------------------------------------------|------------------------------------------------|--|--|--|--|
| Gross<br><i>I=B=R</i><br>Output<br>1000 Btu | Net <i>I=B=R</i> Rating        |                |                   | Piping<br>and<br>Pickup<br>Factor | Time<br>Available<br>Fuel<br>Will Last,<br>Hr | Maximum<br>Stack<br>Height <sup>a</sup><br>Fe | Minimum<br>Stack<br>Area <sup>b</sup><br>Sq In. | Gross<br><i>I=B=R</i><br>Output<br>1000 Btu | Net <i>I=B=R</i> Rating |                 |             | Piping and<br>Pickup Factor |       | Minimum<br>Stack<br>Area <sup>b</sup><br>Sq In. | Maximum<br>Allowable<br>Draft Loss<br>In. W.G. |  |  |  |  |
|                                             | Steam and<br>water<br>1000 Btu | Steam<br>Sq Ft | Water<br>1000 Btu |                                   |                                               |                                               |                                                 |                                             | Steam<br>1000 Btu       | Sq Ft           | Water<br>12 | Steam<br>13                 |       |                                                 |                                                |  |  |  |  |
|                                             |                                |                |                   |                                   |                                               |                                               |                                                 |                                             |                         |                 |             |                             |       |                                                 |                                                |  |  |  |  |
| 57                                          | 24                             | 100            | 2.360             | 7.50                              | 29.0                                          | 50                                            | 37                                              | 28                                          | 9                       | 10              | 11          | 12                          | 13    | 15                                              | 0.044                                          |  |  |  |  |
| 215                                         | 96                             | 400            | 2.168             | 6.33                              | 38.5                                          | 60                                            | 146                                             | 110                                         | 24                      | 24              | 100         | 1.333                       | 1.560 | 60                                              | 0.083                                          |  |  |  |  |
| 359                                         | 168                            | 700            | 2.039             | 5.73                              | 42.0                                          | 64                                            | 261                                             | 188                                         | 96                      | 96              | 400         | 1.333                       | 1.525 | 50                                              | 0.073                                          |  |  |  |  |
| 489                                         | 240                            | 1000           | 1.987             | 5.33                              | 46.0                                          | 62                                            | 352                                             | 284                                         | 240                     | 240             | 1000        | 1.333                       | 1.465 | 52                                              | 0.072                                          |  |  |  |  |
| 614                                         | 312                            | 1300           | 1.914             | 4.93                              | 49.0                                          | 60                                            | 451                                             | 358                                         | 312                     | 312             | 1300        | 1.333                       | 1.444 | 73                                              | 0.084                                          |  |  |  |  |
| 735                                         | 384                            | 1600           | 1.872             | 4.73                              | 52.0                                          | 58                                            | 547                                             | 410                                         | 384                     | 384             | 1600        | 1.333                       | 1.424 | 95                                              | 0.098                                          |  |  |  |  |
| 854                                         | 456                            | 1900           | 1.837             | 4.49                              | 54.5                                          | 56                                            | 643                                             | 482                                         | 456                     | 456             | 1900        | 1.333                       | 1.408 | 115                                             | 0.108                                          |  |  |  |  |
| 974                                         | 528                            | 2200           | 1.805             | 4.34                              | 56.5                                          | 55                                            | 736                                             | 553                                         | 528                     | 528             | 2200        | 1.333                       | 1.394 | 135                                             | 0.116                                          |  |  |  |  |
| 1093                                        | 600                            | 2500           | 1.774             | 4.24                              | 59.0                                          | 53                                            | 829                                             | 623                                         | 600                     | 600             | 2500        | 1.333                       | 1.382 | 155                                             | 0.130                                          |  |  |  |  |
| 1213                                        | 672                            | 2800           | 1.744             | 4.15                              | 61.0                                          | 51                                            | 920                                             | 690                                         | 672                     | 672             | 2800        | 1.333                       | 1.369 | 173                                             | 0.141                                          |  |  |  |  |
| 1333                                        | 744                            | 3100           | 1.717             | 4.07                              | 63.0                                          | 49                                            | 1011                                            | 758                                         | 744                     | 744             | 3100        | 1.333                       | 1.359 | 192                                             | 0.152                                          |  |  |  |  |
| 1451                                        | 816                            | 3400           | 1.691             | 4.00                              | 64.5                                          | 47                                            | 1101                                            | 826                                         | 816                     | 816             | 3400        | 1.333                       | 1.349 | 211                                             | 0.162                                          |  |  |  |  |
| 1569                                        | 888                            | 3700           | 1.664             | 4.00                              | 66.5                                          | 46                                            | 1199                                            | 892                                         | 888                     | 888             | 3700        | 1.333                       | 1.339 | 230                                             | 0.172                                          |  |  |  |  |
| 1688                                        | 960                            | 4000           | 1.634             | 4.00                              | 68.5                                          | 45                                            | 1296                                            | 960                                         | 960                     | 960             | 4000        | 1.331                       | 1.331 | 249                                             | 0.182                                          |  |  |  |  |
| 1806                                        | 1032                           | 4300           | 1.605             | 4.00                              | 70.0                                          | 44                                            | 1392                                            | 1026                                        | 1032                    | 1032            | 4300        | 1.320                       | 1.320 | 274                                             | 0.192                                          |  |  |  |  |
| 1925                                        | 1104                           | 4600           | 1.577             | 4.00                              | 71.5                                          | 42                                            | 1488                                            | 1092                                        | 1104                    | 1104            | 4600        | 1.310                       | 1.310 | 297                                             | 0.206                                          |  |  |  |  |
| 2043                                        | 1176                           | 4900           | 1.552             | 4.00                              | 73.0                                          | 41                                            | 1584                                            | 1158                                        | 1176                    | 1176            | 4900        | 1.301                       | 1.301 | 318                                             | 0.212                                          |  |  |  |  |
| 2161                                        | 1248                           | 5200           | 1.526             | 4.00                              | 74.5                                          | 39                                            | 1679                                            | 1224                                        | 1248                    | 1248            | 5200        | 1.294                       | 1.294 | 339                                             | 0.218                                          |  |  |  |  |
| 2279                                        | 1320                           | 5500           | 1.500             | 4.00                              | 76.0                                          | 40                                            | 1788                                            | 1290                                        | 1320                    | 1320            | 5500        | 1.290                       | 1.290 | 359                                             | 0.224                                          |  |  |  |  |
| 2397                                        | 1392                           | 5800           | 1.474             | 4.00                              | 77.5                                          | 38                                            | 1888                                            | 1356                                        | 1392                    | 1392            | 5800        | 1.288                       | 1.288 | 377                                             | 0.230                                          |  |  |  |  |
| 2515                                        | 1464                           | 6100           | 1.448             | 4.00                              | 79.0                                          | 37                                            | 1992                                            | 1422                                        | 1464                    | 1464            | 6100        | 1.288                       | 1.288 | 395                                             | 0.236                                          |  |  |  |  |
| 2633                                        | 1536                           | 6400           | 1.422             | 4.00                              | 80.5                                          | 36                                            | 2104                                            | 1488                                        | 1536                    | 1536            | 6400        | 1.288                       | 1.288 | 408                                             | 0.242                                          |  |  |  |  |
| 2751                                        | 1608                           | 6700           | 1.396             | 4.00                              | 81.5                                          | 34                                            | 2216                                            | 1554                                        | 1608                    | 1608            | 6700        | 1.288                       | 1.288 | 428                                             | 0.248                                          |  |  |  |  |
| 2869                                        | 1680                           | 7000           | 1.370             | 4.00                              | 83.0                                          | 33                                            | 2318                                            | 1620                                        | 1680                    | 1680            | 7000        | 1.288                       | 1.288 | 448                                             | 0.254                                          |  |  |  |  |
| 2987                                        | 1752                           | 7300           | 1.344             | 4.00                              | 84.5                                          | 31                                            | 2420                                            | 1686                                        | 1752                    | 1752            | 7300        | 1.288                       | 1.288 | 468                                             | 0.260                                          |  |  |  |  |
| 3105                                        | 1824                           | 7600           | 1.318             | 4.00                              | 86.0                                          | 30                                            | 2522                                            | 1752                                        | 1824                    | 1824            | 7600        | 1.288                       | 1.288 | 488                                             | 0.266                                          |  |  |  |  |
| 3223                                        | 1896                           | 7900           | 1.292             | 4.00                              | 87.5                                          | 28                                            | 2624                                            | 1818                                        | 1896                    | 1896            | 7900        | 1.288                       | 1.288 | 508                                             | 0.272                                          |  |  |  |  |
| 3341                                        | 1968                           | 8200           | 1.266             | 4.00                              | 89.0                                          | 27                                            | 2726                                            | 1884                                        | 1968                    | 1968            | 8200        | 1.288                       | 1.288 | 528                                             | 0.278                                          |  |  |  |  |
| 3459                                        | 2040                           | 8500           | 1.240             | 4.00                              | 90.5                                          | 25                                            | 2828                                            | 1950                                        | 2040                    | 2040            | 8500        | 1.288                       | 1.288 | 548                                             | 0.284                                          |  |  |  |  |
| 3577                                        | 2112                           | 8800           | 1.214             | 4.00                              | 92.0                                          | 24                                            | 2930                                            | 2016                                        | 2112                    | 2112            | 8800        | 1.288                       | 1.288 | 568                                             | 0.290                                          |  |  |  |  |
| 3695                                        | 2184                           | 9100           | 1.188             | 4.00                              | 93.5                                          | 22                                            | 3032                                            | 2082                                        | 2184                    | 2184            | 9100        | 1.288                       | 1.288 | 588                                             | 0.296                                          |  |  |  |  |
| 3813                                        | 2256                           | 9400           | 1.162             | 4.00                              | 95.0                                          | 21                                            | 3134                                            | 2148                                        | 2256                    | 2256            | 9400        | 1.288                       | 1.288 | 608                                             | 0.302                                          |  |  |  |  |
| 3931                                        | 2328                           | 9700           | 1.136             | 4.00                              | 96.5                                          | 19                                            | 3236                                            | 2214                                        | 2328                    | 2328            | 9700        | 1.288                       | 1.288 | 628                                             | 0.308                                          |  |  |  |  |
| 4049                                        | 2400                           | 10000          | 1.110             | 4.00                              | 98.0                                          | 18                                            | 3338                                            | 2280                                        | 2400                    | 2400            | 10000       | 1.288                       | 1.288 | 648                                             | 0.314                                          |  |  |  |  |
| 4167                                        | 2472                           | 10300          | 1.084             | 4.00                              | 99.5                                          | 16                                            | 3440                                            | 2346                                        | 2472                    | 2472            | 10300       | 1.288                       | 1.288 | 668                                             | 0.320                                          |  |  |  |  |
| 4285                                        | 2544                           | 10600          | 1.058             | 4.00                              | 101.0                                         | 15                                            | 3542                                            | 2412                                        | 2544                    | 2544            | 10600       | 1.288                       | 1.288 | 688                                             | 0.326                                          |  |  |  |  |
| 4403                                        | 2616                           | 10900          | 1.032             | 4.00                              | 102.5                                         | 14                                            | 3644                                            | 2478                                        | 2616                    | 2616            | 10900       | 1.288                       | 1.288 | 708                                             | 0.332                                          |  |  |  |  |
| 4521                                        | 2688                           | 11200          | 1.006             | 4.00                              | 104.0                                         | 12                                            | 3746                                            | 2544                                        | 2688                    | 2688            | 11200       | 1.288                       | 1.288 | 728                                             | 0.338                                          |  |  |  |  |
| 4639                                        | 2760                           | 11500          | 0.980             | 4.00                              | 105.5                                         | 11                                            | 3848                                            | 2610                                        | 2760                    | 2760            | 11500       | 1.288                       | 1.288 | 748                                             | 0.344                                          |  |  |  |  |
| 4757                                        | 2832                           | 11800          | 0.954             | 4.00                              | 107.0                                         | 10                                            | 3950                                            | 2676                                        | 2832                    | 2832            | 11800       | 1.288                       | 1.288 | 768                                             | 0.350                                          |  |  |  |  |
| 4875                                        | 2904                           | 12100          | 0.928             | 4.00                              | 108.5                                         | 9                                             | 4052                                            | 2742                                        | 2904                    | 2904            | 12100       | 1.288                       | 1.288 | 788                                             | 0.356                                          |  |  |  |  |
| 4993                                        | 2976                           | 12400          | 0.902             | 4.00                              | 110.0                                         | 8                                             | 4154                                            | 2808                                        | 2976                    | 2976            | 12400       | 1.288                       | 1.288 | 808                                             | 0.362                                          |  |  |  |  |
| 5111                                        | 3048                           | 12700          | 0.876             | 4.00                              | 111.5                                         | 7                                             | 4256                                            | 2874                                        | 3048                    | 3048            | 12700       | 1.288                       | 1.288 | 828                                             | 0.368                                          |  |  |  |  |
| 5229                                        | 3120                           | 13000          | 0.850             | 4.00                              | 113.0                                         | 6                                             | 4358                                            | 2940                                        | 3120                    | 3120            | 13000       | 1.288                       | 1.288 | 848                                             | 0.374                                          |  |  |  |  |
| 5347                                        | 3192                           | 13300          | 0.824             | 4.00                              | 114.5                                         | 5                                             | 4460                                            | 3006                                        | 3192                    | 3192            | 13300       | 1.288                       | 1.288 | 868                                             | 0.380                                          |  |  |  |  |
| 5465                                        | 3264                           | 13600          | 0.798             | 4.00                              | 116.0                                         | 4                                             | 4562                                            | 3072                                        | 3264                    | 3264            | 13600       | 1.288                       | 1.288 | 888                                             | 0.386                                          |  |  |  |  |
| 5583                                        | 3336                           | 13900          | 0.772             | 4.00                              | 117.5                                         | 3                                             | 4664                                            | 3138                                        | 3336                    | 3336            | 13900       | 1.288                       | 1.288 | 908                                             | 0.392                                          |  |  |  |  |
| 5701                                        | 3408                           | 14200          | 0.746             | 4.00                              | 119.0                                         | 2                                             | 4766                                            | 3204                                        | 3408                    | 3408            | 14200       | 1.288                       | 1.288 | 928                                             | 0.398                                          |  |  |  |  |
| 5819                                        | 3480                           | 14500          | 0.720             | 4.00                              | 120.5                                         | 1                                             | 4868                                            | 3270                                        | 3480                    | 3480            | 14500       | 1.288                       | 1.288 | 948                                             | 0.404                                          |  |  |  |  |
| 5937                                        | 3552                           | 14800          | 0.694             | 4.00                              | 122.0                                         | 0                                             | 4970                                            | 3336                                        | 3552                    | 3552            | 14800       | 1.288                       | 1.288 | 968                                             | 0.410                                          |  |  |  |  |
| 6055                                        | 3624                           | 15100          | 0.668             | 4.00                              | 123.5                                         | 0                                             | 5072                                            | 3402                                        | 3624                    | 3624            | 15100       | 1.288                       | 1.288 | 988                                             | 0.416                                          |  |  |  |  |
| 6173                                        | 3696                           | 15400          | 0.642             | 4.00                              | 125.0                                         | 0                                             | 5174                                            | 3468                                        | 3696                    | 3696            | 15400       | 1.288                       | 1.288 | 1008                                            | 0.422                                          |  |  |  |  |
| 6291                                        | 3768                           | 15700          | 0.616             | 4.00                              | 126.5                                         | 0                                             | 5276                                            | 3534                                        | 3768                    | 3768            | 15700       | 1.288                       | 1.288 | 1028                                            | 0.428                                          |  |  |  |  |
| 6409                                        | 3840                           | 16000          | 0.590             | 4.00                              | 128.0                                         | 0                                             | 5378                                            | 3600                                        | 3840                    | 3840            | 16000       | 1.288                       | 1.288 | 1048                                            | 0.434                                          |  |  |  |  |
| 6527                                        | 3912                           | 16300          | 0.564             | 4.00                              | 129.5                                         | 0                                             | 5480                                            | 3666                                        | 3912                    | 3912            | 16300       | 1.288                       | 1.288 | 1068                                            | 0.440                                          |  |  |  |  |
| 6645                                        | 3984                           | 16600          | 0.538             | 4.00                              | 131.0                                         | 0                                             | 5582                                            | 3732                                        | 3984                    | 3984            | 16600       | 1.288                       | 1.288 | 1088                                            | 0.446                                          |  |  |  |  |
| 6763                                        | 4056                           | 16900          | 0.512             | 4.00                              | 132.5                                         | 0                                             | 5684                                            | 3798                                        | 4056                    | 4056            | 16900       | 1.288                       | 1.288 | 1108                                            | 0.452                                          |  |  |  |  |
| 6881                                        | 4128                           | 17200          | 0.486             | 4.00                              | 134.0                                         | 0                                             | 5786                                            | 3864                                        | 4128                    | 4128            | 17200       | 1.288                       | 1.288 | 1128                                            | 0.458                                          |  |  |  |  |
| 6999                                        | 4200                           | 17500          | 0.460             | 4.00                              | 135.5                                         | 0                                             | 5888                                            | 3930                                        | 4200                    | 4200            | 17500       | 1.288                       | 1.288 | 1148                                            | 0.464                                          |  |  |  |  |
| 7117                                        | 4272                           | 17800          | 0.434             | 4.00                              | 137.0                                         | 0                                             | 5990                                            | 3996                                        | 4272                    | 4272            | 17800       | 1.288                       | 1.288 | 1168                                            | 0.470                                          |  |  |  |  |
| 7235                                        | 4344                           | 18100          | 0.408             | 4.00                              | 138.5                                         | 0                                             | 6092                                            | 4062                                        | 4344                    | 4344            | 18100       | 1.288                       | 1.288 | 1188                                            | 0.476                                          |  |  |  |  |
| 7353                                        | 4416                           | 18400          | 0.382             | 4.00                              | 140.0                                         | 0                                             | 6194                                            | 4128                                        | 4416                    | 4416            | 18400       | 1.288                       | 1.288 | 1208                                            | 0.482                                          |  |  |  |  |
| 7471                                        | 4488                           | 18700          | 0.356             | 4.00                              | 141.5                                         | 0                                             | 6296                                            | 4194                                        | 4488                    | 4488            | 18700       | 1.288                       | 1.288 | 1228                                            | 0.488                                          |  |  |  |  |
| 7589                                        | 4560                           | 19000          | 0.330             | 4.00                              | 143.0                                         | 0                                             | 6398                                            | 4260                                        | 4560                    | 4560            | 19000       | 1.288                       | 1.288 | 1248                                            | 0.494                                          |  |  |  |  |
| 7707                                        | 4632                           | 19300          | 0.304             | 4.00                              | 144.5                                         | 0                                             | 6500                                            | 4326                                        | 4632                    | 4632            | 19300       | 1.288                       | 1.288 | 1268                                            | 0.500                                          |  |  |  |  |
| 7825                                        | 4704                           | 19600          | 0.278             | 4.00                              | 146.0                                         | 0                                             | 6602                                            | 4392                                        | 4704                    | 4704            | 19600       | 1.288                       | 1.288 | 1288                                            | 0.506                                          |  |  |  |  |
| 7943                                        | 4776                           | 19900          | 0.252             | 4.00                              | 147.5                                         | 0                                             | 6704                                            | 4458                                        | 4776                    | 4776            | 19900       | 1.288                       | 1.288 | 1308                                            | 0.512                                          |  |  |  |  |
| 8061                                        | 4848                           | 20200          | 0.226             | 4.00                              | 149.0                                         | 0                                             | 6806                                            | 4524                                        | 4848                    | 4848            | 20200       | 1.288                       | 1.288 | 1328                                            | 0.518                                          |  |  |  |  |
| 8179                                        | 4920                           | 20500          | 0.200             | 4.00                              | 150.5                                         | 0                                             | 6908                                            | 4590                                        | 4920                    | 4920            | 20500       | 1.288                       | 1.288 | 1348                                            | 0.524                                          |  |  |  |  |
| 8297                                        | 4992                           | 20800          | 0.174             | 4.00                              | 152.0                                         | 0                                             | 7010                                            | 4656                                        | 4992                    | 4992            | 20800       | 1.288                       | 1.288 | 1368                                            | 0.530                                          |  |  |  |  |
| 8415                                        | 5064                           | 21100          | 0.148             | 4.00                              | 153.5                                         | 0                                             | 7112                                            | 4722                                        | 5064                    | 5064            | 21100       | 1.288                       | 1.288 | 1388                                            | 0.536                                          |  |  |  |  |
| 8533                                        | 5136                           | 21400          | 0.122             | 4.00                              | 155.0                                         | 0                                             | 7214                                            | 4788                                        | 5136                    | 5136            | 21400       | 1.288                       | 1.288 | 1408                                            | 0.542                                          |  |  |  |  |
| 8651                                        | 5208                           | 21700          | 0.096             | 4.00                              | 156.5                                         | 0                                             | 7316                                            | 4854                                        | 5208                    | 5208            | 21700       | 1.288                       | 1.288 | 1428                                            | 0.548                                          |  |  |  |  |
| 8769                                        | 5280                           | 22000          | 0.070             | 4.00                              | 158.0                                         | 0                                             | 7418                                            | 4920                                        | 5280                    | 5280            | 22000       | 1.288                       | 1.288 | 1448                                            | 0.554                                          |  |  |  |  |
| 8887                                        | 5352                           | 22300          | 0.044             | 4.00                              | 159.5                                         | 0                                             | 7520                                            | 4986                                        | 5352                    | 5352            | 22300       | 1.288                       | 1.288 | 1468                                            | 0.560                                          |  |  |  |  |
| 9005                                        | 5424                           | 22600          | 0.018             | 4.00                              | 161.0                                         | 0                                             | 7622                                            | 5052                                        | 5424                    | 5424            | 22600       | 1.288                       | 1.288 | 1488                                            | 0.566                                          |  |  |  |  |
| 9123                                        | 5496                           | 22900          | 0.000             | 4.00                              | 162.5                                         | 0                                             | 7724                                            | 5118                                        | 5496                    | 5496            | 22900       | 1.288                       | 1.288 | 1508                                            | 0.572                                          |  |  |  |  |
| 9241                                        | 5568                           | 23200          | 0.000             | 4.00                              | 164.0                                         | 0                                             | 7826                                            | 5184                                        | 5568                    | 5568            | 23200       | 1.288                       | 1.288 | 1528                                            | 0.578                                          |  |  |  |  |
| 9359                                        | 5640                           | 23500          | 0.000             | 4.00                              | 165.5                                         | 0                                             | 7928                                            | 5250                                        | 5640                    | 5640            | 23500       | 1.288                       | 1.288 | 1548                                            | 0.584                                          |  |  |  |  |
| 9477                                        | 5712                           | 23800          | 0.000             | 4.00                              | 167.0                                         | 0                                             | 8030                                            | 5316                                        | 5712                    | 5712            | 23800       | 1.288                       | 1.288 | 1568                                            | 0.590                                          |  |  |  |  |
| 9595                                        | 5784                           | 24100          | 0.000             |                                   |                                               |                                               |                                                 |                                             |                         |                 |             |                             |       |                                                 |                                                |  |  |  |  |

rating boilers that are not rated in accordance with the *SBI* or  $I=B=R$  Codes. Ratings are expressed on a Net Load basis in square feet of steam radiation.

The *HP&ACCNA*, has also adopted a *Testing and Rating Code for Boiler-Burner Units*.<sup>6</sup> The purpose of this Code is to provide a basis of rating commercial sizes of steel heating boiler-burner units fired with oil or gas fuel. This code allows a higher rating than is permissible under the *SBI* Code. A gross output is established with certain limiting factors applying to flue gas temperature, carbon dioxide, efficiency and quality of steam. This output is divided by 1.5 to determine the *net rating*.

### BOILER EFFICIENCY

The term efficiency, as used for guarantee of boiler performance, is usually construed as follows:

1. *Solid Fuels*. The efficiency of the boiler alone is the ratio of the heat absorbed by the water and steam in the boiler per pound of combustible burned on the grate, to the calorific value of 1 lb of combustible as fired. The combined efficiency of boiler, furnace and grate is the ratio of the heat absorbed by the water and steam in the boiler per pound of fuel as fired, to the calorific value of 1 lb of fuel as fired.

2. *Liquid and Gaseous Fuels*. The combined efficiency of boiler, furnace and burner is the ratio of the heat absorbed by the water and steam in the boiler per pound or cubic foot of fuel, to the calorific value of 1 lb or cubic foot of fuel, respectively.

The following efficiencies apply to current designs of boilers operated under favorable conditions at their gross output ratings. Some older boilers, designed primarily for hand firing, may have lower efficiencies when automatically fired.

|                                   |                  |
|-----------------------------------|------------------|
| Anthracite, hand-fired .....      | 60 to 75 percent |
| Bituminous coal, hand-fired ..... | 50 to 65 percent |
| Stoker-fired .....                | 60 to 75 percent |
| Oil and gas-fired .....           | 70 to 80 percent |

Higher efficiencies for hand-fired bituminous coal may be obtained by careful firing of either a regular or a smokeless boiler.

### RATING OF BOILERS

In referring to boiler rating, it is necessary to know the basis on which the rating has been established in order to understand the exact meaning of the term. The following example will illustrate the meaning of three ratings which might be established for the same boiler.

Assume that an installation has the following loads determined in accordance with the section *Selection of Boilers*:

|                             |                               |
|-----------------------------|-------------------------------|
| Net Load .....              | 1000 sq ft of steam radiation |
| Piping Tax .....            | 200 sq ft of steam radiation  |
| Design Load .....           | 1200 sq ft of steam radiation |
| Pickup Allowance .....      | 240 sq ft of steam radiation  |
| Maximum or Gross Load ..... | 1440 sq ft of steam radiation |

A boiler that is just large enough to carry this system might be said to have a *net load* rating of 1000 sq ft, a *design load* rating of 1200 sq ft, or a *gross load* rating of 1440 sq ft, depending on the basis on which the boiler is rated.

On a *net load* basis the boiler would be rated 1000 sq ft of steam radiation and would have sufficient excess capacity to supply the *normal piping* and *pickup load*. Net  $I=B=R$  Ratings, *SBI* Net Ratings, and Net Load

Ratings of the *Heating, Piping and Air Conditioning Contractors National Association* are established on this basis.

On a *design load* basis the boiler would be rated 1200 sq ft of steam radiation and would have sufficient excess capacity to supply the *pickup load*. It would be of adequate size for a system in which the sum of the *net load* and the *piping heat loss* did not exceed 1200 sq ft of steam radiation. The *SBI* Ratings shown in columns 1, 2, 3, 10, 11 and 12 of Table 1 (not to be confused with *SBI* Net Rating) are established on a *design load* basis.

On a *gross output* basis of rating, the boiler would be rated 1440 sq ft of steam radiation and would be of adequate size for a system in which the sum of the *net load*, *piping load*, and *pickup load* did not exceed 1440 sq ft of steam radiation. Gross  $I=B=R$  Output and A.G.A. Ratings are established on a *gross output* basis.

In the determination of boiler ratings, the *Gross Output* is the quantity of heat available at the boiler nozzle, with the boiler normally insulated and when operating under limitations stipulated in the code or method by which the boiler is rated. The boiler may be capable of producing a greater nozzle output, but in doing so would exceed some of these limitations.

### SELECTION OF BOILERS

#### General Factors

The *Maximum Load* or *Gross Load* on the boiler is the sum of the four following items.

The *Design Load* is the sum of items 1, 2, and 3.

The *Net Load* is the sum of items 1 and 2.

1. *Radiation Load*. The estimated heat emission in Btu per hour of the connected radiation (direct, indirect, or forced convection coils) to be installed.

The connected radiation is determined by calculating the heat losses for each room in accordance with data given in Chapters 9, 11 and 12. The sum of the calculated heat losses for all the rooms represents the total required heat emission of the connected radiation, expressed in Btu per hour. As practically all boilers are now rated on a Btu basis, it is unnecessary to convert the radiation load to square feet of equivalent direct radiation.

2. *Hot Water Supply Load*. The estimated maximum heat in Btu per hour required to heat water for domestic use.

$I=B=R$  recommends that allowance for hot water supply load be made only for bathrooms in excess of two, as follows: Instantaneous Coil 12,000 Btu per hour, and for Storage Tank installation 120 Btu per (hour) (gallon of tank capacity). For instantaneous coil installations the boiler capacity should not be less than required to heat 2 to 3 gal of water, 100 deg per min. See also Chapter 49.

3. *Piping Tax*. The estimated heat emission in Btu per hour of the piping connecting the radiation and other apparatus to the boiler.

As the heating industry as a whole is not entirely agreed upon piping tax allowances for different sizes of installations, it is better to compute the heat emission from both bare and covered pipe surface in accordance with data in Chapter 28. In average house heating systems, it is common practice to consider the piping tax to be equal to 25 percent of the Net Load. In determining Net  $I=B=R$  Ratings from Gross  $I=B=R$  Output, the piping factor allowed varies from 30 percent for small boilers to 12 percent for larger boilers.

4. *Warming-Up or Pick-Up Allowance*. The estimated increase in the normal load in Btu per hour caused by the heating up of the cold system.

The warming-up allowance represents the load due to heating the boiler and contents to operating temperature, and heating up cold radiation and piping.

Other items to be considered in boiler selection are as follows:



- a. Efficiency with hard or soft coal, gas, or oil firing, as the case may be.
- b. Grate area with hand fired coal, or fuel burning rate with stokers, oil, or gas
- c. Combustion space in the furnace.
- d. Type of heat liberation, whether continuous or intermittent, or a combination of both.
- e. Convenience in firing and cleaning.
- f. Adaptability to changes in fuel and kind of attention.
- g. Height of water line.
- h. Miscellaneous items such as draft available, possibility of future extension, possibility of break-down, and head room in the boiler room.
- i. The most economical size of boiler is usually one that is just the right size for the load. Either larger or smaller boilers may be less economical.

### Cast-Iron Boilers

*Net load* ratings of cast-iron boilers are usually available from manufacturers' catalogs. They may also be obtained conveniently from published tables of  $I=B=R$  ratings,<sup>7</sup> or from recommendations of the *Heating, Piping and Air Conditioning Contractors National Association*,<sup>8</sup> and can be used in selection of boilers, unless the heating system contains an unusual amount of bare pipe, or the nature of the connected load is such that the normal allowances for pipe loss and pickup do not apply. In such a case, the selection must be based on the gross output.

### Steel Heating Boilers

*SBI* catalog ratings, in accordance with the previously mentioned *Steel Boiler Institute* code, are intended to correspond with the estimated *design load*. When the heat emission of the piping is not known, the net load to be considered for the boiler may be determined from Tables 1 and 2. The difference between design load and net load represents an amount which is considered normal for piping loss of the ordinary heating system.

Boilers with less than 294 sq ft of heating surface and having *SBI* net ratings (steam) of not more than 5000 sq ft if mechanically fired and 4120 sq ft if hand-fired, are classified as *Table 2 Steel Boilers*, formerly Residential boilers. An insulated *Table 2 boiler* for oil, gas, or stoker firing may carry a *net load* expressed in square feet of steam radiation of not more than seventeen times the square feet of heating surface in the boiler, provided the boiler has been tested in accordance with the *SBI* Code for testing oil-fired steel boilers at output rates of 125, 150 and 175 percent of the steam *SBI* net rating. The *SBI* net rating for a water boiler, automatically fired, expressed in Btu per hour, is 270 times the Steam *SBI* net rating in square feet. The net water rating is 12½ percent greater than the steam rating because a lower piping and pickup factor is generally required in a water system. The *SBI* net rating (sq ft steam) for hand-fired *Table 2 boilers* is not greater than fourteen times the heating surface. If the heat loss from the piping system exceeds 20 percent of the installed radiation, the excess is to be considered as part of the *net load*.

### Heating Surface and Grate Area Basis

Where neither the *net load* nor *gross output* ratings based upon performance tests are available, a good general rule for conventionally designed boilers is to provide 1 sq ft of boiler heating surface for each 14 sq ft of equivalent radiation (240 Btu per sq ft) (hr) represented by the design

load. This is equivalent to allowing 10 sq ft of boiler heating surface per boiler horsepower. In this case it is assumed that the *maximum load* including the warming-up allowance will be provided for by operating the boiler in excess of the *design load*, that is, in excess of the 100 percent rating on a boiler-horsepower basis. *SBI* ratings for hand firing are based on 10 sq ft of heating surface per boiler horsepower.

Due to the wide variation which may be encountered in manufacturers' ratings for boilers of approximately the same capacity, it is advisable to check the grate area required for heating boilers burning solid fuel by means of the following formula:

$$G = \frac{H}{C \times F \times E} \quad (1)$$

where

$G$  = grate area, square feet.

$H$  = required *gross output* of the boiler, Btu per hour (see Selection of Boilers).

$C$  = desirable combustion rate for fuel selected, pounds of dry coal per square foot of grate per hour (see Table 4).

$F$  = calorific value of fuel, Btu per pound.

$E$  = efficiency of boiler, usually taken as 0.60.

*Example 1:* Determine the grate area for a required *gross output* of the boiler of 500,000 Btu per hour, a combustion rate of 6 lb per hour, a calorific value of 13,000 Btu per pound, and an efficiency of 60 percent.

$$G = \frac{500,000}{6 \times 13,000 \times 0.60} = 10.7 \text{ sq ft}$$

The boiler selected should have a grate area not less than that determined by Equation 1. With small boilers, where it is desired to provide

TABLE 4. PRACTICAL COMBUSTION RATES FOR COAL-FIRED HEATING BOILERS OPERATING AT MAXIMUM LOAD ON NATURAL DRAFT OF FROM ½ IN. TO ¾ IN. WATER\*

| KIND OF COAL               | SQ FT GRATE  | LB OF COAL PER SQ FT GRATE PER HOUR |
|----------------------------|--------------|-------------------------------------|
| No. 1 Buckwheat Anthracite | Up to 4      | 3                                   |
|                            | 5 to 9       | 3½                                  |
|                            | 10 to 14     | 4                                   |
|                            | 15 to 19     | 4½                                  |
|                            | 20 to 25     | 5                                   |
| Anthracite Pea             | Up to 9      | 5                                   |
|                            | 10 to 19     | 5½                                  |
|                            | 20 to 25     | 6                                   |
| Anthracite Nut and Larger  | Up to 4      | 8                                   |
|                            | 5 to 9       | 9                                   |
|                            | 10 to 14     | 10                                  |
|                            | 15 to 19     | 11                                  |
|                            | 20 to 25     | 13                                  |
| Butuminous                 | Up to 4      | 9.5                                 |
|                            | 5 to 14      | 12                                  |
|                            | 15 and above | 15.5                                |

\* Steel boilers usually have higher combustion rates for grate areas exceeding 15 sq ft than those indicated in this table.



sufficient coal capacity for approximately an eight-hour firing period plus a 20 percent reserve for igniting a new charge, more grate area may be required depending upon the depth of the fuel pot.

### Gas-Fired Boilers

After determining the *net load* for the installation, gas designed boilers can usually be selected from manufacturers' tables of *net load ratings* which are based on piping and pickup allowances varying from 56 percent for small steam boilers and 33.3 percent for small hot water boilers to 28.8 percent for very large boilers. If the piping and pickup load or other factors create an unusual load, a boiler should be selected which has an A.G.A. *output rating* equal to the maximum output required. Detailed recommendations for selection of gas designed boilers are given in the A.G.A. publication, *Comfort Heating*.<sup>9</sup>

### SPACE LIMITATIONS

Boiler rooms should, if possible, be situated at a central point with respect to the building, and should be designed for a maximum of natural light. The space in front of the boilers should be sufficient for firing, stoking, ash removal and cleaning or renewal of flue tubes, and should be at least 3 ft greater than the length of the tubes.

A space of at least 3 ft should be allowed on at least one side of every boiler for convenience of erection and for accessibility to the various dampers, cleanouts, and trimmings. The space at the rear of the boiler should be ample for the chimney connection and for cleanouts. With large boilers the rear clearance should be at least 3 ft in width.

The boiler room height should be sufficient for the location of boiler accessories, and for proper installation of piping. In general, the ceiling height for small steam boilers should be at least 3 ft above the normal boiler water line. With vapor heating, especially, the height above the boiler water line is of vital importance.

### CONNECTIONS AND FITTINGS

Steam outlet connections should be the full size of the manufacturers' tappings, in order to keep the velocity of flow through the outlet reasonably low, and to avoid fluctuation of the water line and undue entrainment of moisture, and should extend vertically to the maximum height available above the boiler. A steam velocity in boiler outlets not exceeding 25 to 30 fps at maximum load is recommended, unless data are available to show that a higher velocity is satisfactory. See further data on pipe connections to boilers in Chapters 21 and 22 and in the *ASME Boiler Construction Code for Low Pressure Heating Boilers*.

Where a *return header* is used on a cast-iron sectional boiler to distribute the returns to both rear tappings, it is advisable to provide full size plugged tees instead of elbows where the branch connections enter the return tappings. This aids in cleaning of sludge from the bottom of the boiler sections through the large plugged openings. An equivalent cleanout plug should be provided in the case of a single return connection.

*Blow-off or drain connections* should be made near the boiler, and so arranged that the entire system may be drained of water by opening the drain cock. In the case of two or more boilers separate blow-off connections must be provided for each boiler, on the boiler side of the stop valve on the main return connection.

*Water service connections* must be provided for both steam and water

boilers, for refilling and for the addition of make-up water to boilers. This connection is usually of galvanized steel pipe, and is made to the return main near the boiler or boilers.

Fitting connections for pressure gage piping, water gage connections, and safety valves, should be made in accordance with the *ASME Boiler Construction Code for Low Pressure Heating Boilers*.

*Smoke Breeching and Chimney Connections.* The breeching or smoke pipe from the boiler outlet to the chimney should be air-tight and as short and direct as possible, preference being given to long radius and 45-deg instead of 90-deg bends. The breeching entering a brick chimney should not project beyond the flue lining, and where practicable it should be grouted from the inside of the chimney. A thimble or sleeve usually is provided where the breeching enters a brick chimney.

Where a battery of boilers is connected into a breeching, each boiler should be provided with a tight damper. The breeching for a battery of boilers should not be reduced in size as it goes to the more remote boilers. Good connections made to a good chimney will usually result in a rapid response by the boilers to demands for heat.

### ERECTION, OPERATION, AND MAINTENANCE

The directions of the boiler manufacturer should always be read before the assembly or installation of any boiler is started, even though the contractor may be familiar with the boiler. All joints requiring boiler putty or cement, which cannot be reached after assembly is complete, must be finished as the assembly progresses.

Five precautions that should be taken in all installations to prevent damage to the boiler are:

1. There should be provided proper and convenient drainage connections for use if the boiler is not in operation during freezing weather.
2. Strains on the boiler, due to movement of piping during expansion, should be prevented by suitable anchoring of piping, and by proper provision for pipe expansion and contraction.
3. Direct impingement of too intense local heat upon any part of the boiler surface, as with oil burners, should be avoided by protecting the surface with firebrick or other refractory material.
4. Condensation in steam systems must flow back to the boiler as rapidly and uniformly as possible. Return connections should prevent the water from backing out of the boiler.
5. Automatic boiler feeders and low water cut-off devices which shut off the source of heat if the water in the boiler falls below a safe level, are recommended for mechanically-fired boilers.

### Boiler Troubles

A complaint regarding boiler operation generally will be found to be due to one of the following:

1. *The boiler fails to deliver enough heat.* The cause of this condition may be: (a) poor draft; (b) poor fuel; (c) inferior attention or firing; (d) boiler too small; (e) improper piping; (f) improper arrangement of sections; (g) heating surfaces covered with soot; (h) insufficient radiation installed; and (i) with mechanical firing, fuel burning equipment too small.
2. *The water line is unsteady.* The cause of this condition may be: (a) grease and dirt in boiler; (b) water column connected to a very active section and, therefore, not showing actual water level in boiler; and (c) boiler operating at excessive rate of output.
3. *Water disappears from the gage glass.* This may be caused by: (a) priming due to grease and dirt in boiler; (b) too great pressure difference between supply and

return piping preventing return of condensation; (c) valve closed in return line; (d) connection of bottom of water column into a very active section or thin waterway; and (e) improper connections between boilers in battery permitting boiler with excess pressure to push returning condensation into boiler with lower pressure.

4. *Water is carried over into steam main.* This may be caused by: (a) grease and dirt in boiler; (b) insufficient steam dome or too small steam liberating area; (c) outlet connections of too small area; (d) excessive rate of output; and (e) water level carried higher than specified.

5. *Boiler is slow in response to operation of dampers.* This may be due to: (a) poor draft resulting from air leaks into chimney or breeching; (b) inferior fuel; (c) inferior attention; (d) accumulation of clinker on grate; and (e) boiler too small for the load.

6. *Boiler requires too frequent cleaning of flues.* This may be due to: (a) poor draft; (b) smoky combustion; (c) too low a rate of combustion; and (d) too much excess air in firebox causing chilling of gases.

7. *Boiler smokes through fire door.* This may be due to: (a) defective draft in chimney or incorrect setting of dampers; (b) air leaks into boiler or breeching; (c) gas outlet from firebox plugged with fuel; (d) dirty or clogged flues; and (e) improper reduction in breeching size.

8. *Low carbon dioxide.* This may be due on oil burning boilers to: (a) improper adjustment of the burner; (b) leakage through the boiler setting; (c) improper fire caused by a fouled nozzle; or (d) to an insufficient quantity of oil being burned.

### Cleaning Boilers

All boilers are provided with flue clean-out openings through which the heating surface can be reached by means of brushes or scrapers. Flues of solid fuel boilers should be cleaned often to keep the surfaces free of soot or ash. Gas boiler flues and burners should be cleaned at least once a year. Oil burning boiler flues should be examined periodically to determine when cleaning is necessary.

The grease used to lubricate the cutting tools during erection of new piping systems serves as a carrier for sand and dirt, with the result that a scum of fine particles and grease accumulates on the surface of the water in all new boilers, while heavier particles may settle to the bottom of the boiler and form sludge. These impurities tend to cause foaming, preventing the generation of steam and causing an unsteady water line.

This unavoidable accumulation of oil and grease should be removed by blowing off the boiler as follows: If not already provided, install a surface blow connection of at least 1½ in. nominal pipe size with outlet extended to within 18 in. of the floor or to sewer, inserting a valve in line close to boiler. Bring the water line to center of outlet, raise steam pressure, and while fire is burning briskly open valve in blow-off line. When pressure recedes, close valve and repeat process adding water at intervals to maintain proper level. As a final operation bring the pressure in the boiler to about 10 lb, close blow-off, draw the fire or stop burner, and open drain valve. After boiler has cooled partly, fill and flush out several times before filling it to proper water level for normal service. The use of soda, or any alkali, vinegar or any acid is not recommended for cleaning heating boilers because of the difficulty of complete removal and the possibility of subsequent injury, after the cleaning process has been completed.

Effective insoluble compounds have been developed and are available. Special instructions on the proper cleaning compound and directions for its use, as given by the boiler manufacturer, should be carefully followed.

### Treatment of Boiler Water

Corrosion on the water side of a boiler can be prevented by proper treatment of the boiler water. Generally, treatment which will remove the

dissolved oxygen and carbon dioxide and maintain a minimum pH of 11 (slightly alkaline water) will effectively prevent corrosion. A pH higher than 11 may be used although the boiler water is more likely to foam and cause wet steam with the greater concentration of alkali. A number of compounds are being marketed for this purpose. The *Steel Boiler Institute* adopted a conditioning compound for use with steel boilers after an extensive cooperative study and many members of the Institute either supply this compound with their boilers or have it available.

It should be emphasized that when the character of the water is such that treatment is required, the treatment should be administered immediately after the boiler and system have been cleaned. It is not good practice to fill a boiler with fresh water and allow it to stand idle as the dissolved gases in fresh water available in many localities can start corrosive action in a very short time. After refilling a system it is advisable to elevate the temperature close to the boiling point to drive off the dissolved gases immediately.

### Care of Idle Heating Boilers

Heating boilers are often seriously damaged during summer months due chiefly to corrosion resulting from the combination of sulfur in the soot with the moisture in the cellar air. At the end of the heating season the following precautions should be taken:

1. All heating surfaces should be cleaned thoroughly of soot, ash and residue, and the heating surfaces of steel boilers should be given a coating of lubricating oil on the fire side.
2. All machined surfaces should be coated with oil or grease.
3. Connections to the chimney should be cleaned, and in case of small boilers, the pipe should be placed in a dry place after cleaning.
4. If there is much moisture in the boiler room, it is desirable to drain the boiler to prevent atmospheric condensation on the heating surfaces of the boiler when they are below the dew-point temperature. Due to the hazard that some one may inadvertently build a fire in a dry boiler, however, it is safer to keep the boiler filled with water, particularly in residential installations. Air can be excluded from a steam boiler by raising the water level into the steam outlets. A hot water system usually is left filled to the expansion tank.
5. The grates and ashpit should be cleaned.
6. Clean and repack the gage glass if necessary.
7. Remove any rust or other deposit from exposed surfaces by scraping with a wire brush or sandpaper. After boiler is thoroughly cleaned, apply a coat of preservative paint where required to external parts normally painted.
8. Inspect all accessories of the boiler carefully to see that they are in good working order. In this connection, oil all door hinges, damper bearings, and regulator parts.
9. If a system has been drained and refilled with fresh water, the boiler should be fired long enough to elevate the water temperature close to the boiling point to drive off dissolved oxygen and carbon dioxide. These gases can be responsible for excessive corrosion if allowed to remain in the system.

### WARM AIR FURNACES

Warm air heating furnaces of a number of types and a wide range of sizes are listed and illustrated in the *Catalog Data Section*.

Warm air furnaces may be classified in several different ways:

1. According to method of heat distribution—these are either gravity or mechanical (blower) furnaces.

2. According to fuels for which the furnaces are designed—these are coal hand-fired or stoker-fired, oil, gas, or wood.

3. According to materials of construction—they are cast-iron, low carbon steel, and occasionally high temperature steel alloys.

4. According to design or construction, such as drum and radiator, tubular, horizontal, etc.

### Gravity Warm Air Furnaces

A gravity furnace is one in which the motive head producing air flow depends upon the difference in density between the heated air leaving the top of the casing and cooled air entering the bottom of the casing. Since this gravity head is relatively low, the furnace must have low internal resistance to the flow of air, and relatively large areas must be available for free circulation within the furnace casing. It is common practice to provide approximately 50 percent free air area through gravity type furnaces.

Furnaces for gravity type systems are available in designs suitable for central heating, pipeless furnace, or unit floor furnace installations. Booster fans are sometimes used in conjunction with gravity design systems, to increase air circulation. Where a fan is to be used with a furnace casing sized for gravity air flow, some form of baffling must be employed to restrict the free area within the casing and to force impingement of the air against the heating surfaces. Where square casings are used, the corners must be baffled.

### Mechanical Warm Air Furnaces

Mechanical or forced warm air furnaces include fans or blowers as integral parts, for the purpose of circulating the air, and usually include air filters.

Centrifugal fans with either backward or forward curved blades are the type most commonly used. Motors may be mounted on the fan shaft or connected to the fan by a belt drive. Adjustable pulleys are desirable to provide means of regulating the quantity of air distributed to the heated spaces. Either the motor load or the noise considerations may limit the maximum operating fan speed. Two-speed motors have given successful operating results. Motors and mountings must be carefully selected for quiet operation. Electrical conduit and water piping must not be fastened to, nor make contact with the fan housing.

### Filters

Several types of filters are available for mechanical warm air furnace applications, and are discussed in Chapter 34. For maximum efficiency and life under operating conditions, filters should not be subjected to a temperature in excess of 150 F. Filters should have at least 80 percent average efficiency on an 8-hr test at a maximum resistance of 0.25 in. of water. Filter resistance rises rapidly with the accumulation of dirt, and may reduce the air circulation over heating surfaces. In domestic furnaces, the maximum velocity, based on nominal filter area, should not exceed 300 fpm.

### Fuel Utilization

A combustion rate of from 5 to 8 lb of coal per (square foot of grate) (hour) is recommended for residential furnaces. A higher combustion rate is permissible with larger furnaces for buildings other than residences.

depending upon the ratio of grate surface to heating surface, firing period, and available draft.

In residential furnaces for coal burning, the ratio of heating surface to grate area will average about 20 to 1; in commercial sizes the ratio may be as high as 50 to 1, depending on fuel and draft. Furnaces may be installed singly, each furnace with its own fan, or in batteries of a number of furnaces, using one or more fans.

Where oil fuel is used, care must be exercised in selecting the proper size and type of burner for the particular size and type of furnace used. Furnaces for burning oil fuel are usually designed for blow-through installations so that the pressure in the air space is higher than that in the combustion chamber or flues. The *National Warm Air Heating and Air Conditioning Association* has prepared a Tentative Code for Testing and Rating of Oil-Fired Furnaces. Compact fan-furnace-burner units are available, suitable for basement, closet, or attic installations.

Gas-fired forced air furnaces should conform in construction and performance to A.G.A. Approval Requirements.

### Heavy Duty Fan Furnaces

Fan furnaces for large commercial and industrial buildings, churches, schools, etc., are available in sizes ranging from 300,000 to 6,000,000 Btu per (hour) (unit). Heavy duty furnace heaters may be arranged in battery combinations of one or more units.

Most manufacturers of heavy duty furnaces rate their furnaces in Btu per hour, and also in the number of square feet of heating surface. Conservative practice indicates that at no time in the heating-up period should the furnace surface be required to emit more than an average of 3500 Btu per square foot. A higher rate of heat emission tends to increase the heat loss up the chimney, and raise fuel consumption, to shorten the life of the furnace, and to overheat the air. The ratio of heating surface to grate area of furnaces for this type of work should never be less than 30 to 1 and, as indicated previously, may run as high as 50 to 1.

Control of temperature is secured through (1) controlling the quantity of heated air entering the room, (2) using mixing dampers, or (3) regulating the fuel supply.

The design of heavy duty fan furnace heating systems is in many respects similar to that of the central fan heating systems described in Chapter 30. Ducts are designed by the method outlined in Chapter 32.

### MATERIALS AND CONSTRUCTION

Both cast-iron and steel furnaces are made in capacities ranging from those for small insulated residence application with inputs of 40,000 Btu per hour or less, to capacities as large as 600,000 Btu per hour.

Cast-iron furnaces are usually constructed with a minimum sectional thickness of  $\frac{1}{4}$  in., and effectively resist high temperatures and corrosion. They usually have a fairly large heat capacity because of their mass, which provides a distinct *fly wheel* or carry-over heating effect.

In steel furnaces welding, riveting, or both are used to join the formed metal. The use of steel castings, however, is rare, because of the cost, and because high stresses are not encountered in normal furnace construction. Steel furnaces have low heat capacities as a result of their relatively low mass and, therefore, deliver heat rapidly on demand.

## FURNACE RATING

Rating Equations for Gravity Warm Air Furnaces<sup>10</sup>

Until a method of testing and rating gravity warm air furnaces has been developed, the following empirical rating equations are recommended by the *National Warm Air Heating and Air Conditioning Association*.

Gravity warm-air furnaces of conventional design, having ratios (of heating surface to grate area) of 15 to 1 or greater, and having a ratio of casing area to face area not less than 0.4, are rated by the following equations:

1. *Hand-fired furnaces converted to Stoker, Gas, or Oil Firing.*

$$\text{Bonnet Capacity in Btu per hour} = 1785 \times S \times 1.333 \quad (2)$$

2. *Hand-fired furnaces, with ratios of heating surface to grate area greater than 15 to 1 and less than 25 to 1.*

$$\text{Bonnet Capacity in Btu per hour} = 1785 \times S \times 1.333 \quad (3)$$

3. *Hand-fired furnaces with ratios of heating surface to grate area in excess of 25 to 1.*

$$\text{Bonnet Capacity in Btu per hour} = 1785 \times 25 \times G \times 1.333 \quad (4)$$

where

$S$  = heating surface, in square feet.

$G$  = actual grate area, in square feet.

The *Register Delivery Rating* is equal to  $0.75 \times (\text{Bonnet Capacity})$ . The *Leader Pipe Rating* in square inches, formerly used as a rating unit, may be found by dividing the *Register Delivery Rating* by 136.

## Heating Surface of Furnace

*Prime heating surface* is defined<sup>10</sup> as surface above the top of the grate having hot gases or live fuel on one side and circulating air over the other, and in all cases is measured on the exterior or air side. The areas of the outer casing, the inner liner, and any radiation shields shall not be considered as heating surface.

In determining the amount of heating surface, extended surfaces are considered to be prime heating surface subject to the following limitations:

1. Extended heating surface may consist of fins, ribs, webs, lugs, or other projections from the prime heating surface. Projections less than  $\frac{1}{4}$  in. thick at the base, and extending more than 1 in. from the prime surface are classified as fins.

2. Integral fins are continuously welded to, or cast as a part of, the prime heating surface. Both sides are included as heating surface, subject to the following allowances:

| Distance from Prime Surface           | 1st inch | 2nd inch | 3rd inch | Over 3 in. |
|---------------------------------------|----------|----------|----------|------------|
| Ratio of Effective Area to Total Area | 0.40     | 0.30     | 0.20     | None       |

3. Non-integral fins are spot welded to, or otherwise held in line contact with the prime heating surface. Both sides are included as heating surface, subject to the following allowances:

| Distance from Prime Surface           | 1st inch | 2nd inch | 3rd inch | Over 3 in. |
|---------------------------------------|----------|----------|----------|------------|
| Ratio of Effective Area to Total Area | 0.30     | 0.20     | 0.15     | None       |

4. In the case of ribs, webs, or lugs more than  $\frac{1}{4}$  in. thick at the base and extending less than 1 in. from the prime surface, the entire surface in contact with circulating air is included as heating surface.

5. In the case of ribs, webs, or lugs more than  $\frac{1}{4}$  in. thick at the base and extending more than 1 in. from the prime heating surface, the areas of both sides of the first inch are included as prime heating surface. The portions projecting beyond 1 in. are treated as integral fins.

## Grate Area

Grate area is defined<sup>10</sup> and treated for purpose of rating as follows:

1. The *nominal grate area* is defined as the total cross-sectional area of the bottom of the firepot. In steel furnaces the nominal grate area is the cross-sectional area inside the firebrick lining.

2. The *actual grate area*, used for calculating the ratios of heating surface to grate area, is the nominal grate area minus certain areas that cannot be considered as part of the grate itself. The following rules govern these deductions: (1) If a solid, continuous ledge extends around the grate and inside the firepot, any area of this ledge extending inside of a circle, the diameter of which is 1 in. less than the diameter of the bottom of the firepot, shall be deducted. (2) If separate, solid projections extend from the firepot towards the grate, the areas of any portions of these projections extending inside of a circle, the diameter of which is 3 in. less than the diameter of the bottom of the firepot, shall be deducted. (3) In the case of grates which are inclined, or are conical, the projected area is the same as the nominal grate area. The latter should, therefore, be used after making any necessary deductions.

## Ratings for Forced Air Furnaces

For solid fuel burning, forced air furnaces having bonnet capacities between 80,000 and 250,000 Btu per hour, no standard method of test has been accepted, although eventually such codes will be developed. The *National Warm Air Heating and Air Conditioning Association* recommends the following empirical equations for use in rating solid fuel forced air furnaces:

1. *Hand-fired furnaces converted to Stoker, Gas, or Oil Firing.*

$$\text{Bonnet Capacity in Btu per hour} = 2265 \times S \times 1.177 \quad (5)$$

2. *Hand-fired furnaces, with ratios of heating surface to grate area greater than 15 to 1 and less than 25 to 1.*

$$\text{Bonnet Capacity in Btu per hour} = 2265 \times S \times 1.177 \quad (6)$$

3. *Hand-fired furnaces with ratios of heating surface to grate area in excess of 25 to 1*

$$\text{Bonnet Capacity in Btu per hour} = 2265 \times 25 \times G \times 1.177 \quad (7)$$

where

$S$  = heating surface, in square feet.

$G$  = actual grate area, in square feet.

The *Register Delivery Rating* is equal to  $0.85 \times (\text{Bonnet Capacity})$ .

The following testing and rating codes have been generally accepted in the industry:

*Commercial Standard CS-109-44* for rating solid fuel-burning, forced-air furnaces having bonnet outputs of 80,000 Btu per hour or less. This provides a method of rating small coal-fired forced-air furnaces by test.

*A Tentative Code for Testing Oil-Fired Furnaces*. This code has been adopted by the *National Warm Air Heating and Air Conditioning Association* for rating oil-fired furnaces by test.

The *American Gas Association* method of rating gas-fired furnaces on performance under tests. This is described in the *Approval Requirements for Central Heating Gas Appliances*.

*Commercial Standard 113-51* is a method of rating oil-burning floor furnaces by test.

*Commercial Standard CS 104-49* is a method of rating warm air furnaces equipped with pot-type oil burners by test.

Various codes covering the construction and performance of appliances as related to fire hazards have been developed by Underwriter Laboratories, Inc. In addition, there are many municipal codes<sup>11</sup> which regulate construction and installation of furnace equipment.

The yardstick of the *National Warm Air Heating and Air Conditioning Association* provides criteria for evaluating a furnace design and installation against industry accepted standards.

### FURNACE EFFICIENCY

Rating formulas of the *National Warm Air Heating and Air Conditioning Association* are based on 55 percent efficiency for gravity coal furnaces and 65 percent efficiency for forced-air coal furnaces. In the tentative Oil Testing Code the contemplated minimum efficiency is 70 percent for oil-fired forced-air furnaces. Gravity gas furnaces approved by the *American Gas Association* are assigned a rating based on 75 percent efficiency. All forced-air gas-fired furnaces approved by *American Gas Association* are assigned a rating based on 80 percent efficiency.

### DESIGN CONSIDERATIONS

Considerations of prime importance in the design of warm air furnaces and some general suggestions to be observed in connection with each, are as follows:

1. *Adequate heat transfer surface.*
  - a. Heat transfer rates of 2,000 to 4,500 Btu per (hour) (square foot) of heating surface may be obtained without unduly high metal temperatures.
  - b. Fins, pins and bosses are frequently used to add surface and to break down superficial gas films, both on gas-to-metal and metal-to-air surfaces.
  - c. Surface and stack (flue gas) temperatures are good indications of the amount and effectiveness of the heating surfaces.
2. *Safe and efficient combustion of fuel.*
  - a. Proper mixture of fuel and air is necessary for efficient combustion. This necessitates careful attention to the design of grates, nozzles, burners, air inlet areas and location, and combustion chamber baffling.
  - b. Regulation of the quantity and the distribution of the air for combustion should be provided by use of check dampers, draft regulators, draft hoods, air shutters and air orifices.
  - c. Total draft loss through appliances should not exceed that available from chimneys which would normally be obtainable in the size of building which the appliance will supply with heat.
  - d. The use of ignition safety devices such as safety pilots, hold-fire controls, and the like is recommended.
3. *Fuel capacity of appliance.*
  - a. With solid fuels adequate coal capacity should be provided for at least 5 hr of operation at the maximum rated combustion rate.
4. *Adequate circulation of air over heating surface.*
  - a. In gravity furnaces, free air space between casing and heat exchanger should be great enough to permit free flow over all surfaces.
  - b. Forced air furnace design must include fans having proper capacity and suitable performance characteristics. Internal static pressures must be minimized without losing the advantages of high velocity circulation over the heat exchanger surfaces.
  - c. The air flow over the heating surface must be directed to obtain maximum efficiency and to eliminate hot spots and air noises.
  - d. Air velocities at bonnet should not be much in excess of 1,000 fpm, and air temperature distribution at the furnace outlet should be uniform within approximately  $\pm 30$  deg.

### 5. Durability.

- a. A minimum metal weight for gas-fired heat exchangers is established as No. 20 U.S. Gage for plain carbon steel by the A.G.A. Approval Requirements for Central Heating Gas Appliances, with some municipal codes specifying 18 gage. Cast-iron sectional thicknesses of  $\frac{1}{4}$  in. to  $\frac{3}{4}$  in. are recommended.
- b. Added strength and reinforced designs may be required to preclude damage in shipment, burning out from overfiring, or corrosion from condensation.
- c. Maximum heat exchanger surface temperatures which may be used vary with the metal. The *American Gas Association* Approval Requirements for Central Heating Gas Appliances specify a maximum of 875 F for cast-iron or steel gas furnaces, and the *National Bureau of Standards CS 109-44* Code for Forced Air Solid Fuel-Burning Furnaces specifies 1000 F as a maximum surface temperature. These temperatures define the range in which oxidation of non-alloy ferrous metal begins. The use of proper alloy additions increases the temperature resistance properties of metals.
- d. Casing temperatures should be controlled so that they do not become hazards to burn those who touch them, or to create fires.

### 6. Serviceability.

- a. Those parts of the furnace which may be subject to soot, fly-ash, or condensation deposits should be accessible for cleaning.
- b. Parts which may require adjustments or replacements, such as grates, baffles, liners, controls, should be removable.
- c. Furnaces should be so designed that they can be installed with a minimum of difficulty.

### 7. Control.

- a. Thermostatic controls of various types should be used to correlate space temperatures with unit operation.
- b. Controls should be provided wherever possible, to prevent the occurrence of excessive temperatures or other conditions in any part of the unit which might cause unsafe operation.

### 8. General design considerations.

- a. Furnace casings are normally constructed of formed and painted sheet steel or of galvanized iron. The casing should be protection from excessive radiation losses and temperatures by use of insulation or sheet steel air space liners. Liners should extend from the grate level to the top of the furnace and should be spaced from 1 in. to  $1\frac{1}{2}$  in. from the outer casing.
- b. The hood or bonnet of the casing above the furnace should be as high as basement conditions will allow, to form a plenum chamber over the top of the furnace. This tends to equalize the pressure and temperature of the air leaving the bonnet through the various openings. It is generally considered advisable to take off the warm air pipes from the side of the bonnet near the top, as this method of take-off allows the use of a higher bonnet and thus provides a larger plenum chamber.
- c. Warm air outlet and return air connections should be designed so that the ductwork may be easily attached. A  $\frac{1}{4}$  in. flange is normally used for this purpose.
- d. Suitable provision should be made in appliances so that the controls and humidifiers may be installed in the proper location. When these auxiliary units are installed in the ductwork, detailed instructions should be provided to insure their proper location.
- e. The flue connection should be of integral flue pipe size, and provision should be made to attach the flue pipe to the flue outlet of the furnace.

### HUMIDIFICATION EQUIPMENT

Evaporating pans are usually located in the outlet air. There is a present trend toward heating the water. Equipment for doing this may make use of sprays, or it may take the form of water circulating coils placed within the combustion chamber, and connected by pipes to the humidifier pans where a constant water level is maintained by some separate float device. All humidifiers require provision for removal of dirt and lime.

## SPACE HEATERS

Space heaters may be classified in several ways, such as:

1. By the type of fuel used as coal, wood, gas, and fuel oil.
2. According to the method of heat distribution as circulators or radiant types. A radiant heater is one in which the heat exchanger surface is exposed directly to the room atmosphere, and the generated heat is dissipated primarily by radiation. A circulating heater is essentially a jacketed radiant heater from which circulation of room air is promoted by the chimney effect caused by the movement of air passing upward between the jacket and heat exchanger surface.
3. According to method of design for particular fuel types, such as: (a) surface-fired and magazine-feed for solid fuels, (b) vaporizing pot-type and blue-flame heater for oil, and (c) vented and unvented heaters for gas. (The type of gas burner design, such as injection, yellow flame, power, and pressure, may also be mentioned.)

## SOLID FUEL-FIRED HEATERS

Surface-fired heaters normally have a front firing door and are operated with relatively shallow fuel beds. A magazine-feed heater includes a deep reservoir of fuel to lengthen the attention intervals. In a true magazine feed heater the rate of fuel ignition would be equal to the rate of burning; and self-feeding should operate to move the unburned fuel by gravity flow from the magazine section into the hearth area. However, the ideal balance between rate of ignition and rate of burning is virtually impossible to attain for any solid fuel under normal usage, although self-feeding may be obtained with wood and some free burning coals. Thus, a magazine-type space heater is essentially a deep surface-fired heater, its principal difference being increased fuel capacity.

## Materials and Construction

There is no accepted code governing the construction of solid fuel burning space heaters. In past years cast-iron was used predominantly in the construction of coal and wood heaters, with the exception of the so-called *air-tight* heaters designed as low-cost wood-burning units with little consideration for long life, and stoves were priced on a poundage basis. The present trend is toward fabricated steel parts and welded assemblies, although cast-iron is still used for grates, firebox liners, and parts subject to high temperatures. Refractory firebox liners are also used quite extensively.

Formed sheet steel is used predominantly for the outer jacket of circulator heaters, although heaters with outer casings formed from cast-iron are still readily available. Circulator cabinets normally have surfaces finished with a porcelain enamel, while the casing of a radiant heater is finished with an air-dried japan or a baked enamel.

Both welding and stove bolts are used in unit assembly, and stove cement is used on section joints to prevent air leakage. This latter is extremely important to obtain a low rate of combustion when desired.

## Testing and Rating

There is no accepted code governing the method of testing and rating solid-fuel space heaters. A tentative procedure, TS-3443, has been issued by the *Division of Trade Standards, National Bureau of Standards*, but is based on use of anthracite as a rating fuel, although bituminous coals are used predominantly as heating fuels. This procedure, which has been the basis of published ratings, consists of determining the heater output, expressed in Btu per hour, by the indirect method. The measurable heat

losses: (1) loss due to moisture in the fuel, (2) loss due to heat in the dry flue gases, (3) loss due to unburned carbon monoxide, and (4) loss due to unburned combustible in the ash and refuse, are measured by test. The total of these four measurable losses, plus an assumed value for unaccounted for losses, are then subtracted from the heat input. The difference multiplied by the burning rate in pounds per hour is the heater output.

When using anthracite as the rating fuel, the unaccounted for loss has been assumed to be zero. It has been accepted practice to use a 20 percent allowance for the unaccounted for losses when burning a bituminous coal. The value of this factor has been under study and, although test work is incomplete, a value of 12 percent of the heat input has been determined as representing the losses due to smoke and unburned hydrocarbons for a surface-fired heater, when burning a high volatile bituminous coal.

No allowance is made for a radiation loss, as this is useful heat.

## Design Considerations

Some important considerations in the design of solid fuel space heaters are:

1. Suitable protection by baffling or insulation against overheating of floors and walls. Although there are no industry-accepted standards by which floor and wall temperatures may be determined, some indication of heater performance, with regard to overheating, may be found by the use of the corner booth test arrangement described in *National Bureau of Standards Commercial Standard CS 103-43 and Underwriter's Laboratories Standard, Subject 896*, mentioned in following section on Oil Heaters.
2. Tight heater construction to prevent air leakage, and to enable maintenance of a suitably low minimum burning rate. This includes a ground, paper tight joint between the ashpit door and door frame.
3. Sufficient free air space, between the casing and heat exchanger of circulating heaters, to permit free air flow over all surfaces and maintain a suitably low casing temperature.
4. Protection of all metal parts from deterioration due to high temperature. This may be accomplished by: (a) fabrication of certain parts from cast-iron or an alloy iron, (b) protection by a refractory liner, (c) use of high temperature enamel coatings, (d) directing air against hot spots.
5. Proper admission of secondary air to complete the combustion process. Care should be taken to prevent this air from also functioning as primary air.
6. Strength in assembly to prevent transportation and use damage.

Considerable work has been directed in the past few years towards improvement of the performance of bituminous coal-fired space heaters, with particular reference to smokeless operation under conditions of normal operation such as obtained in homes. A recent paper describes the smokeless coal heater developed by *Bituminous Coal Research, Inc.*, wherein smokeless combustion is obtained by admitting secondary air through a narrow slot, extending from side to side, above the edge of the fuel bed where the gas leaves to enter a vertical gas passage.<sup>12</sup> Complete mixing of the volatile material, released from the coal in the magazine, with the secondary air supplied is obtained as both streams pass under the bottom of the arch. Complete combustion results from this intimate mixing in a region which maintains itself at high temperatures even during banking periods.

## OIL HEATERS

Vaporizing pot-type oil heaters consist of: (1) a metal pot in the bottom of which the oil is vaporized, the vapors burning at or near the top of the



pot; (2) a secondary combustion chamber, or heat exchanger, in which combustion is completed. The flue connection is made to this chamber or through a second heat exchanger which may be of the diving-flue type installed to increase efficiency. The burner may be designed for operation both with and without mechanical draft.

Blue-flame oil burners differ from the pot-type variety in that removable perforated sleeves are provided above an oil pan instead of a metal pot, and lighting rings or kindlers are used for easy lighting.

Both types of oil burners operate by the burning of the oil vapor rather than the oil itself, the oil being first fed to a chamber in which the oil is entirely vaporized, then mixed with air introduced through suitably located ports and burning at the top of the pot or perforated sleeves. Such heaters are designed to burn No. 1 oil (See Table 4, Chapter 14) or kerosene (coal oil). At no time should oil heavier than that for which the burner is designed be used, as heavier oils may cause excessive carbonization in the burner or fuel feed line.

#### Materials and Construction

Formed sheet steel and welded assemblies are used primarily in oil heater construction. Standards governing construction which have been generally accepted are:

1. Commercial Standard for Flue-Connected Oil-Burning Space Heaters equipped with Vaporizing Pot-Type Burners, CS101-43 (*National Bureau of Standards*).
2. Standard for Oil-burning Stoves, Subject 896 (*Underwriters' Laboratories, Inc.*).
3. Standard for Construction and Performance of Oil Burners for Installation in Stoves and Ranges, Subject 865 (*Underwriters' Laboratories, Inc.*).

Some states or municipalities have codes which apply locally, but these usually apply primarily to installation, and the *Underwriters' Laboratories* label of approval is sufficient to cover acceptance of the unit.

#### Testing and Rating

Commercial Standard CS101-43 is intended to provide a uniform standard method for ascertaining the maximum practical heat output in Btu per hour of flue-connected oil-burning space heaters under approximately normal service conditions. This method is based upon the following equations:

$$H_r = A - B \quad (8)$$

and

$$E = H_r/A \quad (9)$$

where

A = total heat of fuel used.

B = heat lost in flue gases.

$H_r$  = net heat delivered to the room.

E = unit efficiency.

The following minimum performance requirements are stipulated:

1. Adequate provision for ease of lighting and insurance against loss of ignition prior to heating of burner.
2. Ease of operation of controls.

#### Heating Boilers, Furnaces, Space Heaters

3. Proper operation of burner without excessive carbonization with grades of oil recommended by the manufacturer.

4. The heater shall be capable of passing the 6 percent *ICHAM* smoke test.

5. The heater shall be capable of operating with an overall efficiency of not less than 70 percent under conditions of test, or at a lower stack draft recommended by the manufacturer.

#### Design Considerations

Some factors important in the design of oil-burning heaters are:

1. Proper pitch of oil lines from the sump to the burner, thus preventing vapor and air lock.
2. Proper positioning of the oil sump or constant-level valve to maintain the proper oil level in the burners, if factory assembled.
3. Tight construction, not only of oil lines, but of oil tank, sump, and burner to prevent a hazardous condition due to oil leakage.
4. Provision for leveling and aligning the entire heater for maintenance of proper operation. If a separate fuel tank is used, the heater should have provision for secure fastening to the floor to prevent excessive strain on oil supply line, and the consequent danger of leakage of oil.
5. Provision of a draft regulator to prevent abnormal draft fluctuations.
6. Proper shielding of an attached fuel oil supply tank to prevent excessive oil temperatures.
7. All metal parts subjected to the corrosive action of the oil shall be made of non-corrodible metal, or of metal suitably coated to resist corrosion.
8. The heater should have suitable baffling or insulation to prevent overheating of floors and walls.
9. Strength in assembly to prevent transportation and use damage.

#### GAS HEATERS

Vented gas heaters are defined as those capable of removing 90 percent of the flue gases through a single flue outlet. All heaters having a gas input rating in excess of 50,000 Btu per hour must be of the vented type in order to meet ASA Approval Requirements for Gas-Fired Room Heaters.<sup>12</sup>

Space heaters may be classified by burner type as follows:

1. *Injection Burner* type which employs the energy of a jet of gas to inject air for combustion into the burner and mix it with the gas.
2. *Yellow Flame Burner* type in which secondary air only is depended on for the combustion of the gas.

#### Materials and Construction

Standards covering materials and accessories used in the construction of gas heaters are described in ASA Approved Requirements for Gas-Fired Room Heaters<sup>13</sup> and in applicable Listing Requirements.<sup>14</sup>

#### Efficiency Requirement

Vented space heaters having input ratings in excess of 20,000 Btu per hour are required to have a heating efficiency of not less than 70 percent,<sup>15</sup> based on the total heating value of the gas. Vented space heaters having input ratings of 20,000 Btu per hour or less are required to have a heating efficiency of not less than 65 percent.<sup>15</sup> These efficiencies are based upon the following equation:

$$e_t = 100 - \frac{H_t}{q} \times 100 \quad (10)$$

where

$e_t$  = heating efficiency, percent.

$H_t$  = heat above room temperature carried away by the flue products, Btu per hour.

$q$  = hourly gas heat input, Btu per hour.



Radiant heaters are required to have a radiant efficiency of not less than 28 percent.

### Design Considerations

Some factors important in the design of gas heaters are:

1. Proper design of the burner head, port sizes and locations so that the flame will not lift, float, or flash back, and be excessively noisy in operation.
2. Proper venting of combustion chamber for relief of forces resulting from ignition of an explosive mixture of gas and air.
3. Protection of valve handles to prevent excessive temperature rise during operation.
4. Insulation and baffling of heater to prevent over-heating of walls and floor.

### INSTALLATION OF SPACE HEATERS

The two most important considerations involved in the installation of a space heater are safety and chimney draft. The items of chimney details and flue connections which should have special attention, are outlined in Chapter 17, Chimneys and Draft Calculations. In all cases, it is recommended that installation be made in accordance with the current National Building Code.

### REFERENCES

- <sup>1</sup> See A.S.H.V.E. TRANSACTIONS, Vol. 35, 1929, p. 322.
- <sup>2</sup> See A.S.H.V.E. TRANSACTIONS, Vol. 35, 1929, p. 332.
- <sup>3</sup> See A.S.H.V.E. TRANSACTIONS, Vol. 37, 1931, p. 23.
- <sup>4</sup> See A.S.H.V.E. TRANSACTIONS, Vol. 44, 1938, p. 366.
- <sup>5</sup> I=B=R Testing and Rating Code for Low Pressure Heating Boilers, July 1952 (Institute of Boiler and Radiator Manufacturers).
- <sup>6</sup> Testing and Rating Code for Boiler-Burner Units, July, 1954 (Heating, Piping and Air Conditioning Contractors National Association).
- <sup>7</sup> I=B=R Ratings for Cast-Iron Boilers May 10, 1955 (Institute of Boiler and Radiator Manufacturers).
- <sup>8</sup> Engineering Standards, Part II, Net Square Feet Radiation Loads in 70 Deg Fahr, Recommended for Low Pressure Heating Boilers, July, 1954 (Heating, Piping and Air Conditioning Contractors National Association).
- <sup>9</sup> Comfort Heating, 1938, pp. 35 to 39 (American Gas Association).
- <sup>10</sup> Gravity Code and Manual for the Design and Installation of Gravity Warm Air Heating Systems, Manual No. 5, Fifth Ed., (National Warm Air Heating and Air Conditioning Association).
- <sup>11</sup> Recommended forms for municipal installation and fire codes are included in Manual 7—Code and Manual for design and Installation of Warm Air Winter Air Conditioning Systems, Fourth Edition, (National Warm Air Heating and Air Conditioning Association).
- <sup>12</sup> The Development of a Design of Smokeless Stove for Bituminous Coal, by B. A. Landry and R. A. Sherman, presented at the 1943 Annual Meeting of the ASME.
- <sup>13</sup> American Standard Approval Requirements for Gas Fired Room Heaters, ASA Z21.11, 1954 (American Standards Association).
- <sup>14</sup> American Standard Listing Requirements for: Automatic Pilots, Z21.20, 1951, Gas Appliance Thermostats Z21.23, 1941, Domestic Gas Appliance Pressure Regulators, Z21.18, 1936, with addenda effective June 15, 1935, July 8, 1938, Automatic Valves for Gas Appliances, Z21.21, 1952 (American Standards Association).

### CHAPTER 17

## CHIMNEYS AND DRAFT CALCULATIONS

Draft Definitions, Theoretical Natural Draft, Factors Affecting Natural Draft, Available Draft, Required Draft; Industrial Chimneys, Available Draft for the Industrial Chimney, Determining Industrial Chimney Sizes; Residential Chimneys, Available Draft for Residential Chimneys, Short Chimneys, Determining Residential Chimney Sizes, Draft Requirements of Appliances, Chimneys for Gas Appliances; Recommendations of the National Board of Fire Underwriters; General Considerations

**D**RIFT is the pressure difference associated with the movement of flue gases through a flue or chimney. Natural draft is caused and measured by the difference in weight of a column of flue gas within the flue and a corresponding column of air of equal dimension outside the flue. Natural draft is always negative and is expressed in inches of water gage.

When the movement of air is supplied by a fan, the draft is said to be forced or induced. When the fan is located so as to push the flue gases through the flue, the draft is forced. When the fan is located so as to draw the flue gases through the flue, the draft is induced.

### THEORETICAL NATURAL DRAFT

Theoretical natural draft is produced solely by the difference in weight of the column of flue gases within the flue and that of a corresponding column of air of equal dimensions outside the flue. In the determination of theoretical natural draft, no allowance is made for friction or other positive or negative effects. Theoretical natural draft is expressed by the following formula:

$$D_t = 2.96 HB_o \left( \frac{\rho_o}{T_o} - \frac{\rho_c}{T_c} \right) \quad (1)$$

where

$D_t$  = theoretical draft, inches of water.

$H$  = height of flue or chimney, feet.

$B_o$  = barometric pressure, inches of mercury.

$\rho_o$  = density of air at 0 F and 1 atmosphere pressure, pounds per cubic foot.

$\rho_c$  = density of flue gas at 0 F and 1 atmosphere pressure, pounds per cubic foot.

$T_o$  = temperature of air surrounding the chimney, Fahrenheit absolute.

$T_c$  = temperature of the gases, average or effective, in the chimney, Fahrenheit absolute.

Theoretical natural draft may also be expressed by the following simplified formula in which it is assumed that the densities of the flue gas and of the air are equal at the same temperature and pressure:

$$D_t = \frac{\rho H (T_c - T_o)}{5.2 T_c} \quad (2)$$

where:

$\rho$  = mean density of atmospheric air, pounds per cubic foot.

### FACTORS AFFECTING NATURAL DRAFT

As indicated in both Equations 1 and 2, the theoretical natural draft is directly proportional to the height of the flue and is dependent upon the absolute mean temperature of the gases within the flue. It is also directly proportional to the density of the air outside the flue although the effect of this factor is minor.

The formulas for theoretical natural draft are based on mean or average temperature which is one half of the sum of the entering and exit temperature. Since the difference in exit and entering temperatures, or the temperature gradient in the flue, is due to the escape of heat through the walls of the flue and chimney, the heat transfer characteristics of the chimney construction affect draft. Heat transfer is also affected by the rate of flow of the flue gases through the flue so that draft is also affected directly.

The flow of flue gases through the flue is retarded by friction which varies directly with the friction coefficient of the flue surface, and with the rate of flue gas flow. The friction loss may be estimated by means of one of the formulas for ducts such as the Fanning equation or it may be estimated with sufficient accuracy by the method used for air ducts. (See Chapter 32.)

The height of the flue is measured from the point of entrance of the flue gases to the top of the flue. With no wind to produce an aspirating effect and with no obstruction such as a rain cap at the top of the flue, the column of flue gases may extend upward above the top of the flue for several feet. The effect of this column may be sufficient to overcome the negative or retarding effect of friction and to cause the observed draft to exceed the theoretical draft. This added effect has been measured in some test work. A wind blowing across the top of the flue may also produce an aspirating effect sufficient to overcome the effect of friction and to cause the observed draft to exceed the theoretical. Both of these effects are transient and unreliable and should not be considered in determining the proper design of a chimney.

### AVAILABLE DRAFT

The available draft produced by any chimney is equal to the theoretical natural draft minus the friction loss. Given the height, the heat transfer characteristics of the chimney construction, the entering temperature of the flue gases and their volume, and the friction coefficient of the flue and its dimensions, the available draft is readily calculable.

The efficiency of a chimney is defined as the ratio of the observed draft or available draft, produced by the chimney for a given inlet temperature and flow rate, to the ideal draft that would be observed if the same quantity of flue gases traversed the chimney without cooling and without friction. The chimney efficiency may be calculated as follows:

$$\text{Efficiency} = \frac{\text{final measured draft}}{\text{ideal draft calculated from the inlet temperature}}$$

### REQUIRED DRAFT

Before the proper chimney for a particular installation can be selected or designed, the required draft of the combustion unit must be known. The required draft is equal to the sum of all of the resistances to gas flow from the point at which combustion air enters the unit to and including the chimney connection. This is based on the assumption that air for combus-

tion is available without restriction (such as would be caused by tightly enclosed building construction) at that point of entrance to the unit. Particularly in residences, unrestricted supply of combustion air must be assured.

Fig. 1 presents information on the fuel-bed draft loss for various kinds of coal burned at different rates. Rough generalizations can be given for the losses in the flue passages of boiler or furnace but, on account of the great differences in such devices, more reliable data on their flue gas volume, temperature and flue resistance should be obtained for design purposes from their respective manufacturers.

Flue gases encounter resistance to flow in breechings or smoke pipes, and this can probably be treated with sufficient accuracy by means of the

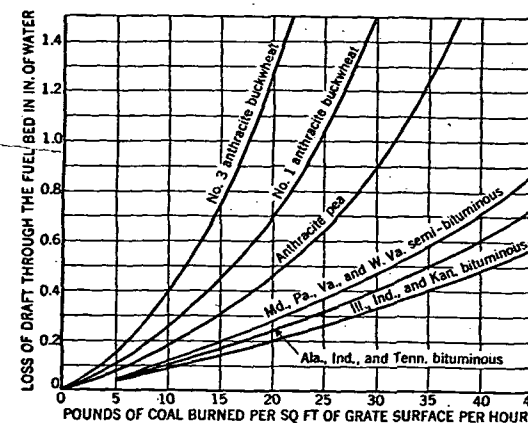


FIG. 1. DRAFT REQUIRED AT DIFFERENT RATES OF COMBUSTION FOR VARIOUS KINDS OF COAL

method used for air ducts. (See Chapter 32.) The friction in straight ducts can be estimated by means of the last term of Equations 3 and 4.

Also, the temperature of flue gases falls during passage through breechings or flue pipes. For uninsulated surfaces this probably can be adequately estimated by assuming a loss of heat from the flue gas of 3 Btu per (hr) (sq ft) (Fahrenheit deg temperature difference between the gases and surrounding air).

### INDUSTRIAL CHIMNEYS

Chimneys can be classified as residential and industrial, the chief difference being their sizes and the types of draft. Chimneys over approximately 1½ ft in diameter are in the industrial chimney class, and their requirements should be treated accordingly. The majority of industrial chimneys operate under induced or forced draft, resorting to natural draft operation only in the case of emergencies. They are built of brick, concrete, or steel, depending upon economy and the type of installation needed. Proper height is of importance because of removal of waste products, inasmuch as the products of combustion are often deflected downward around

the chimney and, with the large amount of gases that are exhausted to the atmosphere through the industrial chimney, downwash can be very objectionable.<sup>1</sup>

### AVAILABLE DRAFT FOR THE INDUSTRIAL CHIMNEY

The available draft,  $D_a$ , for large chimneys and stacks has been estimated with apparent satisfaction in the past by means of formulas which in effect deduct an estimated friction loss from a theoretical draft determined as in Equation 1. The friction loss can be estimated by means of one of the formulas available for ducts, such as the Fanning equation. This procedure results in formulas for the available draft as follows:

For a cylindrical stack:

$$D_a = 2.96 HB_o \left( \frac{\rho_o}{T_o} - \frac{\rho_c}{T_c} \right) - \frac{0.00126 W^2 T_c f L}{d^5 B_o \rho_c} \quad (3)$$

and for a rectangular stack:

$$D_a = 2.96 HB_o \left( \frac{\rho_o}{T_o} - \frac{\rho_c}{T_c} \right) - \frac{0.000388 W^2 T_c f L (x + y)}{(xy)^3 B_o \rho_c} \quad (4)$$

where

$D_a$  = available draft, inches water gage.

$H$  = height of chimney above inlet, feet.

$B_o$  = existing barometric pressure, inches of mercury.

$\rho_o$  = density of air at 0 F, 1 atmosphere pressure.

$\rho_c$  = density of flue gas at 0 F, 1 atmosphere pressure.

$T_o$  = temperature of atmosphere, Fahrenheit, absolute.

$T_c$  = temperature of flue gas, Fahrenheit, absolute.

$W$  = flue gas flow rate, pounds per second.

$f$  = coefficient of friction.

$L$  = length of friction duct (approximately equal to  $H$ ), feet.

$d$  = minimum diameter of round chimney, feet.

$x$  and  $y$  = length and width of cross-section of rectangular chimney, feet.

The following notes facilitate the use of Equations 3 and 4.

1. The barometric pressure, represented by  $B_o$ , is the actual pressure at the site of the chimney and not the pressure reduced to sea level datum.

In general, the barometric pressure decreases approximately 0.1 in. Hg per 100 ft increase in elevation.

2. The unit weight of a cubic foot of chimney gases at 0 F and sea level barometric pressure is given by the equation:

$$\rho_c = 0.131 CO_2 + 0.095 O_2 + 0.083 N_2 \quad (5)$$

In this equation  $CO_2$ ,  $O_2$ , and  $N_2$  represent the percentages of the parts by volume of the carbon dioxide, oxygen and nitrogen content, respectively, of the gas analysis. For ordinary operating conditions, the value of  $\rho_c$  may be assumed at 0.09.

The density effect on the chimney gases, due to superheated water vapor resulting from moisture and hydrogen in the fuel, or due to any air infiltration in the chimney proper, is disregarded. Though water vapor content is not disclosed by Orsat analysis, its presence tends to reduce the actual weight per cubic foot of chimney gases.

3. The atmospheric temperature is the actual observed temperature of the outside air at the time the analysis of the operating chimney is made. The mean atmospheric temperature in the temperate zone is approximately 62 F.

4. The chimney gas temperature decreases from the breeching connection to the top of the stack. This drop in temperature depends upon the material and construction

of the stack, its tightness or freedom from leaks, its area, its height, and the velocity of the gases through it. The same chimney will suffer different temperature losses depending upon the capacity under which it is working, and the variable atmospheric conditions. No general equation covering all these variables has been suggested, but from observations on chimneys varying in diameter from 3 to 16 ft, and in height from 100 to 250 ft, Equation 6 was deduced:<sup>2</sup>

$$T_c = \frac{3.13 T_1 \left[ \left( \frac{H_b}{3} \right)^{0.96} - 1 \right]}{H_b - 3} \quad (6)$$

where

$T_1$  = temperature at the center of the connection from the breeching, Fahrenheit degrees, absolute.

$H_b$  = height of the stack above center line connection to breeching, feet.

5. The coefficient of friction between the chimney gases and a sooted surface has been taken by many workers in this field as a constant value of 0.016 for the conditions involved. This value, of course, would be less for a new unlined steel stack than for a brick or brick-lined chimney, but in time the inside surface of all chimneys, regardless of the materials of construction, becomes covered with a layer of soot, and thus the coefficient of friction has been taken the same for all types of chimneys and generally constant for all conditions of operation. For reasons of simplicity and convenience to the reader, this constant value of 0.016 has been employed in the development of the various special equations and charts shown in this chapter.

In important large chimney design, especially when the construction or the materials are unusual, it is recommended that use be made of the Reynolds number<sup>3</sup> in determining the friction factor,  $f$ .

The following problem illustrates the use of Equation 3:

**Example 1:** Determine the available draft of a natural draft chimney 200 ft in height and 10 ft in diameter, operating under the following conditions: atmospheric temperature, 62 F; chimney gas temperature, 500 F; sea level atmospheric pressure,  $B_o = 29.92$  in. Hg; atmospheric and chimney gas density, 0.0863 and 0.09, respectively; coefficient of friction, 0.016; length of friction duct, 200 ft. The chimney discharges 100 lb of gases per second.

**Solution:** Substituting these values in Equation 3 and reducing,

$$D_a = 2.96 \times 200 \times 29.92 \times \left( \frac{0.0863}{522} - \frac{0.09}{960} \right) - \frac{0.00126 \times 100^2 \times 960 \times 0.016 \times 200}{10^5 \times 29.92 \times 0.09} = 1.27 - 0.14 = 1.13 \text{ in.}$$

Fig. 2 shows the variation in the available draft of a typical 200 ft by 10 ft chimney operating under the general conditions noted in Example 1. When the chimney is under static conditions and no gases are flowing, the available draft is equal to 1.27 in. of water, the theoretical intensity. As the amount of gases flowing increases, the available draft decreases until it becomes zero at a gas flow of 297 lb per second, at which point the draft loss, due to friction, is equal to the theoretical intensity. The point of maximum draft and zero capacity is called shut-off draft, or point of impending delivery, and corresponds to the point of shut-off head of a centrifugal pump. The point of zero draft and maximum capacity is called the wide open point, and corresponds to the wide open point of a centrifugal pump. A set of operating characteristics may be developed for any size chimney operating under any set of conditions by substituting the proper values in Equation 3, and then plotting the results in the manner shown in Fig. 2.

Fig. 3 is a typical chimney performance chart giving the available draft for various gas flow rates and sizes of chimney. This chart is based on an

atmospheric temperature of 62 F, a chimney gas temperature of 500 F, a unit chimney gas weight of 0.09 lb per cu ft, sea level atmospheric pressure, a coefficient of friction of 0.016, and a friction duct length equal to the height of the chimney above the grate level. These curves may be used for general operating conditions. For specific conditions, a new chart may be prepared from Equation 4.

### DETERMINING INDUSTRIAL CHIMNEY SIZES

If the required performance for a proposed chimney is known, and if a chimney-gas velocity is assumed, Equation 3 can be transposed to yield the necessary height, and an equation can be developed for the required diameter. These operations result in the following equations:

$$H = \frac{D_r}{2.96B_o \left( \frac{\rho_o}{T_o} - \frac{\rho_c}{T_c} \right) - \frac{0.184f\rho_c B_o V^2}{T_c d}} \quad (7)$$

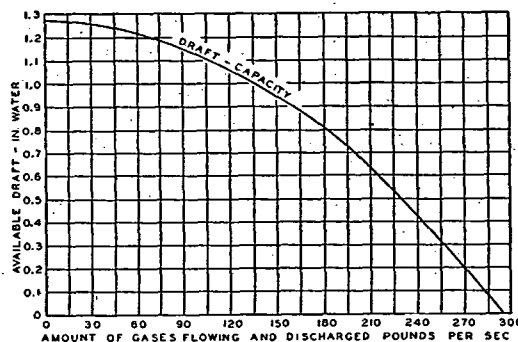


FIG. 2. TYPICAL SET OF OPERATING CHARACTERISTICS OF A NATURAL DRAFT CHIMNEY

The weight of gas per second,  $W = 12.075 \frac{dVB_o\rho_c}{T_c}$  from which

$$d = 0.288 \sqrt{\frac{WT_c}{B_o\rho_c V}} \quad (8)$$

where

$H$  = required height of chimney above grate, feet.

$d$  = required minimum diameter of chimney, feet.

$V$  = chimney gas velocity, feet per second.

$D_r$  = total required draft, inches of water.

For large chimneys, it is usual to assume that total construction cost is least when the product  $Hd$  (height  $\times$  diameter) is minimum. On this assumption, the product of Equations 7 and 8 can be differentiated, and the differential set equal to zero to find the minimum. Solution for velocity then yields the following equation:

$$V_o = \left( \frac{0.772T_c \left( \frac{\rho_o}{T_o} - \frac{\rho_c}{T_c} \right) \sqrt{\frac{WT_c}{B_o\rho_c}}}{f\rho_c} \right)^{2/5} \quad (9)$$

where

$V_o$  = economical chimney gas velocity, feet per second.

Equations 7, 8 and 9 can of course be simplified if values are assumed for some of the factors in it. Some typical figures for boiler plants are:

|                                                      |                              |
|------------------------------------------------------|------------------------------|
| Average chimney gas temperature 500 F.....           | $T_c = 960$ F absolute       |
| Average atmospheric temperature 62 F.....            | $T_o = 522$ F absolute       |
| Average coefficient of friction 0.016.....           | $f = 0.016$                  |
| Average chimney, gas density, 0 F, 1 Atmosphere..... | $\rho_c = 0.09$ lb per cu ft |
| Barometer reading, sea level.....                    | $B_o = 29.92$ in. Hg         |

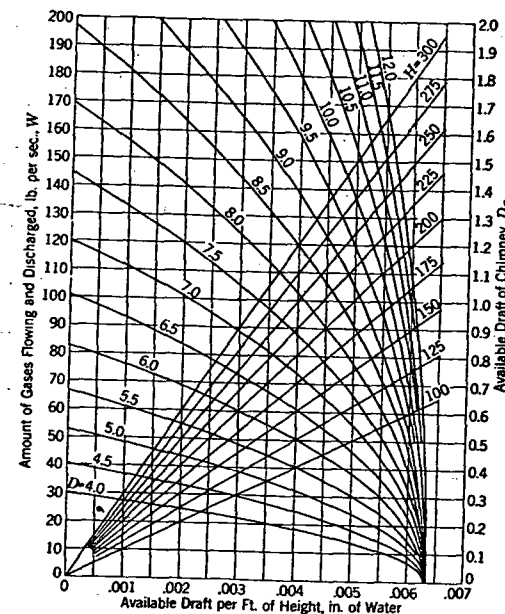


FIG. 3. CHIMNEY PERFORMANCE CHART

To solve a typical example: Proceed horizontally from a Weight Flow Rate point to intersection with diameter line; from this intersection follow vertically to chimney height line; from this intersection follow horizontally to the right to Available Draft scale. Starting from a point of Available Draft, take steps in reverse order.

When these values are substituted in Equations 7, 8 and 9, respectively, the results are:

$$H = 190D_r \quad (10)$$

$$d = 1.5W^{1/5} \quad (11)$$

$$V_o = 13.7W^{1/5} \quad (12)$$

These equations should be used for general operating conditions only, or where the required data necessary for an exact determination are difficult or impossible to secure. Whenever it is possible to obtain accurate data, or the anticipated operating conditions are fairly well known, the required size should be determined from Equations 7, 8, and 9.

Additional construction data for large industrial chimneys, whether

brick, concrete, or steel may be found in *Kent's Mechanical Engineers' Handbook*<sup>4</sup> or the *Handbook of Building Construction*.<sup>5</sup>

### RESIDENTIAL CHIMNEYS

Since residential heating appliances depend to a large extent on the natural draft of residential chimneys for satisfactory performance, the chimneys must be of adequate height and of optimum cross-sectional area, reasonably gas tight, and as smooth as practicable internally. They must be of such construction as to create no fire hazard to the building. The height and location of a residential chimney are usually limited by architectural and structural considerations, and therefore the draft produced

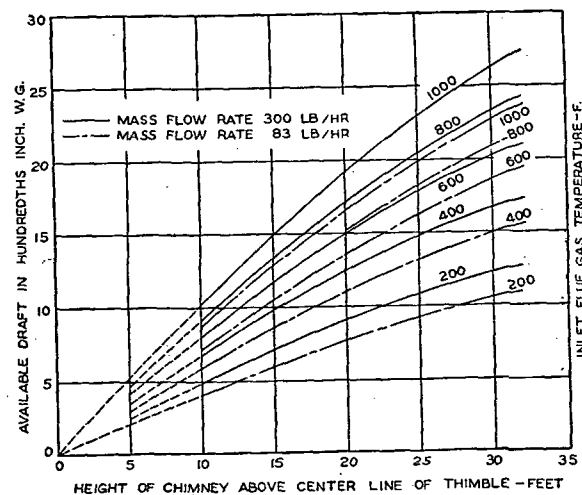


FIG. 4. AVAILABLE DRAFT FOR 9" x 9" AND 9" x 13" MASONRY CHIMNEYS  
(Ambient Temperature 0 F)

will sometimes be inadequate for satisfactory and efficient operation of the fuel burning equipment. The basementless house, the one-story ranch or rambler type, and the flat-roofed structure are usually restrictive, particularly with regard to adequate chimney height. The limitations of chimney height should be carefully considered to determine whether or not the type of heating equipment specified will operate properly. If the available draft of the chimney is less than the draft required for the particular heating equipment specified, auxiliary means such as forced or induced draft should be included.

Until recently most chimneys for residences were constructed of masonry. The National Building Code of the *National Board of Fire Underwriters* specifies a minimum of 4 in. of masonry enclosing a fire clay flue liner. Within the past several years, however, the *Underwriters' Laboratories* have tested and listed as approved *Type A* flues, several chimneys of prefabricated construction. Their advantages, compared with masonry chimneys, are ease of installation, and usually lower cost and a greater degree of safety under abnormal firing conditions. Through the use of insulation or other means to reduce heat transfer through the chimney walls, these *Type A*

flues usually operate at a higher mean temperature for a given entering temperature and therefore produce slightly higher drafts.

### AVAILABLE DRAFT FOR THE RESIDENTIAL CHIMNEY

Equations 3 and 4 cannot readily be used for computing the available draft for residential chimneys because of the relatively greater importance of friction losses, cooling of the gases, and soot deposits in small chimneys. Eddy currents and simultaneous flow both upward and downward can occur in a residential chimney for very low flue-gas velocities.

At present, it is best to rely on actual test data for determining the available draft of residential chimneys. Fig. 4 shows the available draft

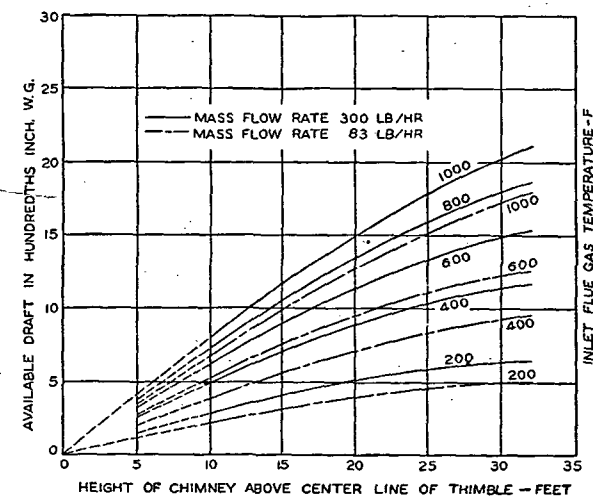


FIG. 5. AVAILABLE DRAFT FOR 9" x 9" AND 9" x 13" MASONRY CHIMNEYS  
(Ambient Temperature 60 F)

of nominal 9 x 9-in. and 9 x 13-in. masonry chimneys with an ambient temperature of 0 F for a range of effective heights from 5 to 32 ft, a range of entering flue-gas temperatures from 200 to 1000 F, and for mass flow rates of 83 and 300 lb per hr. Fig. 5 shows the same information for an ambient temperature of 60 F. The available drafts produced by 9 x 9-in. and 9 x 13-in. masonry chimneys are equal for practical purposes over the range of mass flow from 83 to 300 lb per hr.<sup>6</sup> In tests of these chimneys the smaller chimney produced slightly greater drafts in the lower end of the range of mass flow rates whereas the larger chimney produced slightly higher drafts in the upper end of the range.

The chimney height for heating plants that operate on an *on-off* or *high-fire low-fire* cycle should be selected to produce the desired draft from Fig. 5 since this class of heating system is required to operate at rated input for short periods when the outdoor temperature is 60 F. Heating plants whose fuel-burning rate is gradually increased as the outdoor temperature decreases are not required to operate at rated input except when outdoor temperatures approach design conditions. For such systems, the chimney height should be selected from Fig. 4 which shows the available draft for

an outdoor temperature of 0 F since this is likely to be the more critical condition with respect to chimney draft. The available draft for outdoor temperatures between 0 F and 60 F can be obtained by interpolation from Figs. 4 and 5 with only slight error.

Fig. 6 is a graphical representation of the available draft for a 13-ft brick chimney with a nominal 8 × 8-in. flue liner<sup>a</sup> over a wide range of mass flow rates and for inlet flue-gas temperatures ranging from 200 to 1000 F. This family of curves is a typical group of performance curves showing that there is a certain mass flow rate that produces a maximum available draft for any flue-gas temperature.

The following approximate method may alternately be used to determine the available draft for small residential chimneys, from 10 to 25 ft in height

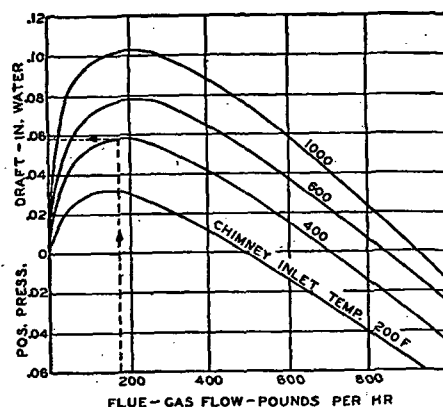


FIG. 6. AVAILABLE CHIMNEY DRAFT FOR 13 FT BRICK CHIMNEY<sup>a, b</sup>

<sup>a</sup> Square Flue Liner 6½ × 6½ in. inside.

<sup>b</sup> Barometric Pressure 29.92 in. Hg. Air Temperature 60 F.

and with internal cross-section areas from 35 to 55 sq in., with a maximum probable error of ± 15 percent at the same flow and temperature conditions. This method is based on the chimney efficiencies<sup>7</sup> shown in Fig. 7 and the ideal draft computed from the chimney inlet temperature. The available draft may be expressed as:

$$D_a = n_c D_i \quad (13)$$

where

$n_c$  = chimney efficiency taken from Fig. 7 at the desired conditions of temperature and flow.

$D_i$  = ideal draft, calculated from Equation 14, assuming that the barometric pressure is 29.92 in Hg, and the ambient temperature is 60 F.

$$D_i = 0.2554 B_o H \left( \frac{1}{T_o} - \frac{1}{T_i} \right) \quad (14)$$

where

$B_o$  = barometric pressure, inches of mercury.

$H$  = chimney height, feet.

$T_i$  = chimney inlet temperature, Fahrenheit degrees, absolute.

$T_o$  = ambient air temperature, Fahrenheit degrees, absolute.

The clay-lined brick chimney is the most commonly used chimney, but recently other building materials have been used for reasons of economy or convenience. Investigations have established that the results shown in Figs. 4 and 5 for brick chimneys can be used, with slight error, for chimneys made of shale tile, concrete block, or cinder block.<sup>8</sup>

### SHORT CHIMNEYS

The application of heating systems to one-story houses without basements requires special consideration because the chimneys in such houses

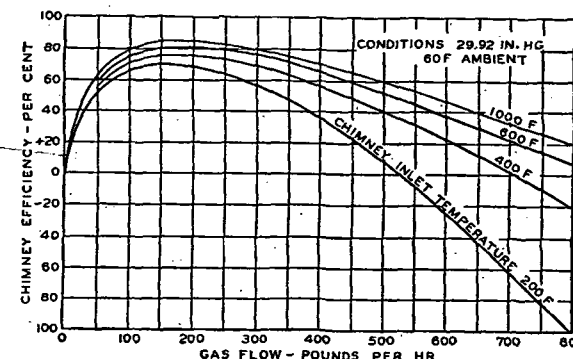


FIG. 7. EFFECT OF GAS FLOW ON CHIMNEY EFFICIENCY<sup>a</sup>

<sup>a</sup> Derived from temperature plots. Liner 8 x 8 in. outside, 6½ x 6½ inside. Height 13 ft.

are often made so low in height for architectural reasons that they produce insufficient draft for some kinds of heating systems. Gas-burning devices do not necessarily require a chimney for proper combustion of the gas, but the chimney must be of adequate size and height to carry the flue gases out of the building since it is undesirable and contrary to *American Standards* to have the products of combustion discharged in the living space. If a natural-draft oil-burning device is operated with insufficient draft because of a short chimney, smoky combustion usually occurs, pulsations are possible in the combustion chamber, the chimney or smoke-pipe may become blocked with soot, and the capacity of the heating equipment may be reduced to the point of inadequacy. Insufficient draft is not ordinarily the cause of smoky combustion in coal-burning heaters, but too short a chimney can cause slow pickup of the fire and insufficient heating capacity of the device.

Based on the amount of draft usually required for present-day heating systems at rated output, any chimney with an effective height of less than 15 ft above the center line of the thimble should be regarded as a short chimney. In short chimneys every precaution should be taken to attain the highest possible average temperature in the chimney and the lowest practicable friction loss. Short chimneys of conventional construction are likely to produce from 60 to 90 percent of the ideal draft and, therefore,

the draft would only be increased from 10 to 40 percent if all friction and cooling could be eliminated.

The available draft for short chimneys can perhaps be determined most readily by using Equation 13, Fig. 8, and Table 1. Fig. 8 shows the relationship between effective chimney height, inlet flue gas temperature, and the ideal draft that would be produced for two values of outside temperature if there were neither friction nor cooling of the gases as they traversed the chimney. After obtaining the ideal draft for a given chimney height and entering flue gas temperature from Fig. 8 and selecting the appropriate efficiency value from Table 1, the available draft can be computed from Equation 13. Fig. 8 can be used in reverse in conjunction with efficiency

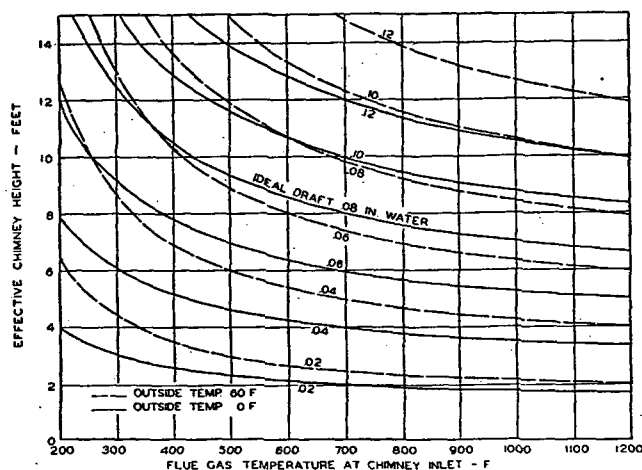


FIG. 8. IDEAL DRAFT FOR SHORT CHIMNEYS AT OUTSIDE TEMPERATURES OF 0 F AND 60 F.

values from Table 1 to determine what chimney height is required to produce the required draft at rated output for a given heating appliance.

Fig. 7 shows that the efficiency of a given chimney varies with the mass flow rate of gases and with the entering flue gas temperature. The efficiency also varies with the height for a given construction and depends somewhat on the method used to connect the smokepipe to the chimney and the amount of exposure to the outdoor air. Experimental data are not sufficiently complete to tabulate efficiencies that take into account all of these variables. However, recommended values of efficiency for several sizes of domestic chimneys of masonry materials and of metal have been selected from the literature<sup>6,7,8,9</sup> and summarized in Table 1 for use with Fig. 8 in determining the available draft produced by short chimneys of 15 ft in height or lower. In parts A and B of Table 1 the value of efficiency chosen from the range cited should be increased as the chimney inlet temperature increases over the applicable range. In part C of Table 1 the efficiency values listed will yield the available draft for the range of mass flows, inlet flue gas temperatures, and chimney height shown within 10 percent.

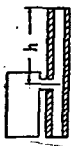
In the application of short chimneys, observance of the following pre-

## Chimneys and Draft Calculations

cautions will assist in obtaining the highest practicable draft and may cure unsatisfactory operation of the chimney and heating plant in certain instances:

1. Use a minimum length of horizontal smokepipe between the heater and chimney.
2. Insulate the smokepipe and the chimney itself, if made of metal. Insulation of the chimney liner in masonry chimneys reduces the heat loss from the flue gases and the infiltration of cold air.

TABLE 1. EFFICIENCY OF SHORT CHIMNEYS

| A. MASONRY CHIMNEYS                                                                   |             |                          |                                                     |                                                           |                    |
|---------------------------------------------------------------------------------------|-------------|--------------------------|-----------------------------------------------------|-----------------------------------------------------------|--------------------|
|    | Height h ft | Flue Gas Flow Rate lb/hr | Internal Liner Size, in.                            |                                                           |                    |
|                                                                                       |             |                          | Dia. 7                                              | 7 x 7                                                     | 7 x 11 and Dia. 10 |
|                                                                                       | 5 to 15     | 90                       | Efficiency, Percent                                 |                                                           |                    |
|                                                                                       |             | 200                      | 75-82                                               | 65-76                                                     | 65-80              |
|                                                                                       |             | 315                      | 83-84                                               | 67-85                                                     | 82-88              |
|                                                                                       |             | 75-89                    | 67-86                                               | 81-89                                                     |                    |
| (Inlet Flue Gas Temp 200 to 1000)                                                     |             |                          |                                                     |                                                           |                    |
| B. UNINSULATED METAL CHIMNEYS                                                         |             |                          |                                                     |                                                           |                    |
|    | Height h ft | Flue Gas Flow Rate lb/hr | Internal Diameter, in.                              |                                                           |                    |
|                                                                                       |             |                          | 6                                                   | 8                                                         |                    |
|                                                                                       | 4 to 8      | 90                       | Efficiency, Percent                                 |                                                           |                    |
|                                                                                       |             | 200                      | 90-100                                              | 85-95                                                     |                    |
|                                                                                       |             | 315                      | a                                                   | 83-88                                                     |                    |
|                                                                                       |             | a                        | 70-80                                               |                                                           |                    |
| (Inlet Flue Gas Temp. 200 to 600 F)                                                   |             |                          |                                                     |                                                           |                    |
| C. METAL CHIMNEYS <sup>b</sup>                                                        |             |                          |                                                     |                                                           |                    |
|  | Height h ft | Uninsulated              | 1-in. insulation with dead air space around chimney | 1-in. insulation with 1-in. open air space around chimney |                    |
|                                                                                       |             |                          | Efficiency, Percent                                 |                                                           |                    |
|                                                                                       | 8 to 14     | 76                       | 85                                                  | 81                                                        |                    |

<sup>a</sup> Six-inch chimney not recommended for these flow rates.

<sup>b</sup> Internal dia. 6-in.; flue gas flow rate 50 to 125 lb/hr; inlet flue gas temp. 200 to 1000 F.

3. Do not use an oversized chimney because larger chimneys produce greater cooling of the flue gases.
4. Avoid downdrafts by proper construction above the roof or by the use of a suitable chimney cap.
5. Avoid the use of barometric dampers in the smokepipe of natural-draft heaters since most barometric dampers permit enough cold air to leak into the chimney to reduce the draft appreciably.
6. Avoid air leaks in the smokepipe and chimney.
7. Avoid connecting more than one heating device to a single chimney.
8. Use construction materials of low heat capacity if the chimney draft must increase quickly for an intermittently-fired heating device.
9. Do not operate a kitchen exhaust fan unless an air intake of ample area is used to prevent lowering the house pressure.
10. Avoid tight utility closets so the chimney draft will not be required to do the added work of drawing combustion air into the closet from the surroundings.



### DETERMINING RESIDENTIAL CHIMNEY SIZES

The flue sizes for small residential chimneys are governed by the National Building Code of the *National Board of Fire Underwriters* for gas-burning appliances. Chimney areas for liquid- and solid-fuel-burning devices are selected primarily to meet the requirements of local building codes, but these requirements are not determined by any rigorous formula based on physical principles.

By calculating the available draft for the chimney in question, and comparing it with the performance values of the heating unit (either natural or forced draft type) at the desired output, it is possible to determine whether the chimney is adequate in height for the particular heating unit it serves.

For calculations where the fuel rate and the percentage  $CO_2$  are the only known factors, the flue-gas rate can easily be determined for coal, oil and gas from Fig. 9. By entering Fig. 9 at the percentage  $CO_2$ , moving verti-

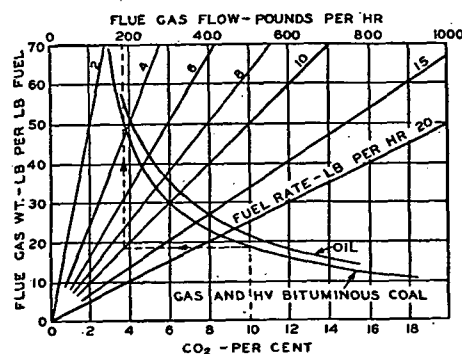


FIG. 9. GRAPHICAL EVALUATION OF RATE OF FLUE GAS FLOW FROM PERCENT  $CO_2$  AND FUEL RATE\*

\* Average density gas 0.0845 lb per cu ft, 62 F. Average weight oil 7.08 lb per gal, 60 F.

cally to the curve for the type of fuel, and then moving horizontally to the fuel rate, the flue-gas rate in pounds per hour may be determined for any fuel.<sup>7</sup>

Any of the described methods of determining available draft may be used, but a graphical solution to the problem may be had for the 8 × 8-in. chimney from Figs. 6, 7 and 9. This solution can be best explained by a numerical example.

**Example 3:** Determine whether a 13-ft, 8 × 8-in. nominal-size flue is sufficient for a coal-heating unit rated at 0.03 in. of water draft at 400 F inlet temperature, fuel rate being 10 lb per hr of bituminous coal, with 10 percent  $CO_2$ .

**Solution:** From Fig. 9, a flue-gas rate of approximately 180 lb per hr is obtained. The available draft for a 180 lb per hr fuel rate, and an inlet temperature of 400 F, obtained from Fig. 6, is 0.056 in. of water. This indicates that the chimney is adequate.

The selection of chimney areas for liquid- and solid-fuel-burning devices is difficult because of the variability in efficiency of different models, the possibility that soot on the lining will restrict the chimney area, and the variation in combustion air requirements of different solid fuels. Figs. 6 and 7 show that a given chimney produces a maximum available draft and

a maximum efficiency for some intermediate mass flow rate for any selected inlet flue-gas temperature. For mass flow rates lower than the optimum the greater cooling of the gases in the chimney causes lower available draft, whereas for mass flow rates above the optimum the greater friction losses reduce the available draft. A chimney for a given heating system should probably be designed to operate at its point of maximum efficiency and maximum available draft for its full rated output. A chimney would have an accelerating effect<sup>10</sup> on the combustion rate of a solid-fuel burning device if it were operating to the left of the optimum point in Fig. 6 because an additional increment in mass flow rate would increase the available draft a small amount and tend to increase the mass flow still more. On the other hand, a chimney operating to the right of the optimum point in Fig. 6 would tend to decelerate the combustion rate for any small increase in mass flow rate.

Data are not complete for the selection of proper chimney areas for heating plants of different capacities, but some information on the effect of cross-section area on the capacity of masonry chimneys is provided by

TABLE 2. APPROXIMATE FLUE-GAS FLOW RATES FOR MAXIMUM AVAILABLE DRAFT IN MASONRY CHIMNEYS

| NOMINAL EXTERNAL LINER DIMENSIONS | INTERNAL AREA OF LINER, Sq In | FLUE GAS TEMPERATURE AT CHIMNEY INLET, FAHR. |           |           |                                         |     |     |
|-----------------------------------|-------------------------------|----------------------------------------------|-----------|-----------|-----------------------------------------|-----|-----|
|                                   |                               | 200 600 1000                                 |           |           | 200 600 1000                            |     |     |
|                                   |                               | Mass Flow Rate, LB/HR                        |           |           | Flue Gas Velocity at Chimney Inlet, FPM |     |     |
| 9 in. Dia.                        | 38.5                          | 170                                          | 150       | 130       | 175                                     | 250 | 300 |
| 9 in. x 9 in.                     | 49                            | 215                                          | 306       | 334       | 175                                     | 400 | 600 |
| 12 in. Dia.                       | 78.5                          | 290                                          | Above 320 | Above 320 | 150                                     | —   | —   |
| 9 in. x 13 in.                    | 77                            | 295                                          | Above 320 | Above 320 | 150                                     | —   | —   |

recent tests<sup>8, 11</sup> on several chimneys with liners having nominal outside dimensions: 9 in. diameter, 12 in. diameter, 9 × 9 in., and 9 × 13 in. These tests showed that for flue gas rates up to 200 lb per hr, and entering flue gas temperatures from 200 to 1000 F, the 9-in. round liner provided an available draft equal to, or greater than, that produced by the other three larger liners. When the flue gas rate was increased to 320 lb per hr, the three larger liners produced a little more draft than the smallest one for entering flue gas temperatures above 600 F. Other data<sup>9</sup> show that metal chimneys with an internal diameter of 6 in. should not be used for mass flow rates greater than 130 lb per hr.

Table 2 shows approximate values of the mass flow rates and flue-gas velocities at the chimney inlet that produce the maximum available draft for masonry chimneys<sup>8</sup> of several conventional sizes and with an effective height of 15 ft. This table shows that a 9-in. round chimney is best suited to mass flow rates from 130 to 170 lb per hr, a 9 × 9-in. chimney performs best for flow rates from about 200 to 300 lb per hr, and a 9 × 13-in. and 12 in. round chimneys are best suited to flow rates above 300 lb per hr. These results were obtained with clean chimneys, so that conclusions about chimney areas require some modification if soot deposits are taken into consideration.

Soot deposits in chimneys reduce the effective area of the liner and may in some cases entirely close the passage. Soot deposits are likely to be

greater in the horizontal passages in the heating plant, the breeching, and the smokepipe, than in the vertical chimney liner. An increase in the liner diameter of one inch above that required for a clean chimney will probably make adequate allowance for soot deposits in all but the worst cases. Where smoky combustion is likely to occur and the mass flow rates on a clean chimney basis approach those listed in Table 2, the next larger commercial size liner should be used. Smoky combustion with oil-burning devices, particularly with vaporizing oil burners, is likely to be caused by inadequate draft which is often due to insufficient chimney height. For coal, inadequate chimney height or chimney area may be a contributing cause, but smoky combustion with coal is related to fuel characteristics and firing methods. Therefore, an increase in chimney area will usually not cure smoky combustion of a coal-burning device, but can be expected to lengthen the interval between cleanings.

New standard sizes of clay flue linings were recently developed by the

TABLE 3. DRAFTS REQUIRED BY TYPICAL RESIDENTIAL HEATING DEVICES OR APPLIANCES

| DEVICE                                         | DRAFT,<br>INCHES WATER    | STACK TEMPERATURE,<br>° F DEG |
|------------------------------------------------|---------------------------|-------------------------------|
| Space Heater, Oil Burning, Pot Burner.....     | 0.06 to 0.08              | 1000                          |
| Warm Air Furnace, Oil Burning, Pot Burner..... | 0.06                      | 860                           |
| Warm Air Furnace, Hand Fired.....              | 0.06 <sup>b</sup>         | 900                           |
| Floor Furnace, Oil Burning, Pot Burner.....    | 0.06                      | 860                           |
| Mechanical Oil Burner, Less than 5 gph.....    | 0.03 <sup>a</sup>         | —                             |
| Mechanical Oil Burner, More than 5 gph.....    | 0.05 <sup>a</sup> or less | —                             |
| Cooking Stove, Solid Fuel.....                 | 0.04 <sup>b</sup>         | 400                           |
| Space Heater, Coal Burning.....                | 0.06 <sup>b</sup>         | 900                           |

<sup>a</sup> Draft in firebox. <sup>b</sup> For chestnut sized anthracite. <sup>c</sup> 18 in. from heater.

industry and approved by the *American Standards Association*, in order to effect economies that can be derived from coordination of the dimensions of building materials. These linings are known as modular clay flue linings, and the dimensions and tolerances are summarized in *ASA Standard A62.4-47*. As the effective areas of these liners are somewhat smaller than those of the corresponding linings used previously, they cannot be used in certain municipalities where building codes specify minimum areas based on the older dimensions.

#### DRAFT REQUIREMENTS OF APPLIANCES

Typical flue-gas temperatures and drafts required at rated output for several kinds of domestic heating appliances<sup>12</sup> are contained in Table 3. Chimney height and chimney area for cast iron boilers are specified in the *I-B-R Testing and Rating Code of the Institute of Boiler and Radiator Manufacturers*.

Mechanically-fired devices such as oil burners and stokers are equipped with blowers, and therefore, the chimney is not required to overcome the resistance of the fuel bed or burner. Nevertheless, a draft in the firebox, of about 0.03 in. of water is desirable so that leakage, if any, will be into the firebox rather than outward from it.

Insufficient draft for natural-draft appliances is likely with installations in attics or in one-story basementless houses. Automatic oil-burning

space heaters, floor furnaces, and warm air furnaces employing natural-draft vaporizing burners require a draft of 0.06 to 0.08 in. water for outdoor temperatures of 60 F. Coal-burning heaters and furnaces which attain design rating of 0 F would require about the same draft. For such requirements, data from Figure 8 and Table 1 show that an effective chimney height, above chimney inlet, should be a minimum of 8 to 12 ft. Because temperature drop and friction loss in the flue pipe cannot be calculated accurately,<sup>7</sup> and the resistance of various chimney connections is uncertain, the minimum calculated heights should have a generous factor of safety applied to allow for these and other uncertainties. Where ample height cannot be provided, forced or induced draft should be provided. Extreme care should be used in the application of forced draft to avoid producing a pressure in the combustion chambers, because they are not usually designed to avoid the leakage of toxic gases which might result.

Induced draft by means of motor-driven fans or blowers will solve low-draft problems, but would usually be employed for residential systems only as a last resort. Operation of a blower entails some cost, introduces maintenance requirements, and may be dangerous in event of power failure unless suitable protective devices are used. Induced draft fans designed to resist effects of high temperature and corrosion are available. Fans not carefully designed or modified to meet these conditions should not be applied to this service.

#### CHIMNEYS FOR GAS APPLIANCES

The Approval Requirements of the *American Gas Association* are such that a gas-fired appliance must be able to operate at its rated input (plus 10 or 15 percent) without a chimney connection, and without producing carbon monoxide. The primary functions of the chimney for the gas-fired appliance are to remove the products of combustion from the living space and to assure safety to the building. The chimney therefore becomes essentially a vent and, in fact, the vents tested and listed by *Underwriters' Laboratories* for use only with gas appliances were for some time designated as *Type B Gas Appliance Vents*. Their use is limited to appliances approved by the *American Gas Association* and operating with flue gas temperatures not in excess of 550 F at the inlet of the draft hood. A draft hood is always required in connection with a *Type B* flue. The *Type B-W* gas flue is further limited to the venting of wall heaters having an input of not more than 50,000 Btu per hr.

Because of the low temperatures to which gas flues are limited care should be taken to ascertain that the appliance is not convertible to fuels other than gas and that the appliance is approved by the *American Gas Association*. It is well also to be certain that gas fuel will continue to be available to the building.

Chimneys for venting appliances designed for burning gas, can therefore be low in height, but must have adequate area. The height is usually established by the building height. Chimney sizes are usually selected on the basis of heat input of the appliance. The chimney sizes adopted by the *American Standards Association* and the *National Board of Fire Underwriters* in 1950 for gas appliances<sup>13</sup> are shown in Fig. 10.

Additional provisions of *ASA Standard Z21.30-1950* relating to chimney size are:

1. In no case shall the vent area be less than the area of a 3-in. diameter pipe.
2. When more than one appliance vents into a flue or vent, the flue or vent area

shall be not less than the area of the largest flue or vent connector plus 50 per cent of the areas of the additional flue or vent connectors.

3. An elliptical flue or vent may be used provided its flue gas venting capacity is equal to the capacity of the round pipe for which it is substituted.

Since Fig. 10 has been prepared for circular flues, relative capacities for rectangular and semi-elliptical flues<sup>14</sup> are shown in Fig. 11.

Heating appliances designed to burn gas, as well as appliances converted to gas burning, except those equipped with power type burners and ex-

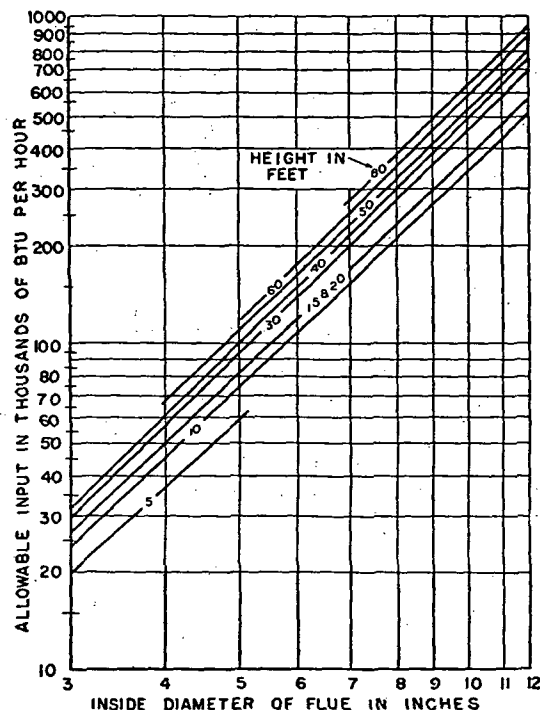


FIG. 10. CAPACITY IN BTU PER HOUR FOR GAS APPLIANCE FLUES OR VENTS

cepting conversion burner installations in excess of 400,000 Btu per hour input in large steel boilers, are always equipped with a draft hood attached to the flue outlet of the appliance. This draft hood is required if the appliance is to meet the approval requirements of the *American Gas Association* and the *American Standards Association*, and is essential for safe operation. It is designed to prevent excessive chimney draft which would lower appliance efficiency, to prevent a blocked flue or a down-draft in the chimney from impairing combustion, to provide a relief opening for the products of combustion during down-draft or blocked flue conditions, and to prevent spillage of the products of combustion to the space surrounding the appliance, if there is a chimney draft equivalent to that provided by a 3-ft chimney. As the draft hood is designed without moving parts, the

relief opening is always open, and consequently some air is drawn into the chimney. This air lowers the gas temperature in the chimney, but it also lowers the dew-point of the gases and tends to prevent condensation.

The installation of conversion burner equipment in large boilers is usually made in accordance with regulations of the local gas company. In such installations a definite chimney draft may be required for proper combustion, and consequently the foregoing reference to the use of draft hoods would not apply.

The products of complete combustion of gas are water vapor ( $H_2O$ ) and carbon dioxide ( $CO_2$ ). In the case of manufactured gas, the presence of organic sulfur compounds, generally between 3 and 15 grains per hundred cubic feet, gives rise to minute percentages of sulfur dioxide and sulfur trioxide. The volume of water vapor in the flue products from natural or coke oven gas is about twice the volume of carbon dioxide. It is extremely

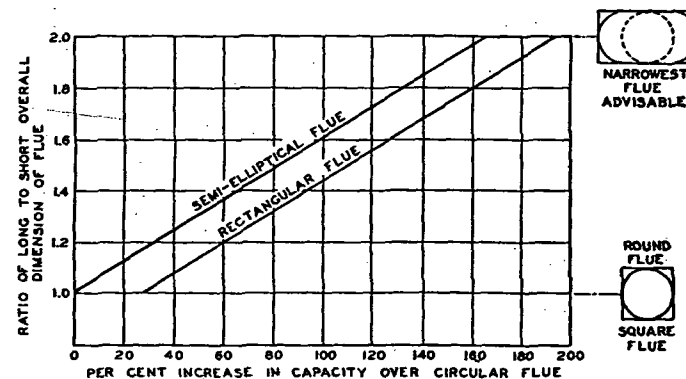


FIG. 11. CAPACITY OF A RECTANGULAR FLUE OR A SEMI-ELLIPTICAL FLUE, WITH SEMI-CIRCULAR ENDS HAVING ITS MINIMUM WIDTH EQUAL TO THE DIAMETER OF A CIRCULAR FLUE, COMPARED WITH THE CAPACITY OF THE CIRCULAR FLUE

important that the chimney be tight and resistant to corrosion, not only from moisture, but also from dilute sulfur trioxide.

Clay linings with joints which prevent retention of moisture and linings made of non-corrosive materials, are advantageous. The interior protection of unlined chimneys by applying an asphalt-chromate emulsion has been investigated by some gas companies but the material is not of current interest because insurance companies do not favor potentially combustible coatings.<sup>15</sup>

An investigation of damage occurring in 78,129 chimneys used for venting gas appliances in a severe climate has been made by the *Minneapolis Gas Company* with the results shown in Table 4 taken from Reference 15.

Advice regarding recommended practice and materials for flue connections and chimney linings can usually be obtained from the local gas company, and should be given careful consideration.

#### RECOMMENDATIONS OF THE NATIONAL BOARD OF FIRE UNDERWRITERS

For general data on the construction of chimneys, reference should be made to the National Building Code, recommended by the *National Board*

of *Fire Underwriters*, Article X, Section 1001 to 1006, in which the following are some of the important provisions listed in the 1951 edition:

1. *Flue Connections Required.* Every heating apparatus or heat producing appliance requiring a flue connection shall be connected with a flue conforming to the provisions of this article. This shall not include electric appliances; gas appliances, except as specifically required in this article; or oil fired appliances especially designed for use without flue connection.

2. *Use of Nonconforming Flues.* Flues not conforming to the requirements of this article for chimneys, metal smokestacks or vents for gas appliances, shall not be used unless listed by *Underwriters' Laboratories, Inc.*, installed in full compliance with the listing and the manufacturer's instructions, and approved for such use by the building official.

### 3. Smoke Pipe Connections.

a. No flue shall have smoke pipe connections in more than one story of a building, unless provision is made for effectively closing smoke pipe openings with devices made of noncombustible materials whenever their use is discontinued temporarily, and completely closing them with masonry when discontinued permanently.

b. Two or more smoke pipes shall not be joined for a single connection, unless the smoke pipes and flue are of sufficient size to serve all the appliances thus connected.

c. The smoke pipe of a heating appliance shall not be connected into the flue of an incinerator which has the rubbish chute identical with the smoke flue.

### 4. Construction of Chimneys.

a. Chimneys hereafter erected within or attached to a structure shall be constructed in compliance with the provisions of this section.

b. Chimneys shall extend at least 3 ft above the highest point where they pass through the roof of the building, and at least 2 ft higher than any ridge within 10 ft of such chimney.

c. Chimneys shall be wholly supported on masonry or self-supporting fireproof construction.

d. No chimney shall be corbeled from a wall more than 6 in.; nor shall a chimney be corbeled from a wall which is less than 12 in. in thickness, unless it projects equally on each side of the wall; provided that in the second story of 2-story dwellings corbeling of chimneys on the exterior of the enclosing walls may equal the wall thickness. In every case the corbeling shall not exceed 1 in. projection for each course of brick projected.

e. No change in the size or shape of a chimney, where the chimney passes through the roof, shall be made within a distance of 6 in. above or below the roof joists or rafters.

### 5. Chimneys for Heating Appliances, Low Heat Industrial Appliances and Portable Type Incinerators.

a. Chimneys for stoves, cooking ranges, warm air, hot water and low pressure steam heating furnaces, fireplaces, and low heat industrial appliances, other than chimneys for incinerators of nonportable type, shall be constructed of solid masonry units or of reinforced concrete. The walls shall be properly bonded or tied with corrosion-resistant metal anchors. In dwellings and buildings of like heating requirements, the thickness of the chimney shall be not less than 4 in. In other buildings the thickness shall be not less than 8 in., except that rubble stone masonry shall be not less than 12 in. thick.

b. Every such chimney hereafter erected or altered shall be lined with a flue lining conforming to the requirements below.

c. Flue linings shall be made of fire clay or other refractory clay which will withstand the action of flue gases and resist, without softening or cracking, the temperatures to which they will be subjected, but not less than 2000 F. Flue linings may be of cast iron of approved quality, form and construction.

d. Required clay flue linings shall be not less than  $\frac{3}{4}$  in. thick for the smaller flues, and shall increase in thickness for the larger flues.

e. Flue linings shall be installed ahead of the construction of the chimney as it is

carried up, carefully bedded one on the other in Type A, Type B, or fire clay mortar with close fitting joints left smooth on the inside.

f. Flue linings shall start from a point not less than 8 in. below the intake, or, in the case of fireplaces, from the throat of the fireplace. They shall extend, as nearly vertically as possible, for the entire height of the chimney, and be extended 4 in. above the top of cap of the chimney.

g. Cleanouts for flues or fireplaces shall be equipped with cast-iron doors and frames arranged to remain tightly closed when not in use.

h. When two or more flues are contained in the same chimney, at least every third flue shall be separated by masonry at least 4 in. thick bonded into the masonry wall of the chimney. Where flue linings are not so separated, the joints of adjacent flue linings shall be staggered at least 7 in.

### 6. Sizes of Flues.

a. The cross-sectional area of smoke flues shall be designed and proportioned to

TABLE 4. RESULTS OF FIELD SURVEY ON CHIMNEY DAMAGE

| TYPE OF CONSTRUCTION                               | NUMBER OF CHIMNEYS | NUMBER REPORTED DAMAGED | PERCENT DAMAGED |
|----------------------------------------------------|--------------------|-------------------------|-----------------|
| Chimneys without liners                            | 4720               | 562                     | 11.9            |
| Chimneys with sewer tile construction              | 8410               | 104                     | 1.2             |
| Wilder metal coated with asphalt chromate emulsion | 5185               | 291                     | 5.6             |
| Steel coated with plastic                          | 9200               | 1928                    | 21.0            |
| Vitreous enamel on steel                           | 614                | No record               | —               |
| Aluminum                                           | 50,000             | 228                     | 0.45            |

meet the conditions of temperature, within and without flue, thickness of masonry, exposure, shape and material of flue, and other influences.

The National Building Code specifies lined chimneys and metal smoke stacks for all gas appliances which may be converted readily to the use of solid or liquid fuel, and also for all boilers and furnaces, except those having a flue-gas temperature not exceeding 550 F at the outlet of the draft hood when burning gas at the manufacturer's rating and which may, therefore, be connected to *Type B* vent piping. Approved *Type B* vent piping is noncombustible, corrosion-resistant piping of adequate strength and heat-insulating value, and having bell and spigot or other acceptable joints. Fig. 10 may be used for selection of vent-pipe size.

Important points to be considered in the use of *Type B* vent piping are:

1. *Type B* flues must be plainly and permanently marked at the point where the vent connection enters the flue: *For Use of Gas Appliances Only.*

2. *Type B* gas vents shall be installed with a clearance to combustible material or construction, whether plastered or unplastered, of not less than one inch, provided that for vents of floor furnaces, such clearance shall be not less than 3 ft from the outlet of the draft hood, measured along the center line of the vent piping.

Other important points that should be considered for flues and vents for gas appliances are as follows:

1. Clearances from combustible material to gas appliance vent piping other than approved *Type B* gas vents shall be in accordance with the Building Code Standards

of the *National Board of Fire Underwriters* for the Installation of Heat Producing Appliances, Heating, Ventilating, Air Conditioning, Blower and Exhaust Systems.

2. Every flue-connected appliance, except an incinerator, unless its construction serves the same purpose, shall be equipped with an effective draft hood which either (a) has been approved as part of the appliance or (b) complies with nationally recognized standards for draft hoods. The draft hood shall be attached to the flue collar of the appliance as conditions permit, and in a position for which it is designed with reference to horizontal and vertical planes. The draft hood shall be so located that the relief opening is not obstructed by any part of the appliance or adjacent construction.

3. No vent pipe from a gas appliance shall be interconnected with any other vent pipe, smoke pipe, or flue, unless such gas appliance is equipped with an automatic device to prevent the escape of unburned gas at the main burner or burners. Where a gas appliance vent pipe is joined with a smoke pipe from an appliance burning some other type of fuel, for connection into a single flue opening, they shall be joined by a Y fitting located as close as practicable to the chimney. With liquefied petroleum gases, the automatic device to prevent the escape of unburned gas shall shut off the pilot light, as well as the main burner or burners.

Recent tests of masonry chimneys<sup>16</sup> made of a variety of materials have developed additional recommendations regarding the construction of masonry chimneys that will decrease the hazard to surrounding combustible materials.

### GENERAL CONSIDERATIONS FOR CHIMNEYS

The draft of domestic chimneys may be subject to a variety of influences not usually encountered in power chimneys<sup>17</sup> because of the low available draft often supplied by a short chimney. Horizontal winds have an aspirating effect as they cross the chimney and are an aid to draft. However, surrounding objects, such as trees or other buildings, may affect the direction of the wind at the chimney top, and may even direct it down the chimney, tending to reduce the draft or even to cause it to change to a positive pressure.

It is not to be assumed that increasing the cross-sectional area of a chimney will always effect a cure for poor draft. The opposite result may occur because of the cooling effect of the larger area, and the effect of recirculation of the flue gases. The flow of gases into the chimney top has been observed at low rates, and recirculation in small residential chimneys has been noted throughout the entire length of a chimney and smoke pipe, with the greater amount of recirculation occurring at the thimble. The effect of recirculation decreases with chimney height and the increase in flue-gas velocity.

It is also important to consider the course of the air supply for proper combustion. The boiler or furnace is usually located in the basement. In the majority of cases, the furnace room has windows and doors opening to the outside on two or more sides of the house. Through these enough air leaks into the furnace room to sustain combustion. In some cases, however, windows and doors are so tight as to restrict the flow of combustion air, and thereby affect the correct operation of the chimney. In case the boiler room is fairly tight and is open to the outside on only one side of the house, then the draft will be affected in windy weather even with windows or doors open. If the wind is blowing toward the boiler room, the draft will be increased, but if blowing in the opposite direction, the draft may be decreased.

The surrounding of a heating appliance with a restrictive enclosure that will limit entrance of combustion air is more likely to occur in a small utility closet installation on the first floor than in a basement installation. An opening with a free area approximately twice the area of the smoke-

pipe should therefore, be provided between the utility closet and the living space or the outdoors. If the utility closet is connected to the outdoors, greater difficulty with wind pressures will be encountered. Where a draft regulator is used it should have ample communication with the same space from which the combustion air is taken. Where forced warm air furnaces are enclosed in utility closets, care should be used to make the return air connection inside the utility closet airtight so that the blower cannot reduce the pressure in the closet and cause a downdraft in the chimney.

Two or more chimneys, either large or small, should never be connected together. If connected at the bottom, hot gases in the U-tube thus formed would be in unstable equilibrium. Cold air from the top would descend through one such chimney and drive the hot gases out of the other, thus annulling the draft.

More than one device can be served by one chimney. Batteries of boilers are commonly connected to a single chimney in power plants. However, if two or more chimneys are used, each chimney should be used separately for part of the boilers, and not connected in manifold with another chimney, in order to avoid the difficulty described previously.

In domestic installations it is sometimes necessary to serve a space heater or cooking stove and a water heater with the same chimney flue. This is not desirable, especially for low chimneys, since doors left open on one device, while it is unfired, will tend to annul the draft on another device. Gas burning devices, with their draft hoods and lack of draft dampers, are especially bad in this respect. The traditional method of avoiding this with brick chimneys has been to construct multiple-flue chimneys, so that each fuel-burning device could be served by a separate opening. If two devices must be served by one flue-opening in a chimney, their connections to the chimney should not be located opposite each other. The connection from the larger device should be reasonably low, and that from the smaller, up near the ceiling, so that each device can be serviced as well as possible, regardless of the treatment of the other.

Even where such precautions are taken, there is, under unusual conditions, some possibility of flow of combustible gases from one appliance into another. Reverse flow of cooled gases has been demonstrated in a chimney at very low rates of flow.<sup>7</sup> Under certain similar quiescent conditions, accidental discharge of combustible gases from a defective device into a chimney could result in flow of these gases counter current into the combustion chamber of another device attached to the same chimney. If ignition occurred in this second device, an explosion could result.

Excessive height in a chimney does no harm, but means for controlling the draft are more than ordinarily essential if the chimney is too tall. Coal-burning devices often have air leaks around the firebox, and the draft doors sometimes fit so poorly that the fire cannot be controlled at a low rate. The simplest remedy for such cases is the barometric damper which admits air into the flue pipe and thus reduces draft.

Where a chimney serves a fireplace, it is important that no other heating device be connected to it unless the fireplace is effectively sealed.

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## CHAPTER 18

## ESTIMATING FUEL CONSUMPTION FOR SPACE HEATING

Bases of Fuel Estimates; Season Efficiency; Calculated Heat Loss Method: Computation and Application, Examples and Solutions, Short Methods for Estimating Heat Loss; Degree-Day Method: Computation and Application, Unit Fuel Consumption per Degree-Day, Estimating Consumption for Various Fuels, Examples and Solutions, Degree-Day as an Operating Unit; Industrial Degree-Days; Maximum Demand and Load Factors

IT IS often necessary to estimate the anticipated heat requirements and fuel consumptions of heating plants for either short or long terms of operation. There are various general methods for estimating these conditions, and frequently the methods can be so modified as even to become useful in evaluating the effectiveness of heat production or fuel utilization during plant operation.

In applying a consumption-estimating method to a particular building, it is well to note that the bases of the methods may vary as to reliability. For example:

1. Records of past heat requirements or fuel consumption of the particular building are a better basis for estimates than are averages from records of similar buildings.
2. In the absence of past records for a particular building, the data from similar plants in the same locality may become very helpful.
3. Averages of consumption taken from many types of plants in many types of buildings in various localities can only produce an average estimate which may prove to be very inaccurate as applied to the particular building being considered.
4. Estimates based upon computed heat losses (without benefit of operating data) are wholly dependent, of course, on the degree to which the computation represents the actual facts.

Where unusual operating conditions exist due to factors such as excessive ventilation, abnormal inside temperatures and heat gains from external sources, or where, in the case of proposed buildings of unusual design, no information is available regarding former consumption, it is necessary to estimate fuel consumption from the computed heat losses.

In preparing fuel consumption estimates it is well to realize that any estimating method used will produce a more reliable result over a long period operation than over a short period. Nearly all of the methods in common use will give trustworthy results over a full annual heating season, and in some cases such estimates will prove consistent within themselves for monthly periods. As the period of the estimate is shortened, there is more chance that some factor not allowed for in the estimating method will become dominant, and thus give discrepant and even ridiculous results.

The Calculated Heat-Loss Method, and the Degree-Day Method of estimating fuel requirements are illustrative of all methods used. Both methods are based upon an estimate of seasonal efficiency. The former is also based upon an estimate of average seasonal temperature. Neither method takes into account factors which are difficult to evaluate, such as



opening of windows, abnormal heating of the building, poor design of heating system, sun effect, and other variations. The Degree-Day Method is the more practical since it is based, in part, on actual consumption data. The presentation of the two illustrative estimating methods will be preceded by a discussion of *seasonal efficiency*.

### SEASONAL EFFICIENCY

The seasonal efficiency differs from the measured efficiency of the fuel-fired heating unit because it is affected by the many minor sources of extraneous heat gain and heat loss. Throughout a season, useful heat is supplied to a building not only by the heating unit, but also by the external surfaces of the heating unit, the flue pipe, and the chimney. In addition, heat is gained from lights, occupants, cooking and other appliances, and from the sun. Indeterminable amounts of heat are lost through radiation directly to basement or utility-room walls and floors, from the heating unit, the distribution system, and the flue pipe, from stand-by operation of the unit, from opening of doors and windows, and from faulty adjustment and operation of the combustion unit. Fortunately, data which are available permit the making of reasonable estimates of seasonal efficiency for residences.

The average fuel consumption of various types of approved gas-fired equipment has been obtained from a large number of heating systems.<sup>1</sup> Corresponding seasonal efficiencies can be calculated from these data. They show a variation from approximately 72 to 88 percent, depending upon the type and size of system. Laboratory tests on a gas conversion burner in a heating boiler operated with *on* and *off* cycles gave about 72 percent efficiency.<sup>2</sup> Other tests on coal-fired room heaters indicate seasonal efficiencies of 65 to 75 percent, when the heat from the flue pipe was included.<sup>3</sup> A survey of 30 residences in one locality showed a variation of 45 to 75 percent in utilization efficiency, depending upon the condition of the equipment and the fuel used.<sup>4</sup> A summary<sup>5, 6</sup> of many tests in two research residences at the *University of Illinois*, using many fuels and systems, gave values of 67 to 90 percent for overall house efficiency (the ratio of the heat loss from the structure to the heat input to the unit for an average test day).

These data were used by the *Small Homes Council*<sup>7</sup> of the *University of Illinois* in a tabulation of the comparative costs of heating the same building with various fuels.

The approximate seasonal efficiencies shown in Table 1 are suggested as a guide.

TABLE 1. APPROXIMATE SEASONAL EFFICIENCY

| TYPE OF FUEL-BURNING UNIT                         | APPROXIMATE SEASONAL EFFICIENCY, PERCENT | TYPE OF FUEL-BURNING UNIT                    | APPROXIMATE SEASONAL EFFICIENCY, PERCENT |
|---------------------------------------------------|------------------------------------------|----------------------------------------------|------------------------------------------|
| Gas, designed unit.....                           | 75-80                                    | Anthracite, hand-fired with controls.....    | 60-80                                    |
| Gas, conversion unit.....                         | 60-80                                    | Anthracite, hand-fired without controls..... | 50-65                                    |
| Oil, designed unit.....                           | 65-80                                    | Anthracite, stoker-fired.....                | 60-80                                    |
| Oil, conversion unit.....                         | 60-80                                    | Coke, hand-fired with controls.....          | 60-80                                    |
| Bituminous coal, hand fired with controls.....    | 50-65                                    | Coke, hand-fired without controls.....       | 50-65                                    |
| Bituminous coal, hand fired without controls..... | 40-60                                    | Direct electric heating.....                 | 100                                      |
| Bituminous coal, stoker-fired.....                | 50-70                                    |                                              |                                          |

### CALCULATED HEAT LOSS METHOD

In the Calculated Heat-Loss Method a constant average outdoor temperature is assumed throughout the heating season. This average temperature is considerably above the design temperature given in Chapter 12. The method becomes unreliable whenever data on the seasonal average temperature are not available for the particular locality. If the length of time is shown over which the degree-day data apply in the particular locality, it is possible to calculate the average temperature from the definition of the degree-day (see Chapter 1). When this is done, the two methods described in this chapter become identical. The average temperature for the period October to April inclusive, is listed in Table 1, Chapter 12, for U. S. and Canadian cities.

#### Computation and Application

In order to apply the Calculated Heat-Loss Method, the hourly heat loss from the building under maximum load, or design condition, is computed following the principles discussed in Chapters 9, 11, and 12. The fuel requirement is then computed by the equation

$$F = \frac{H(t - t_a)N}{E(t_d - t_o)C} \quad (1)$$

where

- $F$  = quantity of fuel or energy required (in the units in which  $C$  is expressed).
- $H$  = calculated heat loss including infiltration loss, Btu per hour, during the design hour, based on  $t_o$  and  $t_d$ .
- $t$  = average inside temperature maintained during heating period, Fahrenheit.
- $t_a$  = average outside temperature through estimate period, Fahrenheit (for cities with an Oct. 1-May 1 heating season—see Table 1, Chapter 12).
- $t_d$  = inside design temperature, Fahrenheit (usually 70 F).
- $t_o$  = outside design temperature, Fahrenheit (see Table 1 in Chapter 12).
- $N$  = number of heating hours in estimate period (for an Oct. 1-May 1 heating season, 212 days  $\times$  24 hr = 5088).
- $E$  = efficiency of utilization of the fuel over the period, expressed as a decimal; not the efficiency at peak or rated load condition.
- $C$  = heating value of one unit of fuel or energy.

Although the assumption of an Oct. 1-May 1 heating season is reasonably accurate in the well-populated New York-Chicago zone, it is not valid as far north as Minneapolis nor farther south than Washington, D. C. and St. Louis. Consequently, it is suggested that allowance be made for this variation, especially in the far north or southern cities.

**Example 1:** A residence building is to be heated to 70 F from 6 a.m. to 10 p.m. and 65 F from 10 p.m. to 6 a.m. The calculated hourly heat loss is 120,000 Btu per hour based on 70 F inside at -10 F outside. If the building is to be heated by metered steam, how many pounds would be required during an average heating season?

**Solution:** The heating value of steam may be taken as 1000 Btu per lb, and since it is purchased steam, the efficiency can be assumed as 100 percent. Assume average outside temperature as 36.4 F. The average inside temperature is:

$$\frac{(16 \times 70) + (8 \times 65)}{24} = 68.3 \text{ F.}$$



Substituting in Equation 1

$$F = \frac{120,000 (68.3 - 36.4) 5088}{1.00[70 - (-10)]1000} = 243,000 \text{ lb.}$$

**Example 2:** What would be the fuel cost to heat the building in *Example 1* during an average heating season, using stoker-fired bituminous coal at \$14.00 per ton having a calorific value of 13,000 Btu per lb, assuming that the seasonal efficiency of the system is 65 percent?

**Solution:** Substituting in Equation 1

$$F = \frac{120,000 (68.3 - 36.4) 5088}{0.65[70 - (-10)]13,000} = 28,800 \text{ lb.}$$

The fuel cost is then  $(28,800 \div 2000) (14) = \$201.00$

**Example 3:** What will be the estimated fuel cost per year of heating a building with gas, assuming that the calculated hourly heat loss is 92,000 Btu based on 0 F, which includes 26,000 Btu for infiltration? The design temperatures are 0 F and 72 F. The normal heating season is 210 days, and the average outside temperature during the heating season is 36.4 F. The seasonal efficiency will be 80 percent. The heating plant will be thermostatically controlled, and a temperature of 65 F will be maintained from 11 p.m. to 7 a.m. Assume that the price of gas is 7.5 cents per 100,000 Btu of fuel consumption, and disregard the loss of heat through open windows and doors.

**Solution:** The average hourly temperature is

$$t_a = \frac{(72 \times 16) + (65 \times 8)}{24} = 69.7 \text{ F.}$$

The maximum hourly heat loss will be

$$H = 92,000 \text{ Btu.}$$

The seasonal heat loss is

$$M = \frac{92,000 (69.7 - 36.4) \times 24 \times 210}{100,000 \times 0.80 \times (72 - 0)} = 2697 \text{ hundred thousand Btu.}$$

The estimated seasonal fuel cost will be

$$2697 \times \$0.075 = \$202.00$$

It should be noted that savings from night setback may not result as calculated. Room temperature may not decrease and combustion efficiency may be poor during morning pickup. See Reference 8.

Several time-saving procedures have been devised for quickly estimating the hourly Btu loss of one and two-story residences in order that fuel estimates can be predicted more quickly from Equation 1. A graphical method of calculating heat losses has been developed<sup>9</sup> which makes possible a quick solution if the gross wall, ceiling, or floor areas and respective transmission coefficients are known.

The *Federal Housing Administration* has originated a short-cut formula for residential heat loss determinations which makes use of the floor area and three selected transmission coefficients. The formula was developed to apply to detached houses approximately rectangular in shape with total exterior door and window areas equal to about 25 percent of the floor area, and with a floor area not greater than about 1500 sq ft. Equation 2 is for a one-story residence, and Equation 3 is intended for two-story structures.

$$H_1 = A (G + U_w + U_c + U_f) (t_d - t_o) \quad (2)$$

$$H_2 = A (G + 1.2 U_w + 0.5 U_c + 0.5 U_f) (t_d - t_o) \quad (3)$$

where

$H_1$  = heat loss from one-story residence, Btu per hour.

$H_2$  = heat loss from two-story residence, Btu per hour.

$A$  = floor area, square feet, measured to the inside faces of enclosing walls and is the sum of the following areas: (1) all the area on each principal floor level; (2) the area of all finished habitable attic rooms, including bathrooms, toilet compartments, closets, and halls; (3) all other areas intended to be heated and not located in the basement.

$G$  = glass and infiltration factor for ordinary construction: (0.45 for no weatherstripping or storm windows), (0.40 for weatherstripping), (0.30 for storm windows with or without weatherstripping).

$U_w$  = coefficient of transmission for outside wall.

$U_c$  = coefficient of transmission for ceiling.

$U_f$  = coefficient of transmission for floor.

$t_d$  = inside design temperature, Fahrenheit degrees.

$t_o$  = outside design temperature, Fahrenheit degrees.

Notes for application of Equations 2 and 3.

1. The calculation of heat loss from heated spaces into adjacent spaces such as attics, basementless areas, and heated or unheated garages shall be based on the assumption that the temperature of such adjacent spaces is the same as the outside design temperature.

2. For all floors over basements or other warmed spaces assume  $U_f = 0$ .

3. For structures having concrete slab floors laid on the ground a modified application of the formula may be made. Assume  $U_f = 0$  and calculate the heat loss in accordance with the check formula. Then add the slab loss determined in accordance with the procedure developed by the *National Bureau of Standards* and described in BMS Report 103.

4. No basement area is to be included in the formula calculation. If finished habitable rooms in the basement are to be heated, the additional heat loss should be calculated separately and added to the amount obtained by the formula.

Both the graphical method<sup>9</sup> and *FHA* formulas, when used within the limitations established, have been found to give reasonably accurate results for the average residence, but if precise estimates are required, the procedure outlined in Chapter 12 should be used.

In the case of gravity warm air heating installations, the load was formerly expressed in square inches of leader pipe which can be converted into Btu per hour by multiplying the square inches of leader area by 111, 167, and 200 for first, second, and third floors, respectively.

## DEGREE-DAY METHOD

This method is based on consumption data which have been taken from buildings in operation, and the results have been computed on a degree-day basis. While this method may not be as theoretically correct as the Calculated Heat Loss Method, it is considered by many to be of more value for practical use.

The amount of heat required in a building depends upon the outdoor temperature, if other variables are eliminated. Theoretically it is proportional to the difference between the outdoor and indoor temperatures. The *American Gas Association*<sup>10</sup> determined from records in the heating of residences that the gas consumption varied directly as the degree-days, or as the difference between 65 F and the mean outside temperature. In other words, on a day when the mean temperature was 20 deg below 65 F, twice as much gas was consumed as on a day when the temperature was 10

deg. below 65 F. For any one day, when the mean temperature is less than 65 F, there are as many degree-days as there are degrees difference in temperature between the mean temperature for the day and 65 F. Degree-days may be calculated on other than the 65 F base for use mainly for warehouse and other industrial spaces in which temperatures to be maintained are considerably below the 68 to 72 F range. They are listed in a later section of this chapter.

Studies made by the *National District Heating Association*<sup>11</sup> of the metered steam consumption of 163 buildings located in 22 different cities and served with steam from a district heating company, substantiate the approximate correctness of the 65 F base chosen by the gas industry.

Table 2 lists the average number of degree-days which have occurred over a long period of years, by months, and the yearly totals for various cities in the United States and Canada. The number of degree-days for United States cities were calculated by taking the difference between 65 F and the daily mean temperature computed as half the total of the daily maximum and the daily minimum temperatures. The monthly averages were obtained by adding daily degree-days for each month each year and dividing by the number of days in the month; then totaling the respective calendar monthly averages for the number of years indicated and dividing by the number of years. The total or long term yearly average degree-day value is the summation of the 12 monthly averages. Degree days for Canadian cities were supplied by the *Canadian Meteorological Division* of the *Department of Transport*, and were computed from the mean temperature normals on record for the various stations. (See Note c, Table 2.)

Any attempt to apply the degree-day method of estimating fuel consumption for less than one month would be of very little value. It should be noted that this method of calculation is based on a long term average and cannot be expected to coincide with any single year in calculating fuel requirement. Individual yearly degree-day calculations may vary as much as 20 percent above and below the long term average.

If the degree-days occurring each day are totaled for a reasonably long period, the fuel consumption during that period as compared with another period will be in direct proportion to the number of degree-days in the two periods. Consequently, for a given installation, the fuel consumption can be calculated in terms of fuel used per degree-day for any sufficiently long period, and compared with similar ratios for other periods to determine the relative operating efficiencies with the outside temperature variable eliminated.

### Computation and Application

The general equation for calculating the probable fuel consumption by the degree-day method is:

$$F = U \times N \times D \times C_t \quad (4)$$

where

$F$  = fuel consumption for the estimate period.

$U$  = unit fuel consumption, or quantity of fuel used per (degree-day) (building load unit).

$N$  = number of building load units (when available use calculated hourly heat loss instead of actual amount of radiation installed).

$D$  = number of degree-days for the estimate period.

$C_t$  = temperature-correction factor from Table 3.

Values of  $N$  depend on the particular building for which the estimate is

TABLE 2. AVERAGE MONTHLY AND YEARLY DEGREE-DAYS FOR CITIES IN THE UNITED STATES AND CANADA<sup>a, b, c</sup> (BASE 65F)

| STATE                | STATION             | YEARS         | No.<br>OF<br>SEASONS |      |      |       |      |      |      |      |      |      |      |     |      | YEARLY<br>TOTAL |
|----------------------|---------------------|---------------|----------------------|------|------|-------|------|------|------|------|------|------|------|-----|------|-----------------|
|                      |                     |               |                      | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | APR. | MAY | JUNE |                 |
| Ala.                 | Anniston.....A      |               |                      | 0    | 0    | 17    | 118  | 438  | 614  | 614  | 485  | 381  | 128  | 25  | 0    | 2820            |
|                      | Birmingham.....A    |               |                      | 0    | 0    | 13    | 123  | 396  | 598  | 623  | 491  | 378  | 128  | 30  | 0    | 2780            |
|                      | Mobile.....A        |               |                      | 0    | 0    | 25    | 219  | 376  | 416  | 304  | 222  | 47   | 0    | 0   | 0    | 1612            |
|                      | Montgomery.....C    |               |                      | 0    | 0    | 0     | 23   | 198  | 357  | 412  | 290  | 209  | 40   | 0   | 0    | 1529            |
|                      | Montgomery.....A    |               |                      | 0    | 0    | 0     | 69   | 304  | 491  | 517  | 388  | 288  | 80   | 0   | 0    | 2137            |
| Aris.                | Montgomery.....C    |               |                      | 0    | 0    | 0     | 55   | 287  | 458  | 483  | 360  | 265  | 68   | 0   | 0    | 1954            |
|                      | Flagstaff.....A     |               |                      | 49   | 78   | 243   | 588  | 878  | 1135 | 1231 | 1014 | 949  | 687  | 465 | 212  | 7625            |
|                      | Phoenix.....A       |               |                      | 0    | 0    | 0     | 22   | 223  | 400  | 474  | 309  | 196  | 74   | 0   | 0    | 1698            |
|                      | Phoenix.....C       |               |                      | 0    | 0    | 0     | 13   | 182  | 360  | 425  | 275  | 175  | 62   | 0   | 0    | 1492            |
| Ark.                 | Yuma.....A          |               |                      | 0    | 0    | 0     | 0    | 105  | 259  | 318  | 167  | 88   | 14   | 0   | 0    | 861             |
|                      | Bentonville.....A   | 06/07-40/41   | 35                   | 1    | 1    | 3     | 218  | 518  | 810  | 879  | 716  | 519  | 247  | 88  | 7    | 4035            |
|                      | Fort Smith.....A    |               |                      | 1    | 0    | 0     | 3    | 131  | 435  | 698  | 775  | 571  | 418  | 127 | 24   | 3138            |
| Calif.               | Little Rock.....A   |               |                      | 0    | 0    | 0     | 10   | 110  | 405  | 554  | 719  | 543  | 401  | 122 | 18   | 2982            |
|                      | Eureka.....C        |               |                      | 267  | 246  | 264   | 235  | 411  | 508  | 552  | 466  | 493  | 432  | 375 | 282  | 4632            |
|                      | Fresno.....A        |               |                      | 0    | 0    | 0     | 86   | 345  | 580  | 629  | 400  | 304  | 145  | 43  | 0    | 2532            |
| Conn.                | Independence.....C  | 08/99-40/41   | 43                   | 0    | 0    | 0     | 28   | 216  | 512  | 778  | 799  | 619  | 477  | 267 | 120  | 18 3834         |
|                      | Los Angeles.....A   |               |                      | 31   | 22   | 56    | 87   | 200  | 301  | 378  | 305  | 273  | 185  | 121 | 56   | 2015            |
|                      | Los Angeles.....C   |               |                      | 0    | 0    | 17    | 41   | 140  | 253  | 328  | 244  | 212  | 129  | 68  | 145  | 1451            |
|                      | Needles.....A       | 17/18-38/39   | 22                   | 0    | 0    | 0     | 19   | 217  | 416  | 447  | 243  | 124  | 36   | 3   | 0    | 1495            |
|                      | Point Reyes.....A   | 08/99-40/41   | 43                   | 350  | 336  | 263   | 282  | 317  | 425  | 487  | 406  | 437  | 413  | 415 | 363  | 4474            |
|                      | Red Bluff.....A     |               |                      | 0    | 0    | 59    | 319  | 564  | 617  | 423  | 336  | 177  | 51   | 0   | 0    | 2546            |
|                      | Sacramento.....A    |               |                      | 0    | 0    | 22    | 98   | 357  | 595  | 642  | 428  | 348  | 222  | 103 | 7    | 2822            |
|                      | Sacramento.....C    |               |                      | 0    | 0    | 17    | 75   | 321  | 567  | 614  | 403  | 317  | 196  | 85  | 5    | 2600            |
|                      | San Diego.....A     |               |                      | 11   | 7    | 24    | 52   | 147  | 255  | 317  | 247  | 223  | 151  | 97  | 43   | 1674            |
|                      | San Francisco.....A |               |                      | 144  | 136  | 101   | 174  | 318  | 487  | 630  | 398  | 378  | 327  | 264 | 164  | 3421            |
|                      | San Francisco.....C |               |                      | 189  | 177  | 110   | 128  | 237  | 406  | 462  | 336  | 317  | 279  | 243 | 130  | 3069            |
|                      | San Jose.....C      |               |                      | 7    | 11   | 26    | 97   | 270  | 450  | 487  | 342  | 308  | 227  | 131 | 32   | 6026            |
|                      | Colo.               | Denver.....A  |                      |      | 5    | 1     | 120  | 425  | 771  | 1032 | 1225 | 924  | 843  | 525 | 286  | 65              |
| Denver.....C         |                     |               |                      | 5    | 103  | 385   | 711  | 958  | 1042 | 854  | 797  | 492  | 266  | 60  | 5673 |                 |
| Durango.....A        |                     | 04/05-40/41   | 37                   | 25   | 37   | 201   | 535  | 861  | 1204 | 1271 | 1002 | 859  | 615  | 394 | 139  | 7143            |
| Grand Junction.....A |                     |               | 0                    | 0    | 38   | 333   | 792  | 1132 | 1271 | 924  | 738  | 402  | 145  | 23  | 5796 |                 |
|                      | Leadville.....A     | 07/08-40/41   | 34                   | 280  | 332  | 509   | 841  | 1139 | 1413 | 1470 | 1283 | 1245 | 990  | 740 | 434  | 10678           |
|                      | Pueblo.....A        |               |                      | 0    | 0    | 74    | 383  | 771  | 1051 | 1104 | 865  | 775  | 486  | 203 | 27   | 5709            |
| Conn.                | Hartford.....A      |               |                      | 0    | 14   | 101   | 384  | 696  | 1082 | 1178 | 1050 | 871  | 528  | 201 | 31   | 6139            |
|                      | New Haven.....A     |               |                      | 0    | 18   | 93    | 363  | 663  | 1026 | 1113 | 1005 | 866  | 567  | 191 | 32   | 6026            |
| D. C.                | Washington.....A    |               |                      | 0    | 37   | 237   | 519  | 837  | 893  | 781  | 619  | 323  | 87   | 0   | 0    | 4333            |
|                      | Washington.....C    |               |                      | 0    | 0    | 32    | 231  | 510  | 831  | 884  | 770  | 606  | 314  | 80  | 0    | 4258            |
| Fla.                 | Apalachicola.....C  |               |                      | 0    | 0    | 0     | 17   | 154  | 304  | 352  | 263  | 184  | 33   | 0   | 0    | 1307            |
|                      | Jacksonville.....A  |               |                      | 0    | 0    | 0     | 16   | 143  | 309  | 331  | 247  | 169  | 23   | 0   | 0    | 1243            |
|                      | Jacksonville.....C  |               |                      | 0    | 0    | 0     | 11   | 129  | 276  | 303  | 226  | 154  | 14   | 0   | 0    | 1113            |
|                      | Key West.....A      |               |                      | 0    | 0    | 0     | 0    | 22   | 34   | 25   | 8    | 0    | 0    | 0   | 0    | 89              |
|                      | Key West.....C      |               |                      | 0    | 0    | 0     | 0    | 18   | 28   | 24   | 7    | 0    | 0    | 0   | 0    | 77              |
|                      | Miami.....A         |               |                      | 0    | 0    | 0     | 0    | 8    | 52   | 58   | 48   | 12   | 0    | 0   | 0    | 178             |
|                      | Miami.....C         |               |                      | 0    | 0    | 0     | 0    | 5    | 48   | 57   | 48   | 15   | 0    | 0   | 0    | 173             |
|                      | Pensacola.....C     |               |                      | 0    | 0    | 0     | 18   | 177  | 334  | 383  | 275  | 203  | 45   | 0   | 0    | 1435            |
|                      | Tampa.....A         |               |                      | 0    | 0    | 0     | 0    | 60   | 163  | 201  | 148  | 102  | 0    | 0   | 0    | 674             |
|                      | Ga.                 | Atlanta.....A |                      |      | 0    | 0     | 8    | 110  | 393  | 614  | 632  | 512  | 404  | 133 | 20   | 0               |
| Atlanta.....C        |                     |               |                      | 0    | 0    | 8     | 107  | 387  | 611  | 632  | 515  | 392  | 135  | 24  | 0    | 2811            |
| Augusta.....A        |                     |               |                      | 0    | 0    | 0     | 59   | 282  | 494  | 521  | 412  | 308  | 82   | 0   | 0    | 2138            |
| Macon.....A          |                     |               |                      | 0    | 0    | 0     | 63   | 280  | 481  | 497  | 391  | 275  | 62   | 0   | 0    | 2049            |
| Savannah.....A       |                     |               |                      | 0    | 0    | 0     | 38   | 225  | 412  | 424  | 330  | 238  | 43   | 0   | 0    | 1710            |
| Thomasville.....A    |                     | 05/06-40/41   | 36                   | 0    | 0    | 2     | 48   | 208  | 361  | 359  | 299  | 178  | 52   | 5   | 1    | 1513            |
| Boise.....A          |                     |               |                      | 0    | 0    | 135   | 389  | 782  | 1054 | 1169 | 888  | 719  | 453  | 249 | 92   | 5990            |
| Idaho.               | Lewiston.....A      |               |                      | 0    | 0    | 133   | 406  | 747  | 961  | 1060 | 815  | 663  | 408  | 222 | 68   | 5483            |
|                      | Pocatello.....A     |               |                      | 0    | 0    | 183   | 487  | 873  | 1184 | 1333 | 1022 | 880  | 561  | 317 | 136  | 6976            |
| Ill.                 | Cairo.....C         |               |                      | 0    | 0    | 28    | 161  | 492  | 784  | 856  | 683  | 523  | 182  | 47  | 0    | 3756            |
|                      | Chicago.....A       |               |                      | 0    | 0    | 90    | 350  | 765  | 1147 | 1243 | 1053 | 868  | 507  | 229 | 58   | 6310            |
|                      | Peoria.....A        |               |                      | 0    | 11   | 80    | 339  | 739  | 1128 | 1240 | 1028 | 828  | 455  | 192 | 41   | 6087            |
| Ind.                 | Springfield.....A   |               |                      | 0    | 6    | 83    | 315  | 723  | 1068 | 1166 | 958  | 769  | 404  | 17  | 32   | 5693            |
|                      | Evansville.....C    |               |                      | 0    | 6    | 56    | 259  | 686  | 1017 | 1116 | 907  | 713  | 350  | 127 | 14   | 5225            |
|                      | Fort Wayne.....A    |               |                      | 0    | 0    | 59    | 215  | 570  | 871  | 939  | 770  | 589  | 251  | 90  | 8    | 4360            |
|                      | Indianapolis.....A  |               |                      | 0    | 17   | 107   | 377  | 759  | 1122 | 1200 | 1036 | 874  | 516  | 226 | 53   | 6287            |
|                      | Indianapolis.....C  |               |                      | 0    | 0    | 79    | 308  | 705  | 1051 | 1122 | 938  | 772  | 432  | 176 | 30   | 5611            |
|                      | Indianapolis.....A  |               |                      | 0    | 0    | 59    | 247  | 642  | 986  | 1051 | 893  | 725  | 375  | 140 | 16   | 5134            |
|                      | Royal Center.....A  | 18/19-31/32   | 14                   | 11   | 19   | 116   | 373  | 740  | 1104 | 1239 | 976  | 860  | 502  | 245 | 54   | 6239            |
| Iowa.                | Terre Haute.....A   |               |                      | 0    | 5    | 77    | 295  | 681  | 1023 | 1107 | 913  | 725  | 371  | 145 | 24   | 5386            |
|                      | Charles City.....C  |               |                      | 17   | 30   | 161   | 444  | 912  | 1352 | 1494 | 1240 | 1001 | 537  | 256 | 70   | 7504            |
|                      | Davenport.....C     |               |                      | 0    | 7    | 79    | 320  | 756  | 1147 | 1262 | 1044 | 834  | 432  | 175 | 35   | 6091            |
|                      | Des Moines.....A    |               |                      | 5    | 12   | 90    | 355  | 798  | 1203 | 1330 | 1092 | 868  | 438  | 201 | 45   | 6446            |
|                      | Des Moines.....C    |               |                      | 0    | 6    | 89    | 346  | 777  | 1178 | 1308 | 1072 | 849  | 425  | 183 | 41   | 6274            |
|                      | Dubuque.....A       |               |                      | 8    | 28   | 149   | 444  | 882  | 1290 | 1414 | 1187 | 983  | 543  | 267 | 76   | 7271            |
|                      | Keokuk.....A        | 08/99-41/42   | 44                   | 1    | 3    | 71    | 303  | 680  | 1077 | 1191 | 1025 | 781  | 397  | 138 | 18   | 5653            |
| Sioux City.....A     |                     |               | 8                    | 17   | 128  | 405   | 885  | 1290 | 1423 | 1170 | 930  | 474  | 228  | 54  | 7012 |                 |

<sup>a</sup> Data for United States cities from a publication of the *United States Weather Bureau, Monthly Normal Temperatures, Precipitation and Degree Days, 1954* are for the period 1921 to 1950 inclusive. Those United States cities for which years are given in Column 3 are not listed in the above publication and the data are those which were computed by the *United States Weather Bureau* in 1946 and 1947 in accordance with the requirements of the *National Joint Committee on Weather Statistics*.

<sup>b</sup> Data for airport stations, A, and city stations, C, are both given where available.

<sup>c</sup> Data for Canadian cities were computed by the *Meteorological Division, Department of Transport* from normal monthly mean temperatures, adjusted for the summer months by a method described by H. C. S. Thom, "The Rational Relationship between Heating Degree Days and Temperature," *Monthly Weather Review*, Vol. 82, No. 1, January, 1954.

TABLE 2. AVERAGE MONTHLY AND YEARLY DEGREE-DAYS FOR CITIES IN THE UNITED STATES AND CANADA\* b. c. (CONTINUED)

| STATE            | STATION                  | YEARS       | No. OF SEASONS | JULY              | AUG.        | SEPT. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | APR. | MAY  | JUNE | YEARLY TOTAL |      |      |
|------------------|--------------------------|-------------|----------------|-------------------|-------------|-------|------|------|------|------|------|------|------|------|------|--------------|------|------|
| Kan.             | Concordia.....C          | 05/08-40/41 | 36             | 0                 | 0           | 55    | 277  | 687  | 1029 | 1144 | 899  | 725  | 341  | 145  | 20   | 5323         |      |      |
|                  | Dodge City.....A         |             |                | 0                 | 0           | 40    | 262  | 669  | 980  | 1076 | 840  | 694  | 347  | 135  | 15   | 5058         |      |      |
|                  | Iola.....A               |             |                | 0                 | 1           | 40    | 236  | 579  | 930  | 1026 | 817  | 599  | 282  | 99   | 8    | 4618         |      |      |
|                  | Topeka.....A             |             |                | 0                 | 0           | 59    | 271  | 672  | 1017 | 1123 | 885  | 694  | 326  | 137  | 15   | 5209         |      |      |
| Ky.              | Topeka.....C             | 05/08-40/41 | 36             | 0                 | 0           | 42    | 242  | 630  | 977  | 1083 | 851  | 669  | 295  | 112  | 13   | 4919         |      |      |
|                  | Wichita.....A            |             |                | 0                 | 0           | 32    | 219  | 597  | 915  | 1023 | 778  | 619  | 280  | 101  | 7    | 4571         |      |      |
|                  | Louisville.....A         |             |                | 0                 | 0           | 51    | 232  | 579  | 871  | 933  | 778  | 611  | 285  | 94   | 5    | 4439         |      |      |
|                  | Louisville.....C         |             |                | 0                 | 0           | 41    | 206  | 549  | 849  | 911  | 762  | 605  | 270  | 86   | 0    | 4279         |      |      |
| La.              | Lexington.....A          | 05/08-40/41 | 36             | 0                 | 0           | 56    | 259  | 636  | 933  | 1008 | 854  | 710  | 368  | 140  | 15   | 4979         |      |      |
|                  | New Orleans.....A        |             |                | 0                 | 0           | 0     | 7    | 169  | 308  | 364  | 248  | 190  | 31   | 0    | 0    | 1317         |      |      |
|                  | New Orleans.....C        |             |                | 0                 | 0           | 0     | 5    | 141  | 283  | 341  | 223  | 163  | 19   | 0    | 0    | 1175         |      |      |
|                  | Shreveport.....A         |             |                | 0                 | 0           | 0     | 53   | 305  | 490  | 550  | 386  | 272  | 87   | 0    | 0    | 2117         |      |      |
| Me.              | Eastport.....C           | 07/08-40/41 | 36             | 141               | 136         | 261   | 521  | 798  | 1206 | 1333 | 1201 | 1063 | 774  | 524  | 288  | 8246         |      |      |
|                  | Greenville.....C         |             |                | 42/43-45/46       | 38          | 60    | 113  | 315  | 643  | 1012 | 1464 | 1625 | 1443 | 1251 | 842  | 468          | 194  | 9439 |
| Md.              | Portland.....A           | 07/08-40/41 | 38             | 15                | 58          | 199   | 515  | 825  | 1237 | 1373 | 1218 | 1039 | 693  | 394  | 117  | 7681         |      |      |
|                  | Baltimore.....A          |             |                | 0                 | 0           | 50    | 278  | 582  | 908  | 955  | 840  | 676  | 378  | 115  | 5    | 4787         |      |      |
| Mass.            | Baltimore.....C          | 05/08-40/41 | 43             | 0                 | 0           | 29    | 207  | 489  | 812  | 880  | 776  | 611  | 326  | 73   | 0    | 4203         |      |      |
|                  | Boston.....A             |             |                | 0                 | 0           | 7     | 77   | 315  | 618  | 998  | 1113 | 1002 | 849  | 534  | 236  | 42           | 5791 |      |
| Mich.            | Fitchburg.....A          | 05/08-40/41 | 43             | 12                | 29          | 144   | 432  | 774  | 1139 | 1240 | 1137 | 940  | 572  | 254  | 70   | 6743         |      |      |
|                  | Nantucket.....A          |             |                | 22                | 34          | 111   | 372  | 615  | 924  | 1020 | 949  | 880  | 642  | 394  | 139  | 6102         |      |      |
|                  | Alpena.....C             |             |                | 50                | 85          | 215   | 530  | 864  | 1218 | 1358 | 1263 | 1156 | 762  | 437  | 135  | 8073         |      |      |
|                  | Detroit Willow Run.....A |             |                | 0                 | 0           | 10    | 96   | 393  | 759  | 1125 | 1231 | 1089 | 915  | 552  | 244  | 55           | 6469 |      |
| Minn.            | Detroit City.....A       | 00/01-40/41 | 45             | 0                 | 8           | 96    | 381  | 747  | 1101 | 1203 | 1072 | 927  | 558  | 251  | 60   | 8404         |      |      |
|                  | Escanaba.....C           |             |                | 62                | 95          | 247   | 555  | 933  | 1321 | 1473 | 1327 | 1203 | 804  | 471  | 166  | 8657         |      |      |
|                  | Grand Rapids.....A       |             |                | 14                | 29          | 144   | 462  | 822  | 1169 | 1287 | 1154 | 1008 | 606  | 301  | 79   | 7075         |      |      |
|                  | Grand Rapids.....C       |             |                | 0                 | 0           | 20    | 105  | 394  | 756  | 1107 | 1215 | 1086 | 939  | 546  | 248  | 58           | 6474 |      |
|                  | Houghton.....A           |             |                | 70                | 94          | 268   | 582  | 965  | 1356 | 1535 | 1421 | 1251 | 820  | 474  | 185  | 9030         |      |      |
|                  | Lansing.....A            |             |                | 13                | 32          | 140   | 455  | 813  | 1175 | 1277 | 1142 | 986  | 591  | 287  | 70   | 6982         |      |      |
|                  | Ludington.....A          |             |                | 12/13-40/41       | 29          | 41    | 55   | 182  | 472  | 794  | 1135 | 1271 | 1183 | 1056 | 698  | 418          | 153  | 7458 |
|                  | Marquette.....A          |             |                | 69                | 87          | 236   | 543  | 933  | 1299 | 1435 | 1291 | 1181 | 789  | 477  | 189  | 8529         |      |      |
|                  | Sault Ste. Marie.....A   |             |                | 109               | 126         | 298   | 639  | 1005 | 1398 | 1587 | 1442 | 1302 | 846  | 499  | 224  | 9475         |      |      |
|                  | Duluth.....C             |             |                | 56                | 91          | 298   | 651  | 1140 | 1606 | 1758 | 1512 | 1327 | 846  | 474  | 178  | 9937         |      |      |
|                  | Duluth.....A             |             |                | 66                | 91          | 277   | 614  | 1092 | 1550 | 1696 | 1448 | 1252 | 801  | 487  | 200  | 9574         |      |      |
|                  | Miss.                    |             |                | Minneapolis.....A | 05/08-40/41 | 36    | 8    | 17   | 157  | 459  | 960  | 1414 | 1562 | 1310 | 1057 | 570          | 259  | 80   |
| Moorhead.....A   |                          | 20          | 47             | 240               |             |       | 607  | 1105 | 1609 | 1815 | 1555 | 1225 | 679  | 327  | 98   | 9327         |      |      |
| Saint Paul.....A |                          | 12          | 21             | 154               |             |       | 459  | 951  | 1401 | 1553 | 1305 | 1051 | 564  | 256  | 77   | 7804         |      |      |
| Corinth.....A    |                          | 0           | 1              | 13                |             |       | 142  | 418  | 669  | 966  | 570  | 396  | 149  | 32   | 1    | 3087         |      |      |
| Mo.              | Meridian.....A           | 09/10-40/41 | 32             | 0                 | 0           | 0     | 90   | 338  | 628  | 951  | 413  | 309  | 85   | 9    | 0    | 2333         |      |      |
|                  | Vicksburg.....C          |             |                | 0                 | 0           | 0     | 51   | 268  | 456  | 507  | 374  | 273  | 71   | 0    | 0    | 2000         |      |      |
|                  | Columbia.....A           |             |                | 0                 | 6           | 62    | 262  | 654  | 989  | 1091 | 876  | 698  | 326  | 135  | 14   | 5113         |      |      |
|                  | Hannibal.....A           |             |                | 0                 | 1           | 66    | 288  | 652  | 1037 | 1139 | 980  | 710  | 374  | 128  | 15   | 5393         |      |      |
| Mont.            | Kansas City.....A        | 05/08-40/41 | 36             | 0                 | 0           | 44    | 240  | 621  | 970  | 1085 | 851  | 666  | 292  | 111  | 8    | 4888         |      |      |
|                  | Saint Louis.....A        |             |                | 0                 | 0           | 45    | 233  | 600  | 927  | 1017 | 820  | 648  | 297  | 101  | 11   | 4699         |      |      |
|                  | Saint Louis.....C        |             |                | 0                 | 0           | 38    | 202  | 570  | 893  | 983  | 792  | 620  | 270  | 94   | 7    | 4469         |      |      |
|                  | Springfield.....A        |             |                | 0                 | 8           | 61    | 249  | 615  | 908  | 1001 | 790  | 632  | 295  | 143  | 16   | 4632         |      |      |
| Neb.             | Billings.....A           | 15/16-25/26 | 11             | 8                 | 20          | 194   | 497  | 876  | 1172 | 1305 | 1089 | 558  | 564  | 304  | 119  | 7166         |      |      |
|                  | Havre.....C              |             |                | 20                | 38          | 270   | 564  | 1023 | 1383 | 1513 | 1291 | 1076 | 597  | 313  | 125  | 8213         |      |      |
|                  | Helena.....A             |             |                | 36                | 66          | 320   | 617  | 990  | 1311 | 1489 | 1165 | 1017 | 654  | 399  | 197  | 8250         |      |      |
|                  | Helena.....C             |             |                | 51                | 78          | 359   | 598  | 969  | 1215 | 1438 | 1114 | 992  | 660  | 427  | 225  | 8126         |      |      |
|                  | Kalispell.....A          |             |                | 47                | 83          | 326   | 639  | 990  | 1249 | 1386 | 1120 | 970  | 639  | 391  | 215  | 8055         |      |      |
|                  | Miles City.....A         |             |                | 11                | 137         | 611   | 137  | 611  | 137  | 611  | 137  | 611  | 137  | 611  | 137  | 611          | 137  | 611  |
|                  | Missoula.....A           |             |                | 22                | 57          | 292   | 623  | 993  | 1283 | 1414 | 1100 | 939  | 609  | 365  | 176  | 7873         |      |      |
|                  | Drexel.....A             |             |                | 4                 | 6           | 95    | 405  | 788  | 1271 | 1353 | 1096 | 843  | 493  | 219  | 38   | 6511         |      |      |
|                  | Lincoln.....A            |             |                | 0                 | 12          | 82    | 340  | 774  | 1144 | 1271 | 1030 | 822  | 401  | 190  | 38   | 6014         |      |      |
|                  | Lincoln.....C            |             |                | 0                 | 7           | 79    | 310  | 741  | 1113 | 1240 | 1000 | 794  | 377  | 172  | 32   | 5865         |      |      |
|                  | North Platte.....A       |             |                | 7                 | 11          | 120   | 425  | 746  | 1112 | 1271 | 1015 | 887  | 489  | 243  | 59   | 6546         |      |      |
|                  | Omaha.....A              |             |                | 0                 | 5           | 83    | 331  | 783  | 1166 | 1302 | 1058 | 831  | 389  | 175  | 32   | 6160         |      |      |
| Nev.             | Valentine.....C          | 05/08-40/41 | 36             | 11                | 10          | 145   | 461  | 891  | 1212 | 1361 | 1100 | 970  | 543  | 288  | 83   | 7075         |      |      |
|                  | Reno.....A               |             |                | 27                | 61          | 163   | 443  | 744  | 986  | 1048 | 804  | 766  | 519  | 318  | 165  | 6036         |      |      |
|                  | Tonopah.....A            |             |                | 0                 | 5           | 96    | 422  | 723  | 995  | 1082 | 860  | 750  | 504  | 272  | 91   | 5813         |      |      |
|                  | Winnemucca.....A         |             |                | 0                 | 17          | 180   | 508  | 822  | 1085 | 1153 | 854  | 794  | 546  | 299  | 111  | 6369         |      |      |
| N.H.             | Concord.....A            | 05/08-40/41 | 36             | 11                | 57          | 192   | 527  | 849  | 1271 | 1392 | 1226 | 1099 | 660  | 316  | 82   | 7612         |      |      |
| N.J.             | Atlantic City.....C      |             |                | 0                 | 0           | 29    | 230  | 507  | 831  | 905  | 829  | 729  | 468  | 189  | 24   | 4741         |      |      |
|                  | Cape May.....A           |             |                | 0                 | 1           | 2     | 38   | 221  | 527  | 852  | 936  | 737  | 459  | 188  | 33   | 4570         |      |      |
|                  | Newark.....A             |             |                | 0                 | 0           | 47    | 301  | 603  | 961  | 1039 | 932  | 760  | 459  | 148  | 11   | 5252         |      |      |
| N.M.             | Sandy Hook.....A         | 15/16-40/41 | 26             | 1                 | 2           | 40    | 268  | 579  | 921  | 1016 | 873  | 633  | 499  | 206  | 31   | 5389         |      |      |
|                  | Trenton.....C            |             |                | 0                 | 0           | 55    | 285  | 582  | 930  | 1004 | 904  | 735  | 429  | 133  | 11   | 5068         |      |      |
|                  | Albuquerque.....A        |             |                | 0                 | 0           | 10    | 218  | 630  | 899  | 970  | 714  | 589  | 289  | 70   | 0    | 4389         |      |      |
|                  | Roswell.....A            |             |                | 0                 | 0           | 8     | 156  | 501  | 750  | 787  | 566  | 443  | 185  | 28   | 0    | 3424         |      |      |
| N.Y.             | Sante Fe.....A           | 05/08-45/46 | 40             | 12                | 15          | 129   | 451  | 770  | 1071 | 1094 | 892  | 786  | 544  | 297  | 60   | 6123         |      |      |
|                  | Albany.....A             |             |                | 24                | 139         | 443   | 780  | 1197 | 1318 | 1179 | 989  | 597  | 246  | 50   | 5962 |              |      |      |
|                  | Albany.....C             |             |                | 0                 | 6           | 98    | 388  | 708  | 1113 | 1234 | 1103 | 905  | 531  | 202  | 31   | 6319         |      |      |
|                  | Binghamton.....A         |             |                | 16                | 63          | 162   | 518  | 834  | 1228 | 1342 | 1215 | 1051 | 672  | 318  | 88   | 7537         |      |      |
|                  | Binghamton.....C         |             |                | 0                 | 36          | 141   | 428  | 735  | 1113 | 1218 | 1109 | 927  | 570  | 240  | 48   | 6556         |      |      |
|                  | Buffalo.....A            |             |                | 16                | 30          | 122   | 433  | 753  | 1116 | 1225 | 1128 | 992  | 636  | 315  | 72   | 6833         |      |      |
|                  | Canton.....A             |             |                | 27                | 61          | 219   | 550  | 898  | 1368 | 1516 | 1383 | 1139 | 695  | 340  | 107  | 8305         |      |      |
|                  | Ithaca.....A             |             |                | 99/00-42/43       | 44          | 17    | 40   | 156  | 451  | 770  | 1129 | 1236 | 1156 | 978  | 606  | 292          | 83   | 6914 |
|                  | New York.....A           | 09/00-42/43 | 44             | 0                 | 0           | 28    | 250  | 546  | 908  | 992  | 907  | 760  | 447  | 141  | 10   | 4989         |      |      |
| La Guardia.....A |                          |             |                |                   |             |       |      |      |      |      |      |      |      |      |      |              |      |      |

TABLE 2. AVERAGE MONTHLY AND YEARLY DEGREE-DAYS FOR CITIES IN THE UNITED STATES AND CANADA\* b. c. (CONTINUED)

| STATE  | STATION                     | YEARS | No. OF SEASONS | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | APR. | MAY | JUNE | YEARLY TOTAL |
|--------|-----------------------------|-------|----------------|------|------|-------|------|------|------|------|------|------|------|-----|------|--------------|
| N.Y.   | New York Central Park Obs.  |       |                | 0    | 0    | 39    | 263  | 561  | 908  | 995  | 904  | 753  | 456  | 153 | 18   | 5050         |
|        | Oswego                      |       |                | 20   | 0    | 31    | 250  | 552  | 902  | 1001 | 910  | 747  | 435  | 130 | 7    | 4965         |
|        | Rochester                   |       |                | 9    | 34   | 133   | 440  | 759  | 1141 | 1249 | 1148 | 992  | 615  | 289 | 54   | 6863         |
| N.C.   | Syracuse                    |       |                | 0    | 28   | 117   | 306  | 714  | 1135 | 1225 | 1117 | 955  | 670  | 247 | 37   | 6320         |
|        | Asheville                   |       |                | 0    | 0    | 50    | 262  | 552  | 769  | 794  | 872  | 872  | 285  | 105 | 8    | 4083         |
|        | Charlotte                   |       |                | 0    | 0    | 0     | 7    | 147  | 438  | 682  | 704  | 577  | 449  | 172 | 29   | 3205         |
|        | Hatteras                    |       |                | 0    | 0    | 0     | 6    | 324  | 481  | 527  | 487  | 394  | 171  | 25  | 0    | 2392         |
|        | Manteo                      |       |                | 0    | 0    | 7     | 113  | 538  | 595  | 642  | 594  | 469  | 249  | 75  | 7    | 3109         |
|        | Raleigh                     |       |                | 0    | 0    | 16    | 149  | 438  | 701  | 732  | 617  | 577  | 202  | 41  | 0    | 3369         |
|        | Raleigh                     |       |                | 0    | 0    | 10    | 118  | 387  | 651  | 691  | 577  | 440  | 172  | 29  | 0    | 3075         |
| N.D.   | Wilmington                  |       |                | 0    | 0    | 0     | 7    | 288  | 508  | 533  | 463  | 347  | 104  | 7   | 0    | 2323         |
|        | Bismarck                    |       |                | 29   | 37   | 227   | 598  | 1098 | 1535 | 1730 | 1464 | 1187 | 657  | 355 | 116  | 9033         |
|        | Devils Lake                 |       |                | 41   | 61   | 276   | 564  | 1197 | 1668 | 1866 | 1576 | 1314 | 760  | 394 | 137  | 9940         |
|        | Grand Forks                 |       |                |      |      |       |      |      |      |      |      |      |      |     |      |              |
|        | Williston                   |       |                | 32   | 60   | 274   | 663  | 1160 | 1681 | 1895 | 1608 | 1298 | 718  | 359 | 123  | 9678         |
| Ohio.  | Cincinnati                  |       |                | 42   | 261  | 605   | 1011 | 1528 | 1705 | 1442 | 1194 | 683  | 360  | 138 | 138  | 9012         |
|        | Cincinnati                  |       |                | 0    | 6    | 77    | 295  | 648  | 973  | 1029 | 871  | 732  | 392  | 149 | 23   | 5195         |
|        | Cincinnati Abbe Obs.        |       |                | 0    | 0    | 42    | 222  | 567  | 880  | 942  | 812  | 645  | 314  | 108 | 0    | 4532         |
|        | Cleveland                   |       |                | 0    | 0    | 56    | 263  | 612  | 930  | 989  | 846  | 682  | 347  | 132 | 13   | 4870         |
|        | Cleveland                   |       |                | 0    | 10   | 75    | 340  | 699  | 1057 | 1132 | 1019 | 874  | 531  | 223 | 46   | 6006         |
|        | Columbus                    |       |                | 0    | 9    | 80    | 311  | 636  | 995  | 1011 | 977  | 846  | 510  | 223 | 49   | 5717         |
|        | Columbus                    |       |                | 0    | 8    | 89    | 337  | 693  | 1032 | 1094 | 946  | 781  | 445  | 188 | 31   | 5615         |
|        | Dayton                      |       |                | 0    | 59   | 299   | 629  | 1051 | 907  | 741  | 408  | 313  | 227  | 103 | 22   | 4735         |
|        | Dayton                      |       |                | 0    | 5    | 74    | 324  | 693  | 1032 | 1094 | 946  | 781  | 445  | 188 | 39   | 5597         |
|        | Sandusky                    |       |                | 0    | 0    | 66    | 327  | 654  | 1129 | 1122 | 997  | 853  | 513  | 217 | 41   | 6034         |
|        | Toledo                      |       |                | 0    | 12   | 102   | 387  | 756  | 1119 | 1197 | 1056 | 905  | 555  | 245 | 60   | 6394         |
| Okla.  | Broken Arrow                |       |                | 0    | 0    | 28    | 169  | 513  | 805  | 881  | 646  | 506  | 212  | 61  | 5    | 3828         |
|        | Oklahoma City               |       |                | 0    | 0    | 14    | 154  | 480  | 769  | 865  | 560  | 409  | 182  | 40  | 0    | 3644         |
|        | Oklahoma City               |       |                | 0    | 0    | 12    | 149  | 459  | 747  | 843  | 630  | 472  | 169  | 38  | 0    | 3519         |
| Ore.   | Baker                       |       |                | 25   | 47   | 265   | 518  | 852  | 1138 | 1268 | 972  | 837  | 691  | 384 | 200  | 7087         |
|        | Medford                     |       |                | 0    | 0    | 7     | 226  | 624  | 822  | 862  | 687  | 652  | 381  | 207 | 69   | 4434         |
|        | Portland                    |       |                | 25   | 22   | 116   | 319  | 585  | 750  | 856  | 685  | 570  | 396  | 24  | 83   | 4632         |
|        | Portland                    |       |                | 13   | 11   | 35    | 280  | 335  | 701  | 694  | 515  | 343  | 199  | 70  | 174  | 3997         |
| Pa.    | Roseburg                    |       |                | 0    | 9    | 98    | 283  | 531  | 694  | 744  | 563  | 509  | 366  | 223 | 83   | 4127         |
|        | Erie                        |       |                | 0    | 17   | 76    | 352  | 672  | 1020 | 1128 | 939  | 911  | 573  | 273 | 55   | 6110         |
|        | Harrisburg                  |       |                | 0    | 0    | 69    | 308  | 630  | 964  | 1051 | 921  | 750  | 423  | 128 | 14   | 5255         |
|        | Philadelphia                |       |                | 0    | 0    | 47    | 269  | 573  | 902  | 986  | 879  | 704  | 402  | 104 | 0    | 4866         |
|        | Philadelphia                |       |                | 0    | 0    | 33    | 219  | 516  | 856  | 933  | 837  | 667  | 369  | 93  | 0    | 4522         |
|        | Pittsburg Allegheny         |       |                | 0    | 6    | 78    | 336  | 678  | 1004 | 1073 | 955  | 784  | 447  | 167 | 27   | 5555         |
|        | Pittsburg                   |       |                |      |      |       |      |      |      |      |      |      |      |     |      |              |
|        | Greater Pittsburg           |       |                | 0    | 20   | 94    | 377  | 720  | 1057 | 1116 | 986  | 818  | 486  | 195 | 36   | 5040         |
|        | Pittsburg                   |       |                | 0    | 0    | 56    | 298  | 612  | 924  | 992  | 879  | 735  | 402  | 137 | 13   | 5910         |
|        | Reading                     |       |                | 0    | 5    | 57    | 285  | 588  | 936  | 1017 | 902  | 725  | 411  | 123 | 11   | 5056         |
| R. I.  | Seranton                    |       |                | 0    | 18   | 115   | 389  | 693  | 1057 | 1141 | 1028 | 859  | 516  | 196 | 35   | 6041         |
|        | Block Island                |       |                | 6    | 21   | 88    | 330  | 591  | 927  | 1026 | 955  | 865  | 603  | 335 | 96   | 5843         |
|        | Narragansett Pier           |       |                |      |      |       |      |      |      |      |      |      |      |     |      |              |
|        | Providence                  |       |                | 1    | 26   | 121   | 366  | 691  | 1012 | 1113 | 1074 | 916  | 622  | 342 | 113  | 6397         |
|        | Providence                  |       |                | 0    | 28   | 107   | 381  | 672  | 1035 | 1125 | 1019 | 874  | 570  | 258 | 58   | 6121         |
| S. C.  | Charleston                  |       |                | 0    | 7    | 68    | 330  | 624  | 986  | 1072 | 972  | 809  | 507  | 197 | 31   | 5670         |
|        | Charleston                  |       |                | 0    | 0    | 0     | 52   | 270  | 456  | 478  | 379  | 281  | 63   | 0   | 0    | 1907         |
|        | Charleston                  |       |                | 0    | 0    | 0     | 34   | 214  | 410  | 445  | 368  | 260  | 43   | 0   | 0    | 1768         |
|        | Columbia                    |       |                | 0    | 0    | 0     | 82   | 338  | 556  | 566  | 468  | 340  | 83   | 0   | 0    | 2438         |
|        | Columbia                    |       |                | 0    | 0    | 0     | 76   | 308  | 524  | 538  | 443  | 318  | 77   | 0   | 0    | 2288         |
|        | Due West                    |       |                | 0    | 0    | 9     | 142  | 393  | 594  | 651  | 491  | 411  | 158  | 39  | 2    | 2896         |
|        | Greenville                  |       |                | 0    | 0    | 10    | 131  | 411  | 648  | 673  | 552  | 442  | 161  | 32  | 0    | 3069         |
| S. D.  | Huron                       |       |                | 10   | 16   | 149   | 472  | 975  | 1407 | 1597 | 1327 | 1032 | 558  | 279 | 80   | 7900         |
|        | Pierre                      |       |                |      |      |       |      |      |      |      |      |      |      |     |      |              |
|        | Rapid City                  |       |                | 4    | 11   | 136   | 438  | 887  | 1317 | 1460 | 1253 | 971  | 516  | 238 | 52   | 7285         |
| Tenn.  | Chattanooga                 |       |                | 32   | 24   | 193   | 600  | 891  | 1218 | 1361 | 1151 | 1045 | 615  | 357 | 148  | 7538         |
|        | Knoxville                   |       |                | 0    | 0    | 24    | 169  | 477  | 710  | 725  | 588  | 467  | 179  | 45  | 0    | 3389         |
|        | Knoxville                   |       |                | 0    | 0    | 33    | 179  | 498  | 744  | 760  | 630  | 507  | 196  | 50  | 0    | 3595         |
|        | Memphis                     |       |                | 0    | 0    | 17    | 129  | 432  | 673  | 725  | 57   | 427  | 139  | 29  | 0    | 3133         |
|        | Memphis                     |       |                | 0    | 0    | 13    | 98   | 392  | 639  | 716  | 674  | 423  | 133  | 20  | 0    | 3040         |
|        | Nashville                   |       |                | 0    | 0    | 22    | 154  | 471  | 725  | 778  | 638  | 498  | 186  | 43  | 0    | 3515         |
| Texas. | Abilene                     |       |                | 0    | 0    | 5     | 98   | 350  | 595  | 673  | 479  | 344  | 113  | 0   | 0    | 2655         |
|        | Amarillo                    |       |                | 0    | 0    | 37    | 240  | 594  | 959  | 921  | 711  | 536  | 298  | 99  | 0    | 4343         |
|        | Austin                      |       |                | 0    | 0    | 0     | 30   | 214  | 402  | 484  | 322  | 211  | 50   | 0   | 0    | 1717         |
|        | Brownsville                 |       |                | 0    | 0    | 0     | 0    | 5    | 159  | 219  | 106  | 74   | 0    | 0   | 0    | 611          |
|        | Corpus Christi              |       |                | 0    | 0    | 0     | 0    | 113  | 252  | 330  | 192  | 118  | 6    | 0   | 0    | 1011         |
|        | Dallas                      |       |                | 0    | 0    | 0     | 53   | 299  | 518  | 607  | 432  | 288  | 76   | 0   | 0    | 2277         |
|        | Del Rio                     |       |                | 0    | 0    | 0     | 26   | 188  | 371  | 419  | 235  | 147  | 21   | 0   | 0    | 1400         |
|        | El Paso                     |       |                | 0    | 0    | 0     | 70   | 390  | 626  | 670  | 445  | 350  | 110  | 0   | 0    | 2841         |
|        | Fort Worth                  |       |                | 0    | 0    | 0     | 58   | 299  | 553  | 622  | 446  | 308  | 90   | 5   | 0    | 2365         |
|        | Fort Worth Amon Carter Fld. |       |                | 0    | 0    | 0     | 57   | 299  | 524  | 619  | 432  | 326  | 81   | 0   | 0    | 2331         |
|        | Galveston                   |       |                | 0    | 0    | 0     | 0    | 132  | 286  | 362  | 249  | 176  | 28   | 0   | 0    | 1233         |
|        | Galveston                   |       |                | 0    | 0    | 0     | 0    | 131  | 271  | 356  | 247  | 176  | 30   | 0   | 0    | 1211         |
|        | Houston                     |       |                | 0    | 0    | 0     | 7    | 181  | 321  | 394  | 265  | 184  | 36   | 0   | 0    | 1388         |
|        | Houston                     |       |                | 0    | 0    | 0     | 0    | 162  | 303  | 378  | 240  | 166  | 27   | 0   | 0    | 1270         |

TABLE 2. AVERAGE MONTHLY AND YEARLY DEGREE-DAYS FOR CITIES IN THE UNITED STATES AND CANADA<sup>a, b, c</sup> (CONCLUDED)

| STATE OR PROVINCE | STATION                           | YEARS       | NO. OF SEASONS | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | APR. | MAY  | JUNE | YEARLY TOTAL |      |
|-------------------|-----------------------------------|-------------|----------------|------|------|-------|------|------|------|------|------|------|------|------|------|--------------|------|
| Texas.            | Palestine.....C                   |             |                | 0    | 0    | 0     | 45   | 260  | 440  | 531  | 368  | 265  | 71   | 0    | 0    | 1980         |      |
|                   | Port Arthur.....C                 |             |                | 0    | 0    | 0     | 20   | 218  | 349  | 406  | 274  | 211  | 39   | 0    | 0    | 1517         |      |
|                   | Port Arthur.....C                 |             |                | 0    | 0    | 0     | 0    | 8    | 170  | 315  | 381  | 258  | 181  | 27   | 0    | 1340         |      |
|                   | San Antonio.....A                 |             |                | 0    | 0    | 0     | 25   | 201  | 374  | 462  | 293  | 190  | 34   | 0    | 0    | 1579         |      |
|                   | Taylor.....C                      | 01/02-40/41 | 40             | 0    | 0    | 2     | 56   | 234  | 462  | 494  | 375  | 214  | 64   | 8    | 0    | 1909         |      |
| Utah.             | Modena.....C                      | 00/01-45/46 | 46             | 6    | 11   | 156   | 499  | 832  | 1142 | 1190 | 944  | 816  | 507  | 338  | 97   | 6593         |      |
|                   | Salt Lake City.....A              |             |                | 0    | 0    | 88    | 381  | 771  | 1039 | 1194 | 885  | 741  | 453  | 233  | 31   | 5886         |      |
| Vt.               | Salt Lake City.....C              |             |                | 0    | 0    | 61    | 330  | 714  | 995  | 1119 | 857  | 701  | 414  | 208  | 64   | 5463         |      |
|                   | Burlington.....A                  |             |                | 19   | 47   | 172   | 521  | 858  | 1308 | 1460 | 1313 | 1107 | 681  | 307  | 72   | 7865         |      |
| Va.               | Northfield.....A                  | 98/99-42/43 | 45             | 62   | 112  | 283   | 602  | 947  | 1389 | 1524 | 1384 | 1176 | 754  | 405  | 166  | 8804         |      |
|                   | Cape Henry.....C                  |             |                | 0    | 0    | 0     | 120  | 366  | 648  | 698  | 636  | 512  | 267  | 60   | 0    | 3307         |      |
|                   | Lynchburg.....A                   |             |                | 0    | 0    | 49    | 236  | 531  | 809  | 846  | 722  | 584  | 289  | 82   | 5    | 4153         |      |
|                   | Norfolk.....A                     |             |                | 0    | 0    | 9     | 152  | 408  | 688  | 729  | 644  | 500  | 265  | 59   | 0    | 3454         |      |
|                   | Norfolk.....C                     |             |                | 0    | 0    | 5     | 118  | 354  | 636  | 679  | 602  | 464  | 220  | 41   | 0    | 3119         |      |
|                   | Richmond.....A                    |             |                | 0    | 0    | 33    | 210  | 498  | 791  | 828  | 708  | 550  | 271  | 66   | 0    | 3955         |      |
|                   | Richmond.....C                    |             |                | 0    | 0    | 31    | 181  | 456  | 750  | 787  | 678  | 529  | 264  | 57   | 0    | 3720         |      |
| Wash.             | Wytheville.....C                  | 02/03-40/41 | 39             | 7    | 13   | 82    | 352  | 662  | 916  | 945  | 836  | 677  | 410  | 168  | 35   | 5103         |      |
|                   | North Head L.H. Reservation.....C |             |                | 239  | 205  | 234   | 341  | 486  | 636  | 704  | 585  | 598  | 492  | 406  | 285  | 6211         |      |
|                   | Seattle.....C                     |             |                | 49   | 45   | 134   | 329  | 540  | 679  | 753  | 602  | 558  | 396  | 246  | 107  | 4438         |      |
|                   | Seattle-Tacoma.....C              |             |                | 75   | 70   | 192   | 412  | 633  | 781  | 862  | 675  | 636  | 477  | 307  | 155  | 5275         |      |
|                   | Spokane.....A                     |             |                | 17   | 28   | 205   | 508  | 879  | 1113 | 1243 | 988  | 834  | 561  | 330  | 146  | 6852         |      |
|                   | Tacoma.....C                      |             |                | 66   | 62   | 177   | 375  | 579  | 719  | 797  | 636  | 595  | 435  | 282  | 143  | 4866         |      |
|                   | Tatoosh Island.....C              |             |                | 295  | 288  | 315   | 406  | 529  | 648  | 713  | 610  | 629  | 525  | 437  | 330  | 5724         |      |
|                   | Walla Walla.....C                 |             |                | 0    | 0    | 93    | 308  | 675  | 890  | 1023 | 748  | 564  | 338  | 171  | 38   | 4948         |      |
|                   | Yakima.....A                      |             |                | 0    | 0    | 7     | 150  | 446  | 807  | 1066 | 1181 | 932  | 660  | 408  | 205  | 53           | 5845 |
|                   | Elkins.....A                      |             |                | 9    | 31   | 122   | 412  | 726  | 995  | 1017 | 910  | 797  | 477  | 224  | 53   | 5773         |      |
| W. Va.            | Parkersburg.....C                 |             |                | 0    | 0    | 56    | 272  | 600  | 896  | 949  | 826  | 672  | 347  | 119  | 13   | 4750         |      |
|                   | Green Bay.....A                   |             |                | 32   | 58   | 183   | 515  | 945  | 1392 | 1516 | 1336 | 1132 | 695  | 347  | 107  | 8259         |      |
|                   | La Crosse.....A                   |             |                | 11   | 20   | 152   | 447  | 921  | 1380 | 1528 | 1280 | 1035 | 552  | 250  | 74   | 7650         |      |
|                   | Madison.....A                     |             |                | 13   | 31   | 150   | 459  | 891  | 1302 | 1423 | 1207 | 1008 | 579  | 272  | 82   | 7417         |      |
|                   | Madison.....C                     |             |                | 10   | 30   | 137   | 419  | 864  | 1287 | 1417 | 1207 | 1011 | 573  | 266  | 79   | 7300         |      |
| Wyo.              | Milwaukee.....A                   |             |                | 20   | 32   | 134   | 428  | 831  | 1218 | 1336 | 1142 | 983  | 621  | 351  | 109  | 7205         |      |
|                   | Milwaukee.....C                   |             |                | 11   | 24   | 112   | 397  | 795  | 1184 | 1302 | 1117 | 951  | 606  | 325  | 100  | 6944         |      |
|                   | Wausau.....A                      | 15/16-40/41 | 26             | 28   | 58   | 216   | 568  | 982  | 1427 | 1594 | 1381 | 1147 | 680  | 315  | 100  | 8494         |      |
|                   | Cheyenne.....A                    |             |                | 32   | 39   | 241   | 577  | 897  | 1125 | 1225 | 1044 | 1029 | 717  | 462  | 173  | 7562         |      |
|                   | Lander.....A                      |             |                | 7    | 23   | 244   | 632  | 1050 | 1383 | 1494 | 1179 | 1045 | 587  | 396  | 163  | 8303         |      |
|                   | Yellowstone Park.....C            | 04/05-40/41 | 37             | 125  | 173  | 424   | 759  | 1079 | 1386 | 1464 | 1252 | 1165 | 641  | 603  | 334  | 9605         |      |
| Alta.             | Calgary.....C                     | 1921-50     | 30             | 110  | 170  | 410   | 710  | 1110 | 1430 | 1530 | 1350 | 1200 | 770  | 460  | 270  | 9520         |      |
|                   | Edmonton.....C                    | 1921-50     | 30             | 90   | 180  | 440   | 750  | 1220 | 1660 | 1780 | 1520 | 1290 | 780  | 410  | 220  | 10350        |      |
|                   | Lethbridge.....C                  | 1921-50     | 30             | 60   | 100  | 350   | 620  | 1030 | 1380 | 1450 | 1260 | 1130 | 690  | 320  | 130  | 8650         |      |
|                   | Medicine Hat.....C                | 1921-50     | 30             | 20   | 50   | 300   | 600  | 1070 | 1440 | 1590 | 1380 | 1130 | 730  | 470  | 260  | 9500         |      |
|                   | Prince George.....C               | 1921-50     | 30             | 180  | 220  | 440   | 730  | 1100 | 1450 | 1560 | 1290 | 1070 | 730  | 470  | 260  | 9500         |      |
| B.C.              | Prince Rupert.....C               | 1921-50     | 30             | 270  | 240  | 340   | 510  | 680  | 860  | 910  | 810  | 700  | 550  | 400  | 290  | 5230         |      |
|                   | Vancouver.....C                   | 1921-45     | 25             | 60   | 60   | 200   | 410  | 620  | 790  | 850  | 710  | 650  | 460  | 290  | 130  | 5410         |      |
|                   | Victoria.....C                    | 1921-50     | 30             | 160  | 150  | 230   | 410  | 600  | 730  | 800  | 680  | 620  | 470  | 350  | 230  | 5410         |      |
|                   | Brandon.....C                     | 1921-50     | 30             | 60   | 100  | 350   | 730  | 1290 | 1810 | 2010 | 1730 | 1440 | 820  | 420  | 170  | 10530        |      |
|                   | Churhill.....C                    | 1926-50     | 25             | 310  | 370  | 650   | 1110 | 1750 | 2300 | 2520 | 2270 | 2150 | 1590 | 1100 | 690  | 16810        |      |
| Man.              | Winnipeg.....C                    | 1921-50     | 30             | 40   | 70   | 300   | 690  | 1250 | 1770 | 2000 | 1710 | 1440 | 810  | 400  | 150  | 10630        |      |
|                   | Fredericton.....C                 | 1921-50     | 30             | 50   | 70   | 250   | 600  | 940  | 1410 | 1570 | 1410 | 1180 | 780  | 420  | 150  | 8530         |      |
|                   | Moncton.....C                     | 1939-50     | 12             | 40   | 80   | 240   | 580  | 890  | 1340 | 1510 | 1340 | 1180 | 830  | 460  | 210  | 8700         |      |
|                   | Saint John.....C                  | 1921-50     | 30             | 110  | 110  | 250   | 530  | 830  | 1250 | 1400 | 1270 | 1100 | 780  | 500  | 250  | 8380         |      |
|                   | Corner Brook.....C                | 1933-50     | 18             | 90   | 140  | 320   | 640  | 890  | 1230 | 1410 | 1360 | 1240 | 900  | 640  | 350  | 9210         |      |
| Nfld.             | Cander.....C                      | 1937-50     | 14             | 130  | 160  | 320   | 660  | 920  | 1230 | 1430 | 1320 | 1270 | 970  | 650  | 380  | 9440         |      |
|                   | Cooper's Bay.....C                | 1941-51     | 10             | 130  | 220  | 440   | 840  | 1220 | 1740 | 2020 | 1710 | 1530 | 1110 | 770  | 410  | 12140        |      |
|                   | St. John's.....C                  |             | 19             | 170  | 160  | 320   | 580  | 820  | 1100 | 1270 | 1230 | 1160 | 810  | 680  | 380  | 8780         |      |
|                   | Aklavik.....C                     | 1926-50     | 25             | 280  | 460  | 800   | 1400 | 2040 | 2500 | 2580 | 2310 | 2280 | 1690 | 1050 | 480  | 17870        |      |
|                   | Fort Norman.....C                 |             | 25             | 170  | 350  | 700   | 1220 | 1940 | 2460 | 2550 | 2190 | 2040 | 1390 | 730  | 280  | 16020        |      |
| N.S.              | Halifax.....C                     | 1921-50     | 30             | 50   | 70   | 180   | 470  | 740  | 1120 | 1260 | 1180 | 1050 | 790  | 480  | 210  | 7570         |      |
|                   | Port Norman.....C                 | 1921-50     | 30             | 60   | 80   | 220   | 510  | 780  | 1130 | 1310 | 1230 | 1160 | 850  | 570  | 270  | 8220         |      |
|                   | Sydney.....C                      | 1921-50     | 30             | 110  | 120  | 230   | 480  | 720  | 1040 | 1180 | 1100 | 1010 | 750  | 510  | 270  | 7520         |      |
|                   | Yarmouth.....C                    | 1921-50     | 30             | 90   | 120  | 350   | 690  | 1140 | 1590 | 1780 | 1550 | 1360 | 890  | 550  | 240  | 10350        |      |
|                   | Fort William.....C                | 1921-50     | 30             | 110  | 170  | 410   | 780  | 1270 | 1780 | 2060 | 1770 | 1570 | 1030 | 600  | 240  | 11790        |      |
| Ont.              | Hamilton.....C                    | 1921-50     | 30             | 40   | 160  | 500   | 820  | 1250 | 1420 | 1290 | 1110 | 710  | 380  | 100  | 7810 |              |      |
|                   | Kapuskasing.....C                 | 1921-50     | 30             | 20   | 40   | 150   | 490  | 840  | 1200 | 1320 | 1210 | 1040 | 650  | 320  | 90   | 7380         |      |
|                   | Kingston.....C                    | 1921-50     | 30             | 30   | 60   | 210   | 590  | 960  | 1480 | 1640 | 1480 | 1230 | 730  | 340  | 80   | 7020         |      |
|                   | London.....C                      | 1921-50     | 30             | 30   | 60   | 210   | 590  | 960  | 1480 | 1640 | 1480 | 1230 | 730  | 340  | 80   | 7020         |      |
|                   | Ottawa.....C                      | 1921-50     | 30             | 20   | 30   | 140   | 460  | 770  | 1130 | 1260 | 1180 | 1020 | 640  | 320  | 70   | 8350         |      |
| P.E.I.            | Toronto.....C                     | 1921-50     | 30             | 20   | 30   | 140   | 460  | 770  | 1130 | 1260 | 1180 | 1020 | 640  | 320  | 70   | 8350         |      |
|                   | Charlottetown.....C               | 1921-50     | 30             | 40   | 60   | 200   | 510  | 820  | 1230 | 1430 | 1340 | 1180 | 840  | 510  | 220  | 8350         |      |
|                   | Arvida.....C                      | 1931-50     | 20             | 60   | 110  | 330   | 690  | 1100 | 1670 | 1830 | 1660 | 1410 | 880  | 480  | 170  | 10440        |      |
|                   | Montreal.....C                    | 1921-50     | 30             | 10   | 40   | 150   | 430  | 890  | 1370 | 1540 | 1370 | 1150 | 700  | 300  | 50   | 8130         |      |
|                   | Quebec City.....C                 | 1921-50     | 30             | 20   | 70   | 250   | 610  | 990  | 1470 | 1640 | 1460 | 1260 | 810  | 400  | 100  | 9070         |      |
| Sask.             | Sherbrooke.....C                  | 1921-50     | 30             | 20   | 70   | 240   | 590  | 920  | 1400 | 1560 | 1410 | 1190 | 750  | 370  | 90   | 8810         |      |
|                   | Prince Albert.....C               | 1921-50     | 30             | 70   | 140  | 410   | 780  | 1350 | 1870 | 2060 | 1750 | 1500 | 850  | 440  | 210  | 11430        |      |
|                   | Regina.....C                      | 1921-50     | 30             | 70   | 110  | 370   | 750  | 1290 | 1740 | 1940 | 1680 | 1420 | 790  | 420  | 190  | 10770        |      |
|                   | Saskatoon.....C                   | 1921-50     | 30             | 60   | 110  | 380   | 760  | 1320 | 1790 | 1990 | 1710 | 1440 | 800  | 420  | 180  | 10960        |      |
|                   | Swift Current.....C               | 1921-50     | 30             | 50   | 90   | 340   | 680  | 1170 | 1550 | 1710 | 1490 | 1260 | 730  | 400  | 190  | 9560         |      |
| Y.T.              | Dawson.....C                      | 1921-50     | 30             | 170  | 320  | 660   | 1170 | 1890 | 2410 | 2510 | 2160 | 1830 | 1100 | 570  | 250  | 15040        |      |

being prepared and must be found by surveying plans, by observation, or by measurement of the building. Values of  $U$  for use in this equation are the unit fuel consumptions per degree-day, obtained as a result of the collection of operating information and listed in Tables 4, 5 and 6. Attention is directed to the nature of these units in the next following sections.

### Unit Fuel Consumptions per Degree-Day

The quantity of fuel used per degree-day in a given heating plant can be reduced to a unit basis in terms of quantity of fuel or steam per degree-day per thousand Btu hourly heat loss at design conditions. A less frequently used basis is quantity of fuel per (degree-day) (square foot of floor area). In fact any convenient unit can be used to relate the consumption to the degree-day and to the building.

The choice of these units requires explanation, and some discrimination and judgment. If the volume basis is used, the net heated space is preferable to the gross building cubage, since gross cubage includes outer walls and certain portions of attic and basement space which are usually unheated. In the absence of data on net heated volume, a figure of 80 per-

TABLE 3. CORRECTION FACTORS FOR OUTSIDE DESIGN TEMPERATURES<sup>a</sup>

| OUTSIDE DESIGN TEMP. F. | -20   | -10   | 0     | +10   | 20    |
|-------------------------|-------|-------|-------|-------|-------|
| Correction Factor.....  | 0.778 | 0.875 | 1.000 | 1.167 | 1.400 |

<sup>a</sup> The multipliers in Table 3, which are high for mild climates and low for cold regions, are not in error as might appear. The unit figures in Tables 4, 5, and 6 are per square foot of radiator or thousand Btu heat loss per degree-day. For equivalent buildings and heating seasons, those in warm climates have lower design heat losses and smaller radiator quantities than those in cold cities. Consequently, the unit figure in quantity of fuel per (square foot of radiator) (degree-day), is larger for warm localities than for colder regions. Since the northern cities have more radiator surface per given building and a higher seasonal degree-day total than cities in the south, the total fuel per season will be larger for the northern city.

cent of the gross volume may be used to obtain the estimated net heated volume. The volume basis has been rather widely used primarily because it is simple to apply. In industrial buildings it is usually easier to obtain the correct volume of a given building than to measure and evaluate the heating capacity

TABLE 4. UNIT FUEL CONSUMPTION CONSTANTS (*U*) FOR GAS<sup>a</sup>  
Based on 0 F Outside Temperature, 70 F Inside Temperature

| HEATING<br>VALUE OF<br>GAS BTU PER<br>Cu Ft | HOT WATER                                 |                         |                       | STEAM                                     |                        |                      | WARM AIR                                                             |                |
|---------------------------------------------|-------------------------------------------|-------------------------|-----------------------|-------------------------------------------|------------------------|----------------------|----------------------------------------------------------------------|----------------|
|                                             | Cu Ft Gas per Degree-Day<br>per Sq Ft EDR |                         |                       | Cu Ft Gas per Degree-Day<br>per Sq Ft EDR |                        |                      | Cu Ft Gas per Degree-<br>Day per 1000 Btu<br>Hourly Design Heat Loss |                |
|                                             | Up to<br>500<br>Sq Ft                     | 500 to<br>1200<br>Sq Ft | Over<br>1200<br>Sq Ft | Up to<br>300<br>Sq Ft                     | 300 to<br>700<br>Sq Ft | Over<br>700<br>Sq Ft | Gravity                                                              | Fan<br>Systems |
| 500                                         | 0.149                                     | 0.142                   | 0.134                 | 0.254                                     | 0.242                  | 0.231                | 0.896                                                                | 0.861          |
| 535                                         | 0.139                                     | 0.132                   | 0.126                 | 0.237                                     | 0.226                  | 0.216                | 0.840                                                                | 0.805          |
| 800                                         | 0.094                                     | 0.087                   | 0.085                 | 0.159                                     | 0.151                  | 0.144                | 0.560                                                                | 0.538          |
| 1000                                        | 0.075                                     | 0.071                   | 0.068                 | 0.127                                     | 0.121                  | 0.116                | 0.449                                                                | 0.431          |
| 1 Therm<br>=<br>100,000<br>Btu              | Gas Consumption in Therms per Degree-Day  |                         |                       |                                           |                        |                      |                                                                      |                |
|                                             | 0.000743                                  | 0.000709                | 0.000675              | 0.00127                                   | 0.00121                | 0.00116              | 0.00450                                                              | 0.00430        |

<sup>a</sup> Abstracted from Comfort Heating, American Gas Association, 1938 and 5 percent added for operation without night reduction of temperature.

heating plants. They are based on an inside design temperature of 70 F and an outside design temperature of 0 F, and apply only to these conditions. For other outside design conditions corrections must be made by applying factors given in Table 3.

The factors in Table 4, as corrected if necessary, are satisfactory for regions having 3500 to 6500 degree-days per heating season. In regions with less than 3500 degree-days the unit gas consumption is higher than given; where over 6500, the unit is less than given. Ten percent addition or deduction in these cases is recommended by A.G.A. publications. This table cannot be used for making estimates for industrial buildings where low inside temperatures are maintained.

For gas heat values other than those given in Table 4, simply interpolate or extrapolate. It will also be noted that Table 4 applies only to small installations. In general, the larger the installation, the smaller the unit gas consumption becomes, and the values in the table should be used with care, if at all, in large gas-burning installations.

**Example 4:** Estimate the gas required to heat a building located in Chicago, Ill., where the heating season has 6310 degree-days and the gas heating value is 800 Btu per cu ft. The calculated heating requirements are 1000 sq ft of hot water radiation based on design temperature of -10 F and 70 F.

TABLE 5. UNIT FUEL CONSUMPTION<sup>a</sup> CONSTANTS (*U*) FOR OIL<sup>b</sup>  
Based on 0 F Outside Temperature, 70 F Inside Temperature

| UNIT <sup>c</sup>                            | EFFICIENCY IN PERCENT |         |
|----------------------------------------------|-----------------------|---------|
|                                              | 70                    | 80      |
| Gal Oil per Sq Ft Steam Radiator.....        | 0.00105               | 0.00092 |
| Gal Oil per Sq Ft Hot Water Radiator.....    | 0.00066               | 0.00058 |
| Gal Oil per 1000 Btu per Hour Heat Loss..... | 0.00437               | 0.00383 |

<sup>a</sup> Based on a heating value of 141,000 Btu per gallon.

<sup>b</sup> Abstracted by permission from *Degree-Day Handbook* (Second Edition, 1937), by C. Strock and C. H. B. Hotchkiss. Seven percent added for operation without night reduction of temperature and change to heating value of 141,000 Btu per gallon.

<sup>c</sup> Per degree day.

**Solution:** From Table 4, the fuel consumption for a design temperature of 0 F with 800 Btu gas is found to be 0.087 cu ft of gas per (degree-day) (square foot of hot water radiation). From Table 3, the correction factor is 0.875 for -10 F outside design temperature, hence,  $0.875 \times 0.087 = 0.076$ . By Equation 4,

$$F = 0.076 \times 1000 \times 6310 = 480,000 \text{ cu ft.}$$

### Estimating Oil Consumption

Table 5 gives unit fuel consumption factors for oil, similar to those given for gas in Table 4.

The factors in Table 5 apply only to an inside design temperature of 70 F and an outside design temperature of 0 F. For other outside design temperatures, the constants in Table 5 must be multiplied by the values in Table 3 as explained under Estimating Gas Consumption.

Values given in Table 5 assume the use of oil with a heating value of 141,000 Btu per gallon. For other heating values, multiply the values in Table 5 by the ratio of 141,000 divided by the heating value per gallon of fuel being used.

**Example 5:** Estimate the seasonal oil consumption of a boiler, designed for oil firing, in a building located in Toledo, Ohio. The building has a calculated heat loss of 240,000 Btu per hr. The oil heat value is 144,000 Btu per gal, and the assumed seasonal efficiency is 80. The outside design temperature for Toledo is -10 F, and the inside design temperature is 70 F.

**Solution:** From Table 5, under 80 percent efficiency and in the bottom line, the value of *U* is found to be 0.00383 gal per 1000 Btu hourly heat loss for 0 F outside temperature. The correction factor for -10 F outside design temperature from Table 3 is 0.875. Solving  $0.875 \times 0.00383 = 0.00335$ . Making a further correction for the heating value,

$$0.00335 \times \frac{141,000}{144,000} = 0.00328 \text{ gal per 1000 Btu per hr calculated heat loss per degree-day.}$$

From Table 2, the total normal degree-days for Toledo are 6394. Since *U* is expressed in 1000 Btu, *N* is equal to 240. Substituting in Equation 4

$$F = 0.00328 \times 6394 \times 240 = 5030 \text{ gal.}$$

### Estimating Coal or Coke Consumption

Coal or coke consumption estimates are made by following exactly the same procedure as for oil. Values of *U* are given in Table 6 which only apply to an inside design temperature of 70 F and an outside design temperature of 0 F. A correction must be made for other conditions by use of the multiplying factors in Table 3. Data in Table 6 are based on 12,000

TABLE 6. UNIT FUEL CONSUMPTION<sup>a</sup> CONSTANTS (*U*) FOR COAL<sup>b</sup>  
Based on 0 F Outside Temperature, 70 F Inside Temperature

| UNIT <sup>c</sup>                            | EFFICIENCY IN PERCENT |        |        |        |        |
|----------------------------------------------|-----------------------|--------|--------|--------|--------|
|                                              | 40                    | 50     | 60     | 70     | 80     |
| Lb Coal per Sq Ft Steam Radiator....         | 0.0216                | 0.0172 | 0.0143 | 0.0123 | 0.0108 |
| Lb Coal per Sq Ft Hot Water Radiator..       | 0.0135                | 0.0108 | 0.0091 | 0.0078 | 0.0068 |
| Lb Coal per 1000 Btu per Hour Heat Loss..... | 0.0889                | 0.0717 | 0.0592 | 0.0507 | 0.0444 |

<sup>a</sup> Based on a heating value of 12,000 Btu per pound.

<sup>b</sup> Abstracted by permission from *Degree-Day Handbook* (Second Edition, 1937), by C. Strock and C. H. B. Hotchkiss. Eight percent added for operation without night reduction of temperature.

<sup>c</sup> Per degree-day.

Btu per lb coal, and for other heating values of coal they must be multiplied by the ratio of 12,000 divided by the heating value of fuel used.

**Example 6:** A building in Scranton, Pa. has a calculated heat loss of 240,000 Btu per hr based on an inside design temperature of 70 F and an outside design temperature of -10 F. What will be the estimated normal seasonal anthracite or coke consumption for heating if 13,000 Btu per lb fuel is burned in a hand-fired boiler, with automatic control, at a seasonal efficiency of 80 percent, and what part of the total will be used during November, December, and January?

**Solution:** From Table 6,  $U$  is 0.0444 of coal or coke per 1000 Btu per hr heat loss per degree-day. Correcting for the outside design temperature of -10 F from Table 3, the value of  $U$  is  $0.875 \times 0.0444 = 0.0389$ . From Table 2,  $D$  is 6218 and from the problem,  $N$  is 240.

Substituting in Equation 4,

$$F = 0.0389 \times 240 \times 6047 = 56,500 \text{ lb.}$$

Fuel used over any period is, according to the theory of the degree-day, proportional to the number of degree-days during the period. From Table 2, the average numbers of degree-days for November, December, and January in Scranton are 693, 1057 and 1141 respectively, a total of 2953. The yearly total is 27,000, so that during these three months the estimated consumption is

$$\frac{2953}{27000} \times 56,500 = 27,000 \text{ lb.}$$

### Estimating Steam Consumption

In estimating steam consumption the efficiency is generally assumed at 100 percent. If for low-pressure steam an average heating value of 1000 Btu per pound of steam is used, no correction is necessary. In comparing values from different cities, correction should be made for design temperature (see Table 3) when the unit figures are in terms of heat loss but not when the values are in terms of building volume or floor space.

Where the heat loss is calculated in Btu per (hour) (*degree difference in temperature*) the simple Equation 5 may be used:

$$F = \frac{H \times 24 \times D}{1000} \quad (5)$$

where

$F$  = pounds of steam required for estimate period.

$H$  = calculated heat loss, Btu per (hour) (degree difference).

$24$  = hours in one day.

$D$  = number of degree-days for the period of estimation.

1000 = Btu delivered per pound of steam condensed.

In this method the number of degree-days automatically takes care of average inside and outside temperature difference. When degree-days are taken from Table 2, an average inside temperature of approximately 70 F is assumed throughout the period. If an average inside temperature other than approximately 70 F is to be used, the number of degree-days should be obtained for the new base.

**Example 7:** An eight-story building in Pittsburgh is operated with a daytime temperature of 70 F. The calculated heat loss is 10,500 Btu per (hr) (*degree temperature difference*). What is the estimated average yearly steam consumption for building heating?

**Solution:** Since the average inside temperature is approximately 70 F, the degree-

days from Table 2, based on 70 F may be used. Therefore, from Table 2, Pittsburgh has 5048 degree-days per normal season. Inserting in Equation 5:

$$F = \frac{10,500 \times 24 \times 5048}{1000} = 1,272,000 \text{ lb of steam.}$$

Consideration has been given to the difference in steam utilization of different types of buildings, and Table 7 shows actual average units for these various types. These figures were obtained from operating results in 896 buildings located in all sections of the United States. Being averages, and for small groups in each type, the figures may need considerable modification to allow for local variations. It should be especially noted that the steam used for heating water for service is not included in the values given in Table 7.

TABLE 7. STEAM CONSUMPTION OF BUILDINGS WITH VARIOUS TYPES OF OCCUPANCY\*

| TYPE OF BUILDING                    | No. Bldgs | AVERAGE VOLUME HEATED SPACE 1000 Cu Ft | STEAM FOR HEATING        | AVERAGE HOURS OF OCCUPANCY |
|-------------------------------------|-----------|----------------------------------------|--------------------------|----------------------------|
|                                     |           |                                        | Lb per DD per 1000 Cu Ft |                            |
| Office.....                         | 334       | 2160                                   | 0.685                    | 12.1                       |
| Office and Bank.....                | 49        | 3000                                   | 0.577                    | 13.1                       |
| Office and Printing.....            | 8         | 1895                                   | 1.230                    | 17.7                       |
| Office and Theater.....             | 7         | 4950                                   | 0.412                    | 12.9                       |
| Office and Stores or Shops.....     | 26        | 1615                                   | 0.617                    | 13.2                       |
| Bank.....                           | 16        | 806                                    | 0.786                    | 11.7                       |
| Department Store.....               | 63        | 3400                                   | 0.385                    | 11.1                       |
| Stores.....                         | 73        | 310                                    | 0.624                    | 10.4                       |
| Loft.....                           | 63        | 885                                    | 0.588                    | 10.0                       |
| Warehouse.....                      | 24        | 2230                                   | 0.459                    | 9.4                        |
| Hotel and Club.....                 | 73        | 1795                                   | 0.990                    | 22.3                       |
| Apartment or Residence.....         | 51        | 1425                                   | 0.962                    | 21.8                       |
| Theater.....                        | 22        | 1240                                   | 0.482                    | 12.9                       |
| Garage.....                         | 13        | 1540                                   | 0.202                    | 21.4                       |
| Manufacturing.....                  | 19        | 1350                                   | 0.808                    | 9.5                        |
| Church.....                         | 9         | 656                                    | 0.632                    | 7.9                        |
| Hospital.....                       | 4         | 3306                                   | 1.194                    | 22.0                       |
| School.....                         | 8         | 1115                                   | 0.592                    | 11.5                       |
| Municipal or Federal.....           | 15        | 3215                                   | 0.587                    | 15.6                       |
| Lodge, Gym, Hall or Auditorium..... | 12        | 880                                    | 0.390                    | 12.4                       |
| Miscellaneous.....                  | 7         | 1387                                   | 0.479                    | 21.4                       |

\* Principles of Economical Heating, National Association of Building Owners and Managers

**Example 8:** A store in Philadelphia with a heating system designed to maintain 70 F inside in 0 F weather has 250,000 cu ft of heated space. What would be the estimated average yearly steam consumption of purchased steam for heating?

**Solution:** According to Table 7, a store would use 0.624 lb of steam per degree-day per 1000 cu ft heated space. From Table 2, Philadelphia has 4523 degree-days per normal year. Inserting in Equation 4:

$$F = 0.624 \times 250 \times 4523 = 706,000 \text{ lb of steam.}$$

### Degree-Day as an Operating Unit

The degree-day is also widely used as a means of comparing the efficiency of the fuel consumption of one period with another for the same building. Since the fuel consumption is proportional to the weather (degree-days), and since the periods to be compared may not have the same weather conditions, the comparison can be made only after the fuel consumptions have been computed on a comparable weather basis, that is, upon the actual number of degree-days occurring for a given month and year in the city under consideration. Since fuel consumption is proportional to the number



TABLE 8. DEGREE-DAYS FOR INDUSTRIAL HEATING IN VARIOUS CITIES OF THE UNITED STATES\*

Annual Totals for a Normal Heating Season.

| STATE | CITY            | DEGREE-DAYS |          | STATE | CITY             | DEGREE-DAYS |          |
|-------|-----------------|-------------|----------|-------|------------------|-------------|----------|
|       |                 | 45F Base    | 55F Base |       |                  | 45F Base    | 55F Base |
| Ala.  | Birmingham      | 6           | 853      | Mich. | Houghton         | 4029        | 6112     |
|       | Mobile          |             | 245      |       | Lansing          | 2537        | 4444     |
|       | Montgomery      |             | 504      |       | Marquette        | 3713        | 3843     |
| Aris. | Phoenix         |             | 229      |       | Port Huron       | 2630        | 4275     |
|       | Yuma            |             | 37       |       | Saginaw          | 2313        | 4552     |
|       |                 |             |          |       | Sault Ste. Marie | 4049        | 6575     |
| Ark.  | Fort Smith      | 329         | 1478     | Minn. | Duluth           | 4419        | 6774     |
|       | Little Rock     | 276         | 1188     |       | Minneapolis      | 3309        | 5417     |
|       |                 |             |          |       | Moorhead         | 4796        | 6572     |
| Cal.  | Eureka          |             | 1328     |       | St. Paul         | 2497        | 5497     |
|       | Fresno          | 3           | 718      | Miss. | Vicksburg        |             | 468      |
|       | Independence    | 519         | 1930     |       |                  |             |          |
|       | Los Angeles     |             | 17       |       |                  |             |          |
|       | Red Bluff       | 24          | 822      | Mo.   | Columbia         | 1252        | 2939     |
|       | Sacramento      | 3           | 803      |       | Hannibal         | 1635        | 3231     |
|       | San Diego       |             | 26       |       | Kansas City      | 1463        | 2980     |
|       | San Francisco   |             | 384      |       | St. Louis        | 1186        | 2745     |
|       | San Luis Obispo |             | 230      |       | Springfield      | 982         | 2423     |
| Col.  | Denver          | 1548        | 3440     | Mont. | Havre            | 3736        | 5874     |
|       | Grand Junction  | 1757        | 3433     |       | Helena           | 2843        | 5071     |
|       | Pueblo          | 1499        | 3261     |       | Kalispell        | 2874        | 5131     |
| Conn. | Meriden         |             | 734      | Neb.  | Lincoln          | 3023        | 3850     |
|       | New Haven       | 1769        | 3237     |       | North Platte     | 2291        | 4152     |
|       |                 |             |          |       | Omaha            | 2284        | 3982     |
| D. C. | Washington      | 1041        | 2487     |       | Valentine        | 2833        | 4801     |
| Fla.  | Pensacola       |             | 127      | Nev.  | Winnemucca       | 1670        | 3468     |
| Ga.   | Atlanta         | 109         | 1165     | N. H. | Concord          | 2646        | 4640     |
|       | Augusta         |             | 861      | N. J. | Atlantic City    | 1123        | 2904     |
|       | Macon           |             | 711      | N. M. | Sante Fe         | 1634        | 3106     |
|       | Savannah        |             | 231      |       |                  |             |          |
| Idaho | Boise           | 1045        | 2814     | N. Y. | Albany           | 2018        | 4302     |
|       | Lewiston        | 1034        | 2688     |       | Binghamton       | 2073        | 4206     |
|       | Pocatello       | 2161        | 4140     |       | Buffalo          | 2359        | 4316     |
| Ill.  | Cairo           | 749         | 2119     |       | Ithaca           | 2413        | 4023     |
|       | Chicago         | 1969        | 3743     |       | New York         | 1098        | 3089     |
|       | Springfield     | 1677        | 3289     |       | Oswego           | 2274        | 4363     |
|       |                 |             |          |       | Rochester        | 2341        | 4231     |
| Ind.  | Evansville      | 799         | 2335     | N. C. | Charlotte        | 172         | 1388     |
|       | Indianapolis    | 1307        | 2829     |       | Hatteras         |             | 718      |
| Ia.   | Charles City    | 3370        | 5293     |       | Raleigh          | 229         | 1080     |
|       | Davenport       | 2296        | 4142     |       | Wilmington       |             | 729      |
|       | Des Moines      | 2440        | 4180     | N. D. | Bismarck         | 3831        | 6468     |
|       | Dubuque         | 1628        | 4468     |       | Williston        | 4616        | 6399     |
|       | Keokuk          | 1926        | 3579     |       |                  |             |          |
|       | Sioux City      | 2894        | 4732     | Ohio  | Cincinnati       | 1376        | 3003     |
| Kan.  | Concordia       | 1652        | 2690     |       | Cleveland        | 1525        | 3795     |
|       | Dodge City      | 1385        | 2962     |       | Columbus         | 1600        | 3255     |
|       | Topeka          | 1518        | 1811     |       | Dayton           | 1487        | 3147     |
|       | Wichita         | 1152        | 2587     |       | Sandusky         | 1949        | 3425     |
|       |                 |             |          |       | Toledo           | 1990        | 3757     |
| Ky.   | Lexington       |             | 2557     | Okla. | Oklahoma City    | 600         | 1835     |
|       | Louisville      | 1073        | 2294     |       |                  |             |          |
| La.   | New Orleans     |             | 30       | Ore.  | Baker            | 2321        | 4307     |
|       | Shreveport      |             | 565      |       | Portland         | 373         | 1911     |
|       |                 |             |          |       | Roseburg         | 272         | 1868     |
| Me.   | Eastport        | 2956        | 5236     | Pa.   | Erie             | 2337        | 3837     |
|       | Portland        | 2530        | 4572     |       | Harrisburg       | 1565        | 3236     |
| Md.   | Baltimore       | 988         | 2491     |       | Philadelphia     | 1122        | 2695     |
| Mass. | Boston          | 1787        | 3603     |       | Scranton         | 1935        | 3755     |
|       | Nantucket       | 1514        | 3419     |       | Pittsburgh       | 1377        | 3023     |
| Mich. | Alpena          | 3131        | 5499     | R. I. | Block Island     | 871         | 3388     |
|       | Detroit         | 2240        | 4089     | S. C. | Charleston       |             | 336      |
|       | Escanaba        | 3699        | 5918     |       | Columbia         |             | 759      |
|       | Grand Haven     | 2405        | 3435     |       | Greenville       | 297         | 1502     |
|       | Grand Rapids    | 2332        | 4177     |       |                  |             |          |

TABLE 8. DEGREE-DAYS FOR INDUSTRIAL HEATING IN VARIOUS CITIES OF THE UNITED STATES (Continued)

Annual Totals for a Normal Heating Season.

| STATE | CITY           | DEGREE-DAYS |          | STATE  | CITY        | DEGREE-DAYS |          |
|-------|----------------|-------------|----------|--------|-------------|-------------|----------|
|       |                | 45F Base    | 55F Base |        |             | 45F Base    | 55F Base |
| S. D. | Huron          | 3743        | 5678     | Vt.    | Burlington  | 3014        | 4984     |
|       | Pierre         | 3162        | 5234     |        | Northfield  | 3652        | 7121     |
|       | Rapid City     | 2590        | 4628     | Va.    | Lynchburg   | 554         | 1928     |
|       | Yankton        | 2898        | 6045     |        | Norfolk     | 260         | 1496     |
| Tenn. | Chattanooga    | 242         | 1398     |        | Richmond    | 549         | 1895     |
|       | Knoxville      | 431         | 1741     | Wash.  | North Head  | 184         | 2062     |
|       | Memphis        | 166         | 1284     |        | Seattle     | 408         | 2185     |
|       | Nashville      | 419         | 1678     |        | Spokane     | 1741        | 3672     |
| Tex.  | Abilene        |             | 915      |        | Tacoma      | 507         | 2365     |
|       | Amarillo       | 786         | 2220     |        | Walla Walla | 993         | 2565     |
|       | El Paso        | 32          | 919      | W. Va. | Elkins      | 1506        | 3327     |
|       | Fort Worth     |             | 754      |        | Parkersburg | 1147        | 2784     |
|       | Galveston      |             | 43       | Wis.   | Green Bay   | 3318        | 5331     |
|       | Houston        |             | 110      |        | La Crosse   | 3034        | 3992     |
|       | Indianapolis   |             | 484      |        | Madison     | 3067        | 4650     |
|       | San Antonio    |             | 305      |        | Milwaukee   | 2657        | 4617     |
| Utah  | Modena         | 1978        | 3981     | Wyo.   | Cheyenne    | 2500        | 4700     |
|       | Salt Lake City | 1475        | 3202     |        | Lander      | 3208        | 6450     |

\* From Degree-Day Handbook, by C. Strock and C. H. B. Hotchkiss (The Industrial Press, 1937, pp. 132-134). Values are not coordinated with table 2 which is from a later source.

of degree-days, plant operators frequently compute each month the fuel burned per degree-day by the heating plant. The resulting unit value, by eliminating the outside temperature variable, indicates whether the operating efficiency of the plant is above or below the previous month or year.

### INDUSTRIAL DEGREE-DAYS

When estimating the heating requirements of warehouses, factories, and other buildings where the inside temperature to be maintained differs greatly from the usual inside temperature range of 68 to 72 F, it is common to use degree-days based on temperatures of 55 to 45 F. These are generally referred to as industrial degree-days, and are listed in Table 8 for a number of cities using both 55 F and 45 F as the base. In general, the degree-days (55 F base) are used when the temperature of the heated space is to be maintained at approximately 60 F. For an inside temperature of about 50 F, the degree-days calculated on a 45 F base should be used.

The industrial degree-days are useful for estimating fuel consumption by comparison between localities in which the difference in degree-days is not too great, and where the known fuel consumption of one building may be used to determine unit consumption per degree-day.

### MAXIMUM DEMANDS AND LOAD FACTORS

In one form of district heating rates, a portion of the charge is based upon the maximum demand of the building. The maximum demand may be measured in several different ways. It may be taken as the instantaneous peak or as the rate of use during any specified interval. One method is to take the average of the three highest hours during the winter. These figures are shown for a number of buildings in Detroit in Table 9.<sup>12</sup>



These maximum demands were measured by an attachment on the condensation meter, and therefore represent the amounts of condensation passed through the meter in the highest hours, rather than the true rate at which steam is supplied. There might be slight differences in these two quantities due to time lag and to storage of condensate in the system, but wherever this has been investigated it has been found to be negligible.

TABLE 9. BUILDING LOAD FACTORS AND DEMANDS OF SOME DETROIT BUILDINGS

| BUILDING CLASSIFICATION     | LOAD FACTOR | LB OF DEMAND PER (HOUR) (Sq Ft OF EQUIVALENT INSTALLED RADIATOR SURFACE) |
|-----------------------------|-------------|--------------------------------------------------------------------------|
| Clubs and Lodges.....       | 0.318       | 0.184                                                                    |
| Hotels.....                 | 0.318       | 0.207                                                                    |
| Printing.....               | 0.287       | 0.217                                                                    |
| Offices.....                | 0.283       | 0.209                                                                    |
| Apartments.....             | 0.255       | 0.225                                                                    |
| Retail Stores.....          | 0.238       | 0.182                                                                    |
| Auto Sales and Service..... | 0.223       | 0.248                                                                    |
| Banks.....                  | 0.203       | 0.158                                                                    |
| Churches.....               | 0.158       | 0.152                                                                    |
| Department Stores.....      | 0.138       | 0.145                                                                    |
| Theaters.....               | 0.126       | 0.151                                                                    |

The load factor of a building is the ratio of the average load to the maximum load and is an index of the utilization. Thus, in Table 9, the theaters, operating for short hours, have a load factor of 0.126 as compared with the figure of 0.318 for clubs and lodges.

## REFERENCES

- <sup>1</sup> *Comfort Heating* (American Gas Association, 1938).
- <sup>2</sup> Are Automatic Air Shutters Justified on a Gas-Fired Conversion Burner? by W. M. Myler, Jr. and H. W. Nelson (A.S.H.V.E. TRANSACTIONS, Vol. 55, 1949, p. 111).
- <sup>3</sup> Efficiency of Bituminous-Coal-Burning Space Heater, by J. W. Tieman and F. L. Bagby (A.S.H.V.E. TRANSACTIONS, Vol. 57, 1951, p. 89).
- <sup>4</sup> Heat Losses and Efficiencies of Fuels in Residential Heating, by R. A. Sherman and R. C. Cross (A.S.H.V.E. TRANSACTIONS, Vol. 43, 1937, p. 185).
- <sup>5</sup> The Stoker-Fired Warm-Air Furnace in the Research Residence, by S. Konzo (University of Illinois, Engineering Experiment Station, Circular 39, 1939, p. 98).
- <sup>6</sup> Performance of a Hot Water Heating System in the  $I = B = R$  Research Home at the University of Illinois (University of Illinois, Engineering Experiment Station, Bulletin No. 349, Jan. 4, 1944).
- <sup>7</sup> Fuels and Burners (University of Illinois, Small Homes Council, Circular G3.5, July 1949).
- <sup>8</sup> Investigation of Oil-Fired Forced-Air Furnace Systems in the Research Residence, by A. P. Kratz and S. Konzo (University of Illinois, Engineering Experiment Station, Bulletin No. 318, Nov. 7, 1939).
- <sup>9</sup> Graphical Method of Calculating Heat Losses, by Paul D. Close (A.S.H.V.E. TRANSACTIONS, Vol. 49, 1943, p. 345).
- <sup>10</sup> *House Heating* (Industrial Gas Series, American Gas Association, Third Edition).
- <sup>11</sup> Report of Commercial Relations Committee (Proceedings, National District Heating Association, 1932).
- <sup>12</sup> The Heat Requirements of Buildings, by J. H. Walker and G. H. Tuttle (A.S.H.V.E. TRANSACTIONS, Vol. 41, 1935, p. 171).

## CHAPTER 19

## GRAVITY WARM AIR SYSTEMS

Warm Air Leaders, Stacks, and Registers; Return Air Grilles, Ducts, and Connections; Outline of Design Procedure

WARM air heating systems of the *gravity* type are described in this chapter.<sup>1</sup> In these systems the motive head producing flow depends upon the difference in weight between the heated air leaving the top of the casing and the cooled air entering the bottom of the casing, while in the forced air type a fan may supply all or part of the motive head.

A gravity warm-air furnace heating plant consists of a fuel-burning furnace or heater, enclosed in a casing of sheet metal, which is placed in the basement of the building. The heated air, taken from the bonnet on the top of the furnace casing, is distributed to the various rooms of the building through sheet metal warm air pipes. The warm air pipes in the basement are known as leaders, and the vertical warm air pipes which are installed in the inside partitions of the building are called stacks. The heated air is discharged into the rooms through registers which are set in register boxes placed either in the floor or in the side wall, usually at or near the baseboard. A sectional view of a typical plant showing good installation practice is given in Fig. 1.

The air supply to the furnace is usually taken entirely from inside the building through one or more recirculating ducts, although in some cases an outside air supply duct is provided.

## WARM AIR LEADERS, STACKS, AND REGISTERS

In a gravity circulating warm air furnace system, the size of the leader pipe to a given room depends upon the heat loss from the room, the equivalent length of the leader, and the temperature of the warm air entering the room at the register. For most successful operation, the furnace should be centrally located with respect to register and stack positions so that the leaders will be of uniform length and as short as possible, in which case the frictional resistance to air flow and the temperature loss from the ducts will be about the same for all leaders and stacks.

Originally, the design was based on the heat carrying capacities per square inch of leader pipe area with register air temperatures of 175 F. Later, in the revision of the entire design procedure, as shown in the section entitled, Outline of Design Procedure, the carrying capacities of leader pipes have been expressed directly in terms of Btu per hour.

In general, it is necessary to use two or more leader pipes to rooms requiring more than the capacity of a 12 in. round pipe. The tops of all sizes of leader pipes should be cut into the furnace bonnet at the same elevation. Leaders over 12 ft in length, or having a large number of elbow fittings should be avoided if possible. In cases where such leaders are necessary, it is recommended that smooth transition fittings be used, and that duct insulation be applied. Asbestos paper, unless of the corrugated type, should not be considered as insulation. To assist in balancing the air distribution of the system, a damper should be placed in each leader

pipe except one. Some local regulations require that a damper be omitted in one leader connected to a room heated at all times:

In a gravity circulating system, the ratio of stack to leader area is quite important, although little is gained by providing wall stacks with areas in excess of 75 percent of their connected leader pipe area. In most cases

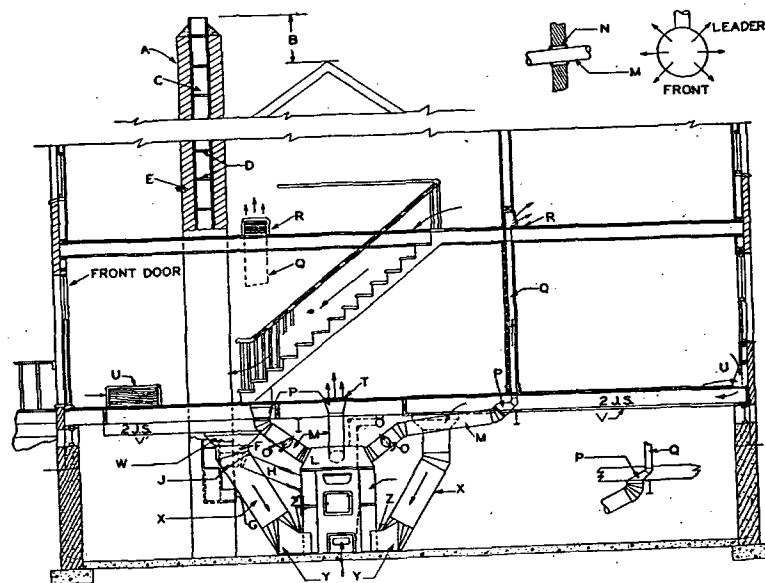


FIG. 1. A SECTIONAL VIEW OF A TYPICAL PLANT SHOWING GOOD INSTALLATION PRACTICE\*

- |                                                                    |                                                                                                          |
|--------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| A. House chimney, no bends nor offsets.                            | N. Sleeve with air space or 1 in. of noncombustible insulation around leader where passing through wall. |
| B. Top of chimney at least 2 ft above ridge of roof.               | O. Dampers in all leaders.                                                                               |
| C. Flue lining, fireclay.                                          | P. Transition fittings.                                                                                  |
| D. All joints air tight.                                           | Q. Rectangular wall stack.                                                                               |
| E. At least 8 in. brick.                                           | R. Baseboard register.                                                                                   |
| F. No other connection beside that to furnace.                     | S. Distributes pipes equally around bonnet.                                                              |
| G. Cleanout frame and door, airtight.                              | T. Floor register.                                                                                       |
| H. Smoke pipe, end flush with inner surface of flue.               | U. Return air face.                                                                                      |
| I. Draft door.                                                     | V. Fanning under joist.                                                                                  |
| J. Use flue thimble.                                               | W. Transition collar.                                                                                    |
| K. Casing body.                                                    | X. Round return pipe.                                                                                    |
| L. Casing hood or bonnet, top of all leader collars on same level. | Y. Transition shoe.                                                                                      |
| M. Round leader, pitch 1 in. per foot.                             | Z. Top of shoe at casing not above grate level.                                                          |

\* From *NWACH&ACA Manual 5: Gravity Code and Manual*, Fifth Edition, 1954.

a  $3\frac{1}{4}$  in. x 12 in. stack is the largest which can be installed in normal wall construction. Hence, any room having a heat loss much in excess of 9000 Btu per hr, will require two or more stacks, or one oversized stack built into a 6 in. studding space, providing the design register temperature is to be retained at the average value of 175 F, which has been recommended.

Registers used for discharging warm air into rooms should have a free area not less than the area of the leader pipe to which the register is at-

tached. First story registers should be connected through boot and register box extensions having areas at least equal to leader areas. Upper story registers should be of the same width as the wall stack, and should be placed either in the baseboard or sidewall, preferably without offsets. First story registers may be of the baseboard or floor type, with the former location preferred. Leader pipes or stacks intended to heat two rooms are not recommended.

### RETURN AIR GRILLES, DUCTS, AND CONNECTIONS

The placement and number of return grilles will depend upon the size, details, and exposure of the house. Small compactly built houses may be adequately served by a single return grille effectively placed in the central hall. It is usually desirable to have two or more returns, provided that in two-story residences one return is placed to receive effectively the return air at the foot of the stairs. A return air connection must be carried to any room whose floor level is below that of adjacent rooms.

Return ducts from upstairs rooms may be necessary in spaces which are closed off from the rest of the house, or which have much outdoor exposure. Return grilles on different floor levels should not be connected to the same vertical return duct.

The return air grilles should have free areas at least equal to the ducts to which they connect, and should be installed in the floor, or in the baseboard with the top edge of the grille not more than about 14 in. above the floor line. As frictional resistance in the return air system is as detrimental as resistance in the warm-air system, care should be exercised in locating return air grilles which require long return ducts.

The frictional resistance of the long ducts used in parallel with short return ducts must be reduced to compensate for the length. This is accomplished by using design data given in the following section, Outline of Design Procedure.

The ducts through which air is returned to the furnace should be designed to minimize resistance to air flow. They should be of ample area, with sizes selected according to capacity and construction, as specified in section, Outline of Design Procedure, and should be streamlined. Avoid fittings which would require lifting of the return air after the duct has passed under some obstacle.

Ducts returning air to the furnace should be protected from heat sources tending to reheat the return air. If the duct must be run over the top of the furnace, or above the vent pipe from the furnace, insulation should be interposed between the heat source and the duct.

The top of the return shoe should enter the casing below the level of the grate of a coal furnace, and not more than 14 in. above the floor of an oil or gas furnace. It must be wide enough to retain proper area.

### OUTLINE OF DESIGN PROCEDURE

The data underlying the design procedure are given in detail in a circular<sup>2</sup> issued by the *University of Illinois*. In this procedure the design of the warm-air duct system is considered as an entire unit, so that for a given heat loss the sizes of leaders, stacks, boots, stackheads, and registers are

TABLE 1. FIRST STORY WARM AIR DUCTS<sup>a</sup>

| WARM AIR COMBINATION No. | THROAT SIZE | LEADER PIPE DIAMETER, Inches | PIPE AREA Sq In | REGISTER SIZE, Inches |           |         |
|--------------------------|-------------|------------------------------|-----------------|-----------------------|-----------|---------|
|                          |             |                              |                 | Baseboard             |           | Floor   |
|                          |             |                              |                 | Size                  | Extension |         |
| 1                        | 6 1/8 x 10  | 8                            | 50              | 10 x 8                | 2 1/4     | 8 x 10  |
| 2                        | 6 1/8 x 12  | 9                            | 64              | 12 x 8                | 2 1/4     | 9 x 12  |
| 3                        | 7 1/8 x 12  | 10                           | 78              | 12 x 9                | 3 1/4     | 10 x 12 |
| 4                        | 9 1/8 x 13  | 12                           | 113             | 13 x 11               | 5 1/4     | 12 x 14 |
| 3d <sup>b</sup>          | 8 1/8 x 12  | 10                           | 78              | 2(12 x 8)             | 2 1/4     | ....    |
| 4d <sup>b</sup>          | 10 1/8 x 12 | 12                           | 113             | 2(12 x 9)             | 3 1/4     | ....    |

<sup>a</sup> When the calculations indicate a requirement for a given room greater than Combination No. 4, two or more smaller units totalling the required capacity are recommended.

<sup>b</sup> Double headers are permissible only where full throat areas are obtainable and room privacy is not essential. Use combination number representing total load. Combinations 3d and 4d have same capacities in Table 6 as combination 3 and 4 respectively.

TABLE 2. SECOND STORY WARM AIR DUCTS—SINGLE WALL STACKS AND FITTINGS

| COMBINATION No.  | STACK SIZE, Inches | LEADER PIPE DIAMETER, Inches | PIPE AREA Sq In | REGISTER SIZE, Inches |           |        |           |
|------------------|--------------------|------------------------------|-----------------|-----------------------|-----------|--------|-----------|
|                  |                    |                              |                 | Baseboard             |           | Floor  | Sidewall  |
|                  |                    |                              |                 | Size                  | Extension |        |           |
| 11               | 10 x 3 1/4         | 8                            | 50              | 10 x 8                | 2 1/4     | 8 x 10 | 10 x 8    |
| 12               | 12 x 3 1/4         | 9                            | 64              | 12 x 8                | 2 1/4     | 9 x 12 | 12 x 8    |
| 14               | 14 x 3 1/4         | 10                           | 78              | 13 x 11               | 2 1/4     | ....   | 12 x 8    |
| 15               | 12 x 5 1/4         | 12                           | 113             | 12 x 9                | 3 1/4     | ....   | ....      |
| 16               | 14 x 5 1/4         | 12                           | 113             | 13 x 11               | 5 1/4     | ....   | ....      |
| 12d <sup>b</sup> | 12 x 3 1/4         | 9                            | 64              | 2(12 x 8)             | 2 1/4     | ....   | 2(12 x 8) |
| 14d <sup>b</sup> | 14 x 3 1/4         | 10                           | 78              | 2(12 x 8)             | 2 1/4     | ....   | 2(12 x 8) |

<sup>a</sup> Recommended stack sizes. Tables may also be applied to 3 in. and 3 1/2 in. stack depths.

<sup>b</sup> Combinations 12-d and 14-d have same capacities in Table 7 as combinations 12 and 14 respectively.

TABLE 3. SECOND STORY WARM AIR DUCTS—DOUBLE WALL STACKS AND FITTINGS

| COMBINATION No. | LEADER PIPE DIAMETER, In. | PIPE AREA Sq In. | STACK SIZE, In.         |                             | REGISTER SIZE, In. |           |            |          |
|-----------------|---------------------------|------------------|-------------------------|-----------------------------|--------------------|-----------|------------|----------|
|                 |                           |                  | Internal                | External                    | Floor              | Baseboard |            | Sidewall |
|                 |                           |                  |                         |                             |                    | Size      | Ex-tension |          |
| 21              | 8                         | 50               | 2 1/2 <sup>a</sup> x 10 | 3 1/8 <sup>a</sup> x 10 1/8 | 8 x 10             | 10 x 8    | 2 1/4      | 10 x 8   |
| 22              | 8                         | 50               | 3 x 10                  | 3 5/8 x 10 5/8              | 8 x 10             | 10 x 8    | 2 1/4      | 10 x 8   |
| 23              | 9                         | 64               | 2 1/2 <sup>a</sup> x 12 | 3 1/8 <sup>a</sup> x 12 5/8 | 9 x 12             | 12 x 8    | 2 1/4      | 12 x 8   |
| 24              | 9                         | 64               | 3 x 12                  | 3 5/8 x 12 5/8              | 9 x 12             | 12 x 8    | 2 1/4      | 12 x 8   |

<sup>a</sup> Commercial sizes vary 1/8 in. from values shown.

all correlated. Similarly in the case of return ducts, the selection specifies a complete unit consisting of return grille, return duct, and shoe connection.

### Recommended Standard Sizes

For the purpose of simplification and standardization, selected combinations of commercial sizes of warm air pipes, return air pipes, ducts, grilles, fittings, and registers are designated as Combination Numbers. The numbers assigned and the combinations selected as standard are listed in the following Tables 1 to 4 inclusive.<sup>3</sup>

The selected types of fittings are shown in Fig. 2, and their resistances ex-

TABLE 4. RETURN AIR DUCTS

| COMBINATION<br>No. | DUCT<br>DIA.<br>IN. | DUCT<br>AREA<br>Sq. IN. | WHEN JOIST<br>SPACE<br>Is Used <sup>a</sup> |                                   | METAL GRILLE SIZES |         |         | BASE-<br>BOARD<br>INTAKE<br>FOR FIRST<br>STORY | AREA AT<br>SHOE CON-<br>NECTION,<br>Sq. IN. | WHEN<br>DUCT<br>Is USED |
|--------------------|---------------------|-------------------------|---------------------------------------------|-----------------------------------|--------------------|---------|---------|------------------------------------------------|---------------------------------------------|-------------------------|
|                    |                     |                         | No. of<br>Joists<br>Lined                   | Min. <sup>b</sup><br>Depth<br>In. | Choose One         |         |         |                                                |                                             | Choose One              |
|                    |                     |                         |                                             |                                   | A                  | B       | C       |                                                |                                             |                         |
| 31                 | 10                  | 78                      | 1                                           | 7                                 |                    | 8 x 14  | 10 x 12 |                                                |                                             | 14 x 6<br>12 x 8        |
| 32                 | 12                  | 113                     | 1<br>or 2                                   | 9<br>5                            | 6 x 30             | 8 x 24  | 12 x 14 | 14 x 10<br>4-In. Ext.                          |                                             | 22 x 6<br>16 x 8        |
| 33                 | 14                  | 154                     | 1<br>or 2                                   | 12<br>6                           | 8 x 30             | 10 x 24 | 14 x 16 |                                                | 170                                         | 28 x 6<br>22 x 8        |
| 34                 | 16                  | 201                     | 1<br>or 2                                   | 16<br>8                           | 10 x 30            | 12 x 24 |         |                                                | 220                                         | 28 x 8<br>22 x 10       |
| 35                 | 18                  | 254                     | 2                                           | 10                                | 12 x 30            | 14 x 24 |         | 30 x 10<br>4-In. Ext.                          | 280                                         | 36 x 8<br>28 x 10       |
| 36                 | 20                  | 314                     | 2                                           | 12.5                              | 14 x 30            | 18 x 24 |         |                                                | 340                                         | 36 x 10<br>30 x 12      |
| 37                 | 22                  | 380                     | 2                                           | 15.0                              | 18 x 30            |         |         |                                                | 420                                         | 42 x 10<br>36 x 12      |
| 38                 | 24                  | 452                     | 2                                           | 18.0                              | 20 x 30            |         |         |                                                | 500                                         | 42 x 12<br>36 x 14      |

<sup>a</sup> Based on 14 in. space between joists.

<sup>b</sup> Use full depth of joist except when joist depth is less than minimum depth required, when pan must be used.

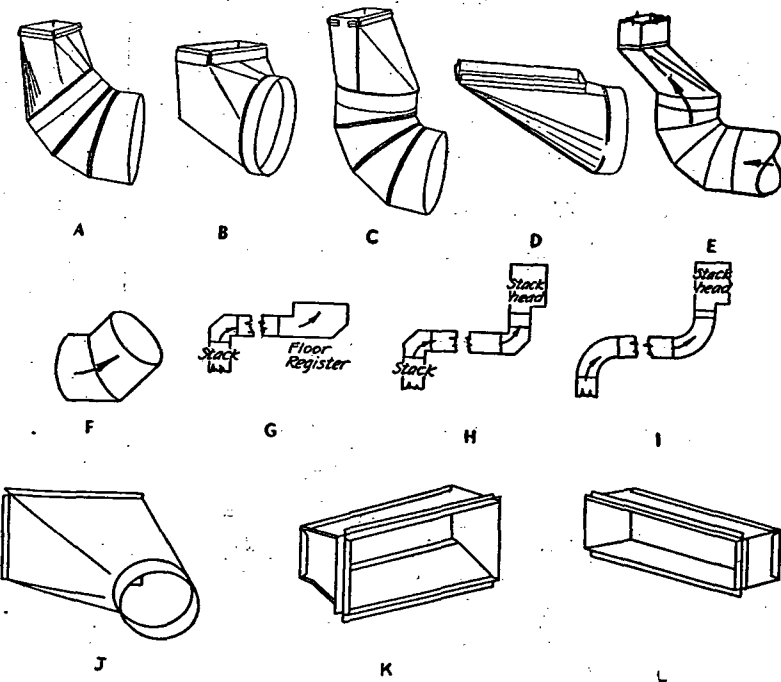


FIG. 2. TYPICAL WARM AIR BOOTS

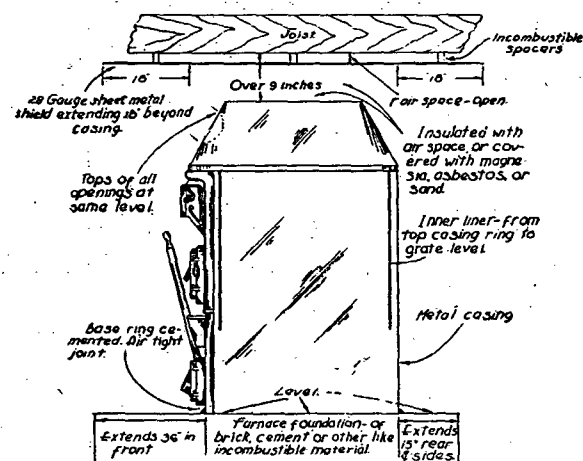


FIG. 3. DETAILS OF FURNACE BONNET, CASING, AND FOUNDATION  
(FROM NWAH & ACA MANUAL 5, FIFTH EDITION)

TABLE 5. RESISTANCES OF WARM AIR BOOT COMBINATIONS EXPRESSED IN ELBOW EQUIVALENTS

| WARM AIR BOOT | NAME OF COMBINATION                | EQUIVALENT No. OF 90-Deg ELBOWS |
|---------------|------------------------------------|---------------------------------|
| A             | 45-Deg Angle Boot and 45-Deg Elbow | 1                               |
| B             | 90-Deg Angle Boot                  | 1                               |
| C             | Universal Boot and 90-Deg Elbow    | 1                               |
| D             | End Boot                           | 2                               |
| E             | Offset Boot                        | 2½                              |
| F             | 45-Deg Angle                       | ½                               |
| G             | Floor Register—Second Story        | 2                               |
| H             | Offset                             | 3                               |
| I             | Offset                             | 2                               |
| J             | Round Side Take-Off                | 1                               |
| K             | Offset Starting Collar             | 1                               |
| L             | Straight Starting Collar           | 3                               |

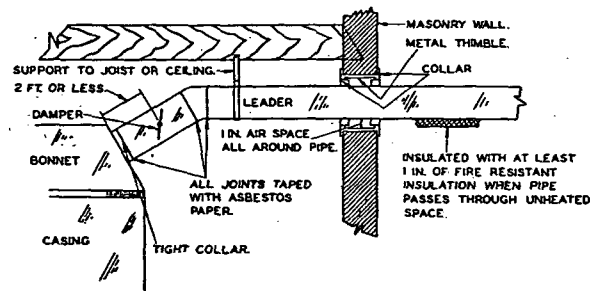


FIG. 4. DETAILS OF BONNET AND LEADER OF GRAVITY WARM-AIR FURNACE  
(FROM NWAH & ACA MANUAL 5, FIFTH EDITION)

TABLE 6. WARM AIR CARRYING CAPACITY, BTUH DELIVERED, FIRST STORY REGISTERS

| COMBINATION No. | No. OF ELBOWS | ACTUAL LENGTH (BONNET TO BOOT) FEET                |        |        |        |        |        |        |        |        |        |
|-----------------|---------------|----------------------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|                 |               | 6                                                  |        |        |        |        |        | 4      | 6      | 8      | 10     |
|                 |               | 6½                                                 |        |        |        |        |        | 4      | 6      | 8      | 10     |
|                 |               | 7                                                  |        |        | 4      | 6      | 8      | 10     | 12     | 14     | 16     |
|                 |               | 7½                                                 | 4      | 6      | 8      | 10     | 12     | 14     | 16     | 18     | 20     |
| 1               | 1             | Height from basement floor to bottom of joist—Feet | 6,020  | 5,850  | 5,680  | 5,510  | 5,340  | 5,170  | 5,000  | 4,830  | 4,660  |
| 2               |               |                                                    | 7,620  | 7,400  | 7,180  | 6,970  | 6,760  | 6,540  | 6,320  | 6,110  | 5,890  |
| 3               |               |                                                    | 9,400  | 9,140  | 8,870  | 8,600  | 8,340  | 8,070  | 7,810  | 7,540  | 7,270  |
| 4               |               |                                                    | 13,350 | 12,970 | 12,590 | 12,210 | 11,830 | 11,450 | 11,080 | 10,700 | 10,320 |
| 1               | 2             | Height from basement floor to bottom of joist—Feet | 5,850  | 5,660  | 5,490  | 5,330  | 5,160  | 5,000  | 4,840  | 4,670  | 4,510  |
| 2               |               |                                                    | 7,360  | 7,150  | 6,940  | 6,730  | 6,520  | 6,320  | 6,110  | 5,910  | 5,700  |
| 3               |               |                                                    | 9,090  | 8,840  | 8,580  | 8,320  | 8,060  | 7,800  | 7,550  | 7,290  | 7,040  |
| 4               |               |                                                    | 12,910 | 12,540 | 12,170 | 11,800 | 11,430 | 11,060 | 10,690 | 10,320 | 9,950  |
| 1               | 3             | Height from basement floor to bottom of joist—Feet | 5,620  | 5,460  | 5,310  | 5,150  | 4,990  | 4,830  | 4,670  | 4,510  | 4,350  |
| 2               |               |                                                    | 7,120  | 6,910  | 6,710  | 6,510  | 6,310  | 6,110  | 5,900  | 5,700  | 5,500  |
| 3               |               |                                                    | 8,780  | 8,530  | 8,280  | 8,030  | 7,780  | 7,530  | 7,290  | 7,040  | 6,800  |
| 4               |               |                                                    | 12,450 | 12,100 | 11,750 | 11,400 | 11,050 | 10,700 | 10,350 | 10,000 | 9,650  |
| 1               | 4             | Height from basement floor to bottom of joist—Feet | 5,420  | 5,260  | 5,110  | 4,960  | 4,800  | 4,650  | 4,500  | 4,350  | 4,190  |
| 2               |               |                                                    | 6,860  | 6,660  | 6,460  | 6,270  | 6,080  | 5,890  | 5,690  | 5,500  | 5,300  |
| 3               |               |                                                    | 8,460  | 8,220  | 7,980  | 7,740  | 7,500  | 7,260  | 7,020  | 6,780  | 6,540  |
| 4               |               |                                                    | 12,010 | 11,670 | 11,330 | 10,990 | 10,650 | 10,310 | 9,970  | 9,630  | 9,290  |
| 1               | 5             | Height from basement floor to bottom of joist—Feet | 5,240  | 5,090  | 4,940  | 4,790  | 4,640  | 4,500  | 4,350  | 4,200  | 4,050  |
| 2               |               |                                                    | 6,630  | 6,440  | 6,250  | 6,060  | 5,880  | 5,690  | 5,500  | 5,320  | 5,130  |
| 3               |               |                                                    | 8,180  | 7,950  | 7,720  | 7,490  | 7,260  | 7,030  | 6,800  | 6,560  | 6,330  |
| 4               |               |                                                    | 11,610 | 11,290 | 10,950 | 10,620 | 10,300 | 9,970  | 9,640  | 9,320  | 8,990  |

Notes: Carrying capacity and length of run increased with basement depth. Length of trunk and carrying capacity of gravity extended plenum installations should be based on the 6 ft basement depth capacities.

pressed in equivalent elbows are shown in Table 5. It is essential that free areas be maintained throughout fittings.

Figs. 3 and 4 show recommended practice as given in Manual 5 of the *National Warm Air Heating and Air Conditioning Association*. For construction, design features, and ratings of gravity furnaces see Chapter 16.

### Carrying Capacity

The Btu per hour carrying capacities of the selected warm air and return air combinations are shown in Tables 6, 7 and 8.

The selected types of return air ducts and fittings are shown in Fig. 5.

### Design Procedure

The steps to be taken in designing a gravity warm air duct system are:

1. Calculate the heat loss from each room as explained in Chapters 9, 11 and 12.
2. Prepare a layout showing (a) furnace, (b) chimney connection, (c) warm air registers (whether floor, baseboard or wall), (d) return air grilles.
3. Indicate on each warm air leader (using symbols shown in Fig. 6): (a) whether the room to be heated is on first or second story; (b) the approximate length of leader pipe in the basement; (c) the number of right angle elbows and equivalent elbows (Table 5) required, including the elbow at the boot connection (see Fig. 2); (d) whether the register is to be located in the floor, in the baseboard, or in the wall.

TABLE 7. WARM AIR CAPACITY, BTUH DELIVERED SECOND STORY REGISTERS

| COMBINATION NO.                  | No. OF ELBOWS | ACTUAL LENGTH (BONNET TO BOOT) FEET |        |        |        |        |        |        |        |        |        |        |        |    |    |  |  |
|----------------------------------|---------------|-------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----|----|--|--|
|                                  |               | 6                                   |        |        | 4      | 6      | 8      | 10     | 12     | 14     | 16     | 18     | 20     | 22 | 24 |  |  |
|                                  |               | 6½                                  |        |        | 4      | 6      | 8      | 10     | 12     | 14     | 16     | 18     | 20     | 22 | 24 |  |  |
|                                  |               | 7                                   | 4      | 6      | 8      | 10     | 12     | 14     | 16     | 18     | 20     | 22     | 24     |    |    |  |  |
| 11 or 22<br>12 or 24<br>14<br>15 |               | 7½                                  | 4      | 6      | 8      | 10     | 12     | 14     | 16     | 18     | 20     | 22     | 24     |    |    |  |  |
|                                  |               |                                     | 8,370  | 8,140  | 7,900  | 7,670  | 7,430  | 7,190  | 6,950  | 6,710  | 6,470  | 6,240  | 6,000  |    |    |  |  |
|                                  |               |                                     | 10,040 | 9,760  | 9,470  | 9,190  | 8,900  | 8,620  | 8,330  | 8,050  | 7,770  | 7,480  | 7,200  |    |    |  |  |
|                                  |               |                                     | 11,710 | 11,380 | 11,050 | 10,720 | 10,390 | 10,060 | 9,720  | 9,390  | 9,060  | 8,730  | 8,400  |    |    |  |  |
| 11 or 22<br>12 or 24<br>14<br>15 |               | 3                                   | 7,940  | 7,720  | 7,500  | 7,280  | 7,050  | 6,830  | 6,600  | 6,370  | 6,150  | 5,930  | 5,700  |    |    |  |  |
|                                  |               |                                     | 9,540  | 9,270  | 9,000  | 8,730  | 8,460  | 8,190  | 7,920  | 7,650  | 7,380  | 7,110  | 6,840  |    |    |  |  |
|                                  |               |                                     | 11,120 | 10,810 | 10,500 | 10,180 | 9,870  | 9,550  | 9,230  | 8,920  | 8,610  | 8,290  | 7,980  |    |    |  |  |
|                                  |               |                                     | 15,400 | 14,970 | 14,530 | 14,100 | 13,670 | 13,230 | 12,800 | 12,360 | 11,930 | 11,500 | 11,070 |    |    |  |  |
| 11 or 22<br>12 or 24<br>14<br>15 |               | 4                                   | 7,530  | 7,320  | 7,110  | 6,900  | 6,680  | 6,470  | 6,250  | 6,040  | 5,830  | 5,620  | 5,400  |    |    |  |  |
|                                  |               |                                     | 9,030  | 8,780  | 8,520  | 8,270  | 8,010  | 7,750  | 7,500  | 7,240  | 6,990  | 6,730  | 6,470  |    |    |  |  |
|                                  |               |                                     | 10,530 | 10,240 | 9,940  | 9,650  | 9,350  | 9,050  | 8,750  | 8,450  | 8,160  | 7,860  | 7,560  |    |    |  |  |
|                                  |               |                                     | 14,580 | 14,180 | 13,780 | 13,370 | 12,950 | 12,530 | 12,120 | 11,710 | 11,300 | 10,890 | 10,480 |    |    |  |  |
| 11 or 22<br>12 or 24<br>14<br>15 |               | 5                                   | 7,120  | 6,920  | 6,720  | 6,520  | 6,310  | 6,110  | 5,900  | 5,700  | 5,500  | 5,300  | 5,100  |    |    |  |  |
|                                  |               |                                     | 8,530  | 8,290  | 8,050  | 7,810  | 7,570  | 7,330  | 7,080  | 6,840  | 6,600  | 6,360  | 6,120  |    |    |  |  |
|                                  |               |                                     | 9,950  | 9,670  | 9,390  | 9,110  | 8,830  | 8,550  | 8,260  | 7,980  | 7,700  | 7,420  | 7,140  |    |    |  |  |
|                                  |               |                                     | 13,780 | 13,390 | 13,000 | 12,610 | 12,220 | 11,830 | 11,440 | 11,050 | 10,670 | 10,280 | 9,890  |    |    |  |  |
| 11 or 22<br>12 or 24<br>14<br>15 |               |                                     | 6,700  | 6,510  | 6,320  | 6,130  | 5,940  | 5,750  | 5,560  | 5,370  | 5,180  | 4,990  | 4,800  |    |    |  |  |
|                                  |               |                                     | 8,040  | 7,810  | 7,580  | 7,350  | 7,130  | 6,900  | 6,670  | 6,440  | 6,220  | 5,990  | 5,760  |    |    |  |  |
|                                  |               |                                     | 9,370  | 9,110  | 8,850  | 8,580  | 8,310  | 8,050  | 7,780  | 7,510  | 7,250  | 6,980  | 6,720  |    |    |  |  |
|                                  |               |                                     | 12,970 | 12,600 | 12,240 | 11,870 | 11,500 | 11,140 | 10,770 | 10,400 | 10,040 | 9,680  | 9,310  |    |    |  |  |

Notes: When floor registers are used on second story rooms, include the equivalent elbow resistance for the cross-over connection as shown in Fig. 2.

Combination Numbers 21 and 23 as shown in Tables 2 and 3 are composed of narrow stacks for narrow stud spaces.

For Combination No. 21, the capacities are the Btuh deliveries shown for Combination Nos. 11 or 22 multiplied by 0.83.

For Combination No. 23, the capacities are the Btuh deliveries shown for Combination Nos. 12 or 24 multiplied by 0.83.

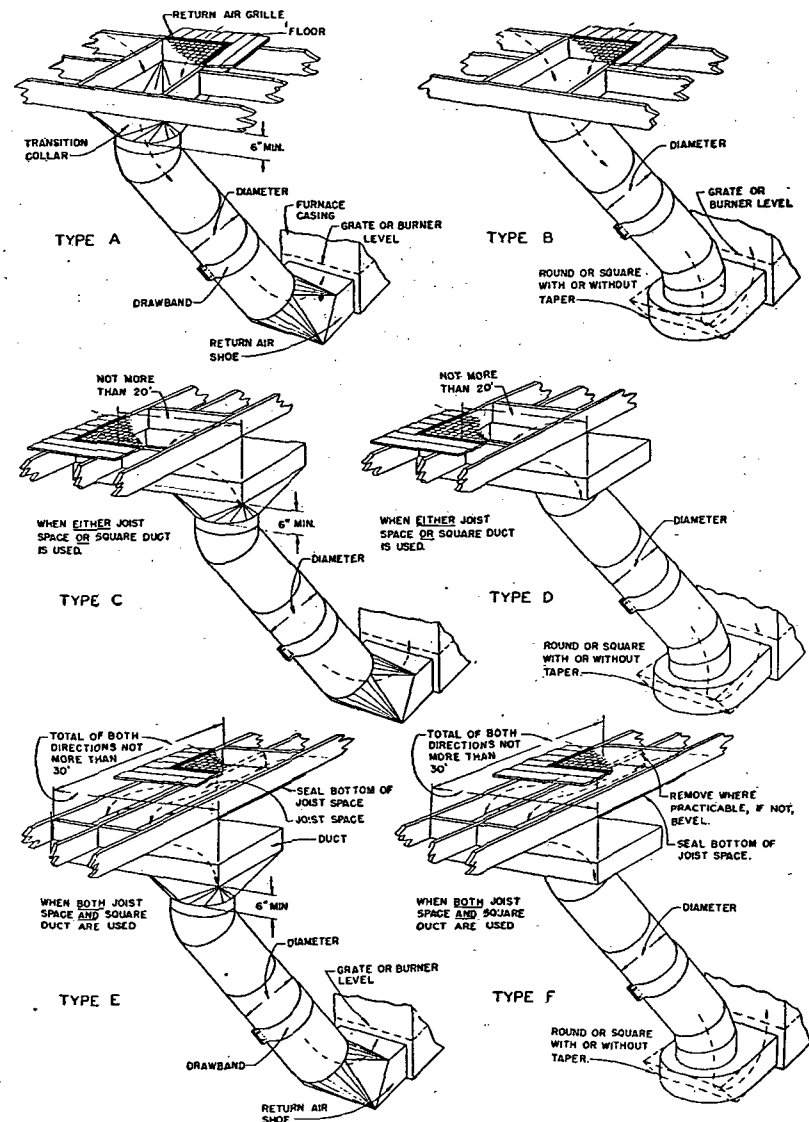
TABLE 8. RETURN AIR—CARRYING CAPACITY—BTUH SERVICED

| RETURN AIR COMBINATION NO. | DUCT DIAM. IN. | TYPE A BTUH | TYPE B AND C BTUH | TYPE D BTUH | TYPE E BTUH | TYPE F BTUH | RETURN AIR COMBINATION NO. |
|----------------------------|----------------|-------------|-------------------|-------------|-------------|-------------|----------------------------|
| 31                         | 10             | 11,300      | 9,500             | 7,800       | 7,800       | 5,000       | 31                         |
| 32                         | 12             | 16,300      | 13,700            | 11,300      | 11,300      | 7,200       | 32                         |
| 33                         | 14             | 22,200      | 18,700            | 15,300      | 15,300      | 9,800       | 33                         |
| 34                         | 16             | 29,000      | 24,400            | 20,000      | 20,000      | 12,800      | 34                         |
| 35                         | 18             | 36,700      | 30,800            | 25,300      | 25,300      | 16,200      | 35                         |
| 36                         | 20             | 45,300      | 38,000            | 31,300      | 31,300      | 20,000      | 36                         |
| 37                         | 22             | 54,800      | 46,000            | 37,800      | 37,800      | 24,100      | 37                         |
| 38                         | 24             | 65,200      | 54,800            | 45,000      | 45,000      | 28,700      | 38                         |

4. Show the number and proposed locations of return air grilles and the type of return-air system (see Fig. 5).

5. From Table 6, for first story, or from Table 7 for second story, select the combination number for the warm air system which will supply the heat required to each room, with the number of elbows and length of leader pipe previously determined. Then, using the combination number as found, read directly in Tables 1, 2, or 3 the leader, stack, and register sizes required.

6. From Table 8 select the combination number for the return air system to cor-



Note: For Types C, D, E, and F return-air systems, reduce the carrying capacities shown in Table 8 by 1 percent for each 4 ft additional length in the horizontal run.

FIG. 5. TYPICAL ARRANGEMENTS OF RETURN-AIR DUCT SYSTEMS

respond with the Btu per hour serviced and the type of return air system. Then from Table 4 select the duct and grille sizes, etc., corresponding to this number.

7. Select a furnace having a bonnet output, in Btu per hour, one-third greater than the heat loss from the structure, to compensate for duct heat loss.

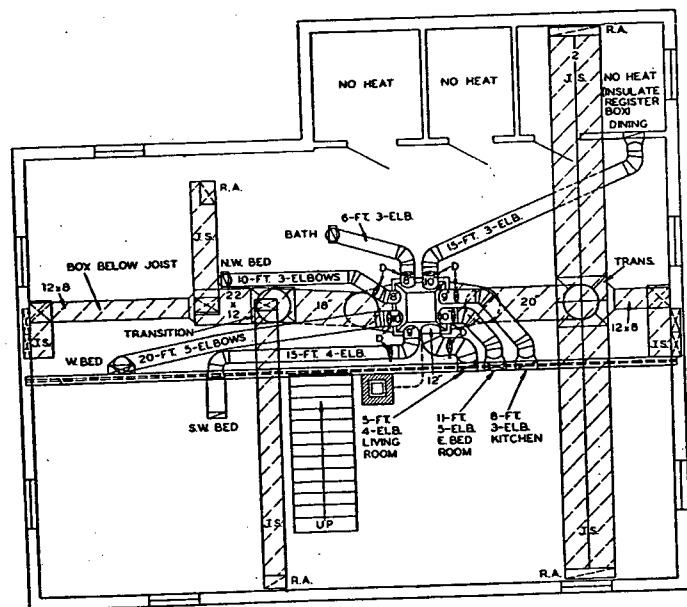


FIG. 6. TYPICAL BASEMENT LINE DRAWING

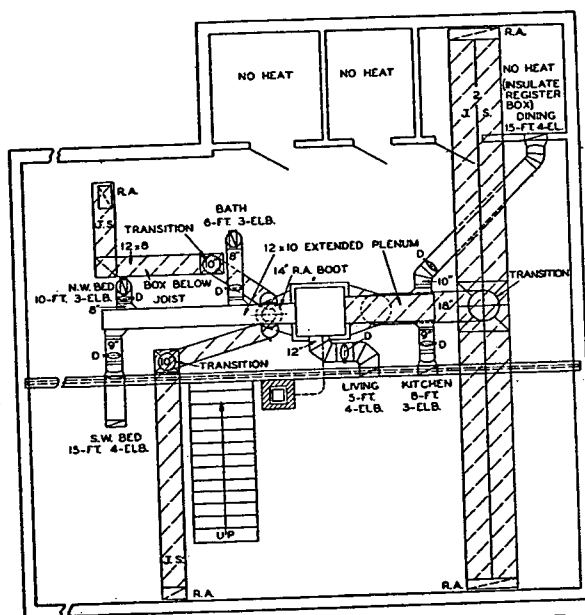


FIG. 7. TYPICAL BASEMENT LINE DRAWING FOR EXTENDED PLENUM

### Design of Extended Plenum Systems

The extended plenum system of gravity warm air heating employs horizontal ducts in the basement leading from an enlargement or extension of the customary plenum to the risers which distribute the conditioned air to the various rooms. A typical basement plan for a system using an extended plenum is shown in Fig. 7.

Extended plenum gravity systems have been satisfactorily designed and installed in small compact single-story houses where the heat losses do not exceed 65,000 Btuh. The dimension from the floor to the bottom of the joists should in every case be at least 7 ft. To design such a system the procedure is the same as for the conventional system already described in this chapter.

It is understood that the length of leader pipe is the horizontal distance measured from the register to the furnace. For takeoffs, use standard fittings designed for extended plenum connection and allow the equivalent length of one 90-degree elbow.

### Sizing an Extended Plenum

To size an extended plenum, proceed as follows:

1. Make a layout of the furnace, extended plenum, branches and registers, similar to Fig. 7.

2. Follow methods given in paragraphs 1, 2, 3 and 5, under Design Procedure for a conventional system, to determine the diameters or equivalent rectangular sizes of the branches from the extended plenum to registers.

3. Starting with the most remote branch connected to an extended plenum, write its equivalent size as if it were 8 in. in depth. For example: an 8-in. diameter branch is equivalent to a 6-in. wide x 8-in. deep duct (see Table 9). As each additional branch is reached, determine its rectangular equivalent size as if it were 8 in. deep. In the last column of Table 9 find the additional width of plenum required to supply the added branch. When all branches have been included, the sum of the widths added for each branch plus the width of the most remote branch will give the equivalent width for a plenum of 8-in. depth.

The depth of plenum to be selected should be that of the largest branch. The width selected can be determined from the lower section of Table 9 where a plenum of desired depth can be found equivalent to the size computed for an 8-in. deep plenum. For example: if the size based on an 8-in. plenum is found to be 22 x 8 in. the plenum may be 17 x 10 in. or 14 x 12 in. The extended plenum is not changed in size from furnace to end of the plenum.

Return air intakes are to be sized by the same method as for conventional gravity systems.

### Design Examples

Examples 1 and 2 will illustrate the use of the tables in selecting warm air and return air system sizes.

**Example 1:** For a room which has a heat loss of 22,500 Btu per hr, select the size of first story warm-air system. There are three elbows, and the leader is approximately 10 ft long.

**Solution:** Since 22,500 Btu is beyond the capacities shown in Table 6, it is necessary to select two units of 11,250 each. From Table 6 in 10 ft leader column, and in section for three elbows, find 11,400 as nearest capacity which corresponds to Combination Number 4 in first column. Refer to Combination Number 4 in Table 1 and find that the leader should be 12 in. in diameter, and should be used with a 12 x 14 in. floor register or a 13 x 11 in. baseboard register with a 5 1/4 in. extension.

**Example 2:** What is the size of a return air system of Type D which is to service 35,000 Btu per hr?

TABLE 9. FOR SIZING EXTENDED PLENUM

| COMBINATION | ROUND BRANCH DIAM<br>Inches | RECTANGULAR SIZE<br>(8-in. Depth) Inches | PLENUM ADDITION<br>Inches |
|-------------|-----------------------------|------------------------------------------|---------------------------|
| 1           | 8                           | 6 x 8                                    | 4                         |
| 2           | 9                           | 8 x 8                                    | 5                         |
| 3 or 3d     | 10                          | 11 x 8                                   | 8                         |
| 4 or 4d     | 12                          | 16 x 8                                   | 12                        |

EQUIVALENT PLENUM SIZE FOR CHANGE TO DEPTH OTHER THAN 8 IN.

| 8-IN. DEPTH<br>Inches | 10-IN. DEPTH<br>Inches | 12-IN. DEPTH<br>Inches |
|-----------------------|------------------------|------------------------|
| 16 x 8                | 12 x 10                |                        |
| 18 x 8                | 14 x 10                | 12 x 12                |
| 20 x 8                | 16 x 10                | 13 x 12                |
| 22 x 8                | 17 x 10                | 14 x 12                |
| 24 x 8                | 18 x 10                | 15 x 12                |
| 26 x 8                | 19 x 10                | 16 x 12                |
| 28 x 8                | 21 x 10                | 17 x 12                |
| 30 x 8                | 22 x 10                | 18 x 12                |
| 32 x 8                | 24 x 10                | 19 x 12                |
| 34 x 8                | 25 x 10                | 21 x 12                |
| 37 x 8                | 27 x 10                | 22 x 12                |
| 39 x 8                | 29 x 10                | 23 x 12                |
| 42 x 8                | 31 x 10                | 25 x 12                |
| 45 x 8                | 33 x 10                | 26 x 12                |
| 47 x 8                | 35 x 10                | 28 x 12                |
| 51 x 8                | 37 x 10                | 29 x 12                |

*Solution:* From Table 8 find Combination Number 37 which will service 37,800 Btu per hr. Refer to Table 4 to find that Combination Number 37 will require a 22-in. diameter duct, a shoe area of 420 sq in., a metal grille 18 x 30 in., a duct 42 x 10 in. or 36 x 12 in. If joist lining is used the minimum depth should be 15 in. for two 2-joist spaces 14 in. wide, or 10 in. for three joist spaces.

## REFERENCES

<sup>1</sup> The engineering data were obtained from *University of Illinois, Engineering Experiment Station Bulletins* Nos. 141, 188, 189 and 246; *Warm Air Furnaces and Heating Systems*, by A. C. Willard, A. P. Kratz, V. S. Day, and S. Konzo. See also Manual 5: Gravity Code and Manual for the Design and Installation of Gravity Warm Air Heating Systems, 5th Edition, 1954, published by the *National Warm Air Heating and Air Conditioning Association*.

<sup>2</sup> *Simplified Procedure for Selecting Capacities of Duct Systems for Gravity Warm Air Heating Plants*, by A. P. Kratz and S. Konzo (*University of Illinois, Engineering Experiment Station Circular* 45, Dec., 1942).

<sup>3</sup> *Gravity Code and Manual for the Design and Installation of Gravity Warm Air Heating Systems*, Manual 5, 5th Edition, 1954, (*National Warm Air Heating and Air Conditioning Association*).

## CHAPTER 20

## FORCED WARM AIR SYSTEMS

Air Distribution, Standard Combinations of Parts, Simplified Method of Design, Design Procedure for Large Systems, Automatic Controls, Ceiling Panel Systems, Perimeter Systems, Summer Operation

IN forced warm air heating systems, the air circulation is effected by motor-driven centrifugal fans, commonly referred to as blowers. The advantages of forced air systems are:

1. The furnace may be placed in any part of the structure.
2. Distribution ducts can be made small enough to be inconspicuous and out of the way, or be completely concealed from view where desired.
3. Circulation of air is positive, and in a properly designed system, can be controlled in such a way as to give a comfortably uniform temperature distribution.
4. Humidity control is readily attained.
5. The air may be cleaned by filters or other means.
6. The fan and duct equipment may be designed for a complete cooling and dehumidifying system for summer, using either ice, mechanical refrigeration, or low temperature water for cooling and dehumidifying, or adsorbents for dehumidifying.
7. The use of the fan permits flexibility in the location of supply and return grilles as required to obtain proper distribution of air for comfort.
8. Ventilation air may be positively introduced and conditioned.

The construction features of forced warm air furnace units and the function and selection of the various parts of a system are discussed in Chapter 16 and other publications.<sup>1</sup>

## AIR DISTRIBUTION

The conditions of comfort obtained in a room are influenced greatly by the type of register used, and the locations of the supply registers and return grilles. In general it has been found that changes in the type, air velocity, and location of the supply register affect the room conditions much more than the changes in the location of the return grilles. One method is to locate the supply register near the floor, or high in the side wall, so that the warm air from the register blankets a cold wall, and mixes with the cold air descending from the exposed walls and glass. Another method is to locate the supply openings near the floor, or high in the side wall, on the inside wall, and the return openings near the greatest outside exposure. Still another method is to locate all supply openings around the outside wall, near the source of the greatest heat loss, usually beneath the windows, and to use grilles designed to blanket the cold area. This causes mixing of the warm air delivered with the cool air from the heat loss area and the



cold air from infiltration thus effectively preventing drafts. This has been called perimeter heating. In any case, the warm air registers should be located so that the air stream never discharges directly against people at rest. Tests<sup>2</sup> in Warm Air Research Residence No. 1 at the *University of Illinois*, have indicated that continuous blower operation gave better results than intermittent operation.

### Register and Grille Openings

Tests also conducted in Warm Air Research Residence No. 1 have indicated that comparable results are obtainable with either high side wall or baseboard registers, if proper registers and air velocities are selected. Baseboard registers should be of a deflecting-diffuser type which throw the

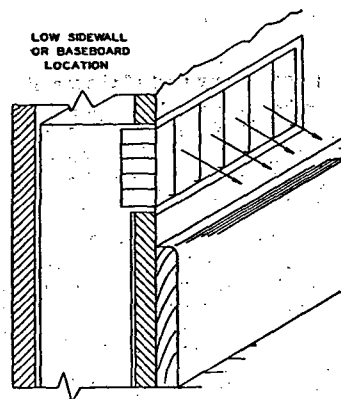


FIG. 1. RECOMMENDED TYPE OF BASEBOARD AND LOW SIDEWALL INSTALLATION ON WARM WALL\*

\* Vertical bars with adjustable deflection, or fixed vertical bars with deflections to right and left not exceeding about 22 deg. For low sidewall location, the deflection for horizontal, multiple vane registers should not exceed 22 deg. For baseboard locations, the deflection for horizontal, multiple vane registers should not exceed about 10 deg.

air downward toward the floor and diffuse it at the same time. For baseboard registers, air velocities over 500 fpm, should be avoided as they may cause discomfort.

High side wall registers should be of such type that the air is delivered horizontally or in a slightly downward direction, and should be so located as to avoid impingement of air on ceiling or wall. Directional flow diffusing type registers should be used to insure best results. Register air velocities should be such that the air velocity will be about 50 fpm three quarters of the distance from the register to the opposite wall.

Velocities through registers may be reduced by the use of registers larger than the connecting ducts. Diffusers should be used to spread the air uniformly over the register face. Basic rules for the location and selection of registers, together with explanations of factors affecting operation, are given<sup>3</sup> in Section 6 of Manual 4, Sections 3 and 4 of Manual 10, or Section B

of Manual 7; these manuals being publications of the *National Warm Air Heating and Air Conditioning Association*.

Registers should be well proportioned and decorated to harmonize with the trim. Air supply registers should be equipped with dampers, and all registers should be sealed against leakage around edges. The register types shown in Figs. 1, 2 and 3 have been recommended as standard by the *National Warm Air Heating and Air Conditioning Association*.

Return air grilles may be located in hallways, near entrance doors, under windows, in exposed corners, or inside walls, depending on location of supply registers. Baseboard returns are preferable to floor grilles where warm air registers are located on inside walls. Where perimeter heating is used, returns placed high on inside walls are preferred.

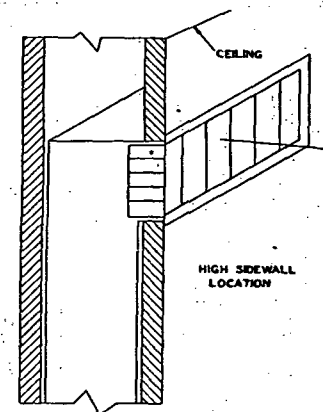


FIG. 2. RECOMMENDED TYPE OF HIGH SIDEWALL INSTALLATION ON WARM WALL\*

\* Horizontal vanes, in back or front, to give downward deflections not to exceed from 15 to 22 deg.

### Dampers

Suitable dampers for air direction or volume control are essential to any duct system. Special care must be used in the design of any system, to minimize resistance. Sharp elbows, angles, and offsets should be avoided. Three types of dampers are commonly used. *Volume dampers* are used to completely cut off or reduce the flow through ducts. *Splitter dampers* are used where a branch is taken off from a main trunk. *Squeeze dampers* are used for adjusting the volume of air flow and resistance through a given duct. A damper with positive locking device should be provided for each main or duct branch. Labels placed on ducts should indicate the room being served. Damper positions should be marked to indicate proper summer and winter settings, and to reveal tampering.

### Ducts

The ducts may be either round or rectangular in cross section. The centerline radii of elbows should preferably be not less than one and one-half times the pipe diameter for round pipes. The throat radius of a turn

in a rectangular duct should be at least one-half the duct dimension in the plane of the turn. Warm air ducts passing through cold spaces or located in exposed walls, should have 1 to 2 in. of insulation.

Special attention should be given to the problem of noise elimination. The metal duct connection to and from the furnace casing and fan housing should be broken by strips of fire resistant fabric. Motors and mountings must be carefully selected for quiet operation. Electrical conduit and water piping must not be fastened to, nor make contact with the fan housing. Installation of a fan directly under a return air grille is usually avoided.

### STANDARD COMBINATIONS OF PARTS

The combinations of parts selected as standard by the *National Warm Air Heating and Air Conditioning Association* are shown in Tables 1 and

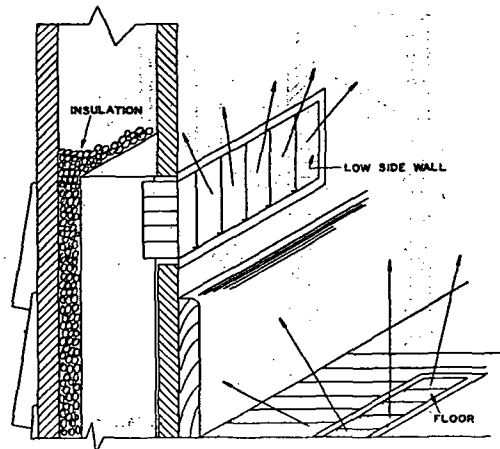


FIG. 3. RECOMMENDED TYPE OF FLOOR OR LOW SIDEWALL INSTALLATION ON OUTSIDE WALL\*

\* Registers set to direct air upward along the wall at as wide an angle as possible.

2. A method for selecting these combinations is indicated in the following section Simplified Method of Design.

### SIMPLIFIED METHOD OF DESIGN

A simplified method for selecting the combinations of branches, boots, stacks, and registers, is given<sup>3</sup> in Manual 7 of the *National Warm Air Heating and Air Conditioning Association*. In this method, the sizes of the branch ducts are obtained from two tables giving their Btu capacities. The proper combination of parts for each branch can be determined if the following information is available.

- Location of room, that is, whether on first or second story.
- Actual horizontal length of duct from bonnet to boot, in feet.
- Btu loss from room to be heated.
- Equivalent lengths in feet of all fittings and of the register. Fig. 4 shows the values of equivalent lengths of fittings commonly used for domestic systems.

### Forced Warm Air Systems

TABLE 1. CAPACITY AND SIZING TABLE—FIRST STORY  
For Warm Air and Return Air Stack, Branch, and Registers

| EQUIV. LENGTH OF FITTINGS AND REGISTERS             | HORIZONTAL LENGTH FURNACE TO REGISTER |                       | FIRST STORY ROOM HEAT LOSS—BTUH |              |              |                |                    |                    |                  |  |
|-----------------------------------------------------|---------------------------------------|-----------------------|---------------------------------|--------------|--------------|----------------|--------------------|--------------------|------------------|--|
|                                                     | Ducts*                                | Insulated Attic Ducts |                                 |              |              |                |                    |                    |                  |  |
| Col. a                                              | Col. b                                | Col. c                | Col. d                          | Col. e       | Col. f       | Col. g         | Col. h             | Col. i             | Col. j           |  |
| Up to 70 Eq. Ft.                                    | Up to 7                               | Up to 5               | 7,200                           | 12,500       | 16,000       | 19,100         | 25,000             | 32,000             | 80,000           |  |
|                                                     | 8-12                                  | 6-9                   | 6,700                           | 11,700       | 15,000       | 18,000         | 23,400             | 30,000             | 75,000           |  |
|                                                     | 13-17                                 | 10-13                 | 6,100                           | 10,800       | 14,000       | 17,000         | 21,800             | 28,000             | 70,000           |  |
|                                                     | 18-25                                 | 14-18                 | 5,600                           | 9,900        | 13,000       | 16,000         | 19,800             | 26,000             | 65,000           |  |
|                                                     | 26-35                                 | 19-25                 | 4,800                           | 8,500        | 11,000       | 14,200         | 17,000             | 22,600             | 56,500           |  |
| 71 to 100 Eq. Ft.                                   | 36-45                                 | 26-35                 | 4,100                           | 7,400        | 9,900        | 12,500         | 14,800             | 19,800             | 49,500           |  |
|                                                     | 46-55                                 | 36-45                 | 3,500                           | 6,400        | 8,700        | 11,000         | 12,800             | 17,400             | 43,500           |  |
|                                                     | .....                                 | 46-55                 | 3,000                           | 5,500        | 7,700        | 9,600          | 11,000             | 15,400             | 38,500           |  |
|                                                     | Up to 7                               | Up to 5               | 5,500                           | 9,900        | 13,100       | 16,300         | 19,800             | 26,200             | 65,500           |  |
|                                                     | 8-12                                  | 6-9                   | 5,100                           | 9,200        | 12,300       | 15,400         | 18,400             | 24,600             | 61,500           |  |
| 101 to 130 Eq. Ft.                                  | 13-17                                 | 10-13                 | 4,800                           | 8,600        | 11,600       | 14,500         | 17,200             | 23,200             | 58,000           |  |
|                                                     | 18-25                                 | 14-18                 | 4,500                           | 8,100        | 10,900       | 13,700         | 16,200             | 21,800             | 54,500           |  |
|                                                     | 26-35                                 | 19-25                 | 3,900                           | 7,100        | 9,700        | 12,200         | 14,200             | 19,400             | 48,500           |  |
|                                                     | 36-45                                 | 26-35                 | 3,400                           | 6,200        | 8,500        | 10,800         | 12,400             | 17,000             | 42,500           |  |
|                                                     | 46-55                                 | 36-45                 | 3,000                           | 5,400        | 7,500        | 9,500          | 10,800             | 15,000             | 37,500           |  |
| 131 to 165 Eq. Ft.                                  | .....                                 | 46-55                 | 2,600                           | 4,600        | 6,500        | 8,300          | 9,200              | 13,000             | 33,500           |  |
|                                                     | Up to 7                               | Up to 5               | 4,600                           | 8,500        | 11,300       | 14,300         | 17,000             | 22,600             | 56,200           |  |
|                                                     | 8-12                                  | 6-9                   | 4,300                           | 7,900        | 10,600       | 13,500         | 15,800             | 21,200             | 52,800           |  |
|                                                     | 13-17                                 | 10-13                 | 4,100                           | 7,400        | 10,000       | 12,700         | 14,800             | 20,000             | 50,200           |  |
|                                                     | 18-25                                 | 14-18                 | 3,800                           | 6,900        | 9,400        | 11,900         | 13,800             | 18,500             | 47,300           |  |
| 166 to 200 Eq. Ft.                                  | 26-35                                 | 19-25                 | 3,300                           | 6,100        | 8,400        | 10,500         | 12,200             | 16,800             | 42,000           |  |
|                                                     | 36-45                                 | 26-35                 | 3,000                           | 5,300        | 7,400        | 9,300          | 10,600             | 14,800             | 37,000           |  |
|                                                     | 46-55                                 | 36-45                 | 2,700                           | 4,700        | 6,500        | 8,300          | 9,400              | 13,000             | 32,400           |  |
|                                                     | .....                                 | 46-55                 | 2,300                           | 4,000        | 5,400        | 7,000          | 8,000              | 10,800             | 27,000           |  |
|                                                     | Up to 7                               | Up to 5               | 4,100                           | 7,300        | 9,800        | 12,300         | 14,600             | 19,600             | 49,200           |  |
| 201 to 240 Eq. Ft.                                  | 8-12                                  | 6-9                   | 3,800                           | 6,900        | 9,100        | 11,700         | 13,800             | 18,200             | 45,800           |  |
|                                                     | 13-17                                 | 10-13                 | 3,600                           | 6,400        | 8,600        | 11,000         | 12,800             | 17,200             | 41,900           |  |
|                                                     | 18-25                                 | 14-18                 | 3,400                           | 6,000        | 8,100        | 10,300         | 12,000             | 16,200             | 40,300           |  |
|                                                     | 26-35                                 | 19-25                 | 2,900                           | 5,300        | 7,200        | 9,100          | 10,600             | 14,400             | 36,000           |  |
|                                                     | 36-45                                 | 26-35                 | 2,600                           | 4,700        | 6,400        | 8,100          | 9,600              | 12,800             | 31,800           |  |
| 241 to 280 Eq. Ft.                                  | 46-55                                 | 36-45                 | 2,300                           | 4,200        | 5,800        | 7,100          | 8,400              | 11,200             | 28,100           |  |
|                                                     | .....                                 | 46-55                 | 2,000                           | 3,600        | 4,700        | 6,000          | 7,200              | 9,400              | 23,500           |  |
|                                                     | Up to 7                               | Up to 5               | 3,800                           | 6,500        | 8,800        | 11,000         | 13,000             | 17,600             | 44,100           |  |
|                                                     | 8-12                                  | 6-9                   | 3,500                           | 6,100        | 8,200        | 10,500         | 12,200             | 16,400             | 51,500           |  |
|                                                     | 13-17                                 | 10-13                 | 3,300                           | 5,700        | 7,700        | 9,900          | 11,400             | 15,400             | 38,800           |  |
| 281 to 320 Eq. Ft.                                  | 18-25                                 | 14-18                 | 3,100                           | 5,400        | 7,200        | 9,300          | 10,800             | 14,400             | 36,000           |  |
|                                                     | 26-35                                 | 19-25                 | 2,700                           | 4,800        | 6,400        | 8,300          | 9,600              | 12,800             | 32,000           |  |
|                                                     | 36-45                                 | 26-35                 | 2,400                           | 4,300        | 5,700        | 7,300          | 8,600              | 11,400             | 28,200           |  |
|                                                     | 46-55                                 | 36-45                 | 2,100                           | 3,800        | 5,000        | 6,400          | 7,600              | 10,000             | 24,700           |  |
|                                                     | .....                                 | 46-55                 | 1,700                           | 3,000        | 3,900        | 5,100          | 6,000              | 7,800              | 19,500           |  |
| Combination Number                                  |                                       |                       | 41                              | 42           | 43           | 44             | 45                 | 46                 | 47               |  |
| Stacks No.                                          |                                       |                       | 1                               | 1            | 1            | 1              | 2                  | 2                  | —                |  |
| Size                                                |                                       |                       | 10x3¾                           | 10x3¾        | 12x3¾        | 14x3¾          | 10x3¾              | 12x3¾              | —                |  |
| Rectangular Branch Size                             |                                       |                       | 3x8                             | 4x8          | 5x8          | 6x8            | 8x8                | 10x8               | 15x8             |  |
| Round Branch Size (Diam)                            |                                       |                       | 5                               | 6            | 7            | 8              | 9                  | 10                 | 12               |  |
| Number of Joist Spaces and Minimum Depth-Return Air |                                       |                       | 1 at 3                          | 1 at 3       | 1 at 4       | 1 at 5         | 1 at 6 or 2 at 3   | 1 at 7 or 2 at 4   | 1 at 9 or 2 at 5 |  |
| Registers: Low Wall, High Wall or Baseboard         |                                       |                       | 10x6                            | 10x6         | 12x6         | 14x6           | (2)10x6 or (1)24x6 | (2)12x6 or (1)30x6 | —                |  |
| Registers: Floor-Warm Air                           |                                       |                       | 8x10                            | 8x10         | 9x12         | 9x12 or longer | 10x12              | 12x14              | —                |  |
| Registers: Floor-Return Air                         |                                       |                       | 6x10 or 4x14                    | 6x10 or 4x14 | 6x12 or 6x14 | 6x14           | 6x30               | 6x30               | 8x30             |  |
| Trunk Duct Increase, Inches                         |                                       |                       | 1                               | 2            | 3            | 4              | 5                  | 7                  | 12               |  |

<sup>a</sup> Uninsulated ducts in heated spaces and insulated ducts in unheated spaces.

<sup>b</sup> Note: For return air a 14x3 3/4 in. stud space may be used instead of 10x3 3/4 in. stack. Where 12x3 3/4 in. or 14x3 3/4 in. stack is required, a 14x3 3/4 in. stud space may be used only when inside of stud space is smooth and without protruding plaster keys. The number of joist spaces for combination 47 is based on 2x8 in. joists. One space may be used with 2x10 in. joists.

The limiting factor for a duct combination is the stack capacity.

TABLE 2. CAPACITY AND SIZING TABLE—SECOND STORY  
For Warm Air and Return Air Stack, Branch, and Registers

| EQUIV.<br>LENGTH OF<br>FITTINGS<br>AND<br>REGISTERS | HORIZONTAL<br>LENGTH FURNACE<br>TO REGISTER            |                             | SECOND STORY<br>ROOM HEAT LOSS—BTUH |                    |                      |                          |                          |                     |        |  |
|-----------------------------------------------------|--------------------------------------------------------|-----------------------------|-------------------------------------|--------------------|----------------------|--------------------------|--------------------------|---------------------|--------|--|
|                                                     | Ducts <sup>a</sup>                                     | Insulated<br>Attic<br>Ducts |                                     |                    |                      |                          |                          |                     |        |  |
| Col. a                                              | Col. b                                                 | Col. c                      | Col. d                              | Col. e             | Col. f               | Col. g                   | Col. h                   | Col. i              | Col. j |  |
| Up to 70<br>Eq. Ft.                                 | Up to 7                                                | Up to 5                     | 6,300                               | 10,900             | 14,000               | 17,000                   | 21,800                   | 28,000              | 70,000 |  |
|                                                     | 8-12                                                   | 6-9                         | 5,700                               | 10,000             | 13,000               | 15,900                   | 20,000                   | 26,000              | 65,000 |  |
|                                                     | 13-17                                                  | 10-13                       | 5,200                               | 9,200              | 12,100               | 14,900                   | 18,400                   | 24,200              | 60,500 |  |
|                                                     | 18-25                                                  | 14-18                       | 4,800                               | 8,500              | 11,400               | 13,900                   | 17,000                   | 22,400              | 57,000 |  |
|                                                     | 26-35                                                  | 19-25                       | 4,100                               | 7,300              | 10,000               | 12,400                   | 14,600                   | 20,000              | 50,000 |  |
| 71 to 100<br>Eq. Ft.                                | 36-45                                                  | 26-35                       | 3,500                               | 6,400              | 8,800                | 11,100                   | 12,800                   | 17,600              | 44,000 |  |
|                                                     | 46-55                                                  | 36-45                       | 3,100                               | 5,600              | 7,800                | 9,900                    | 11,200                   | 15,600              | 39,000 |  |
|                                                     | .....                                                  | 46-55                       | 2,800                               | 5,000              | 6,800                | 9,000                    | 10,600                   | 13,600              | 34,000 |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
| 101 to 130<br>Eq. Ft.                               | Up to 7                                                | Up to 5                     | 5,000                               | 9,000              | 11,900               | 14,800                   | 18,000                   | 23,900              | 59,500 |  |
|                                                     | 8-12                                                   | 6-9                         | 4,600                               | 8,200              | 11,000               | 13,900                   | 16,400                   | 22,000              | 55,000 |  |
|                                                     | 13-17                                                  | 10-13                       | 4,300                               | 7,600              | 10,300               | 13,000                   | 15,200                   | 20,600              | 51,500 |  |
|                                                     | 18-25                                                  | 14-18                       | 4,000                               | 7,100              | 9,600                | 12,200                   | 14,200                   | 19,200              | 48,000 |  |
|                                                     | 26-35                                                  | 19-25                       | 3,400                               | 6,200              | 8,400                | 10,800                   | 12,400                   | 16,800              | 42,000 |  |
| 131 to 165<br>Eq. Ft.                               | 36-45                                                  | 26-35                       | 3,000                               | 5,400              | 7,500                | 9,600                    | 10,800                   | 15,000              | 37,500 |  |
|                                                     | 46-55                                                  | 36-45                       | 2,700                               | 4,700              | 6,700                | 8,500                    | 9,400                    | 13,400              | 33,500 |  |
|                                                     | .....                                                  | 46-55                       | 2,300                               | 4,200              | 6,000                | 7,500                    | 8,400                    | 12,000              | 30,000 |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
| 166 to 200<br>Eq. Ft.                               | Up to 7                                                | Up to 5                     | 4,200                               | 7,700              | 10,400               | 13,000                   | 15,400                   | 21,700              | 52,200 |  |
|                                                     | 8-12                                                   | 6-9                         | 3,900                               | 7,200              | 9,700                | 12,100                   | 14,400                   | 19,400              | 48,400 |  |
|                                                     | 13-17                                                  | 10-13                       | 3,700                               | 6,700              | 9,000                | 11,300                   | 13,400                   | 18,000              | 45,300 |  |
|                                                     | 18-25                                                  | 14-18                       | 3,500                               | 6,200              | 8,400                | 10,600                   | 12,400                   | 16,800              | 42,300 |  |
|                                                     | 26-35                                                  | 19-25                       | 3,000                               | 5,400              | 7,400                | 9,400                    | 10,800                   | 14,800              | 37,000 |  |
| Combination Number                                  | 36-45                                                  | 26-35                       | 2,600                               | 4,700              | 6,500                | 8,300                    | 9,400                    | 13,000              | 32,500 |  |
|                                                     | 46-55                                                  | 36-45                       | 2,400                               | 4,100              | 5,800                | 7,400                    | 8,200                    | 11,600              | 29,000 |  |
|                                                     | .....                                                  | 46-55                       | 2,000                               | 3,600              | 4,800                | 6,500                    | 7,200                    | 9,600               | 24,000 |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
| Stacks <sup>b</sup> No.                             | Up to 7                                                | Up to 5                     | 3,800                               | 6,800              | 9,100                | 11,400                   | 13,600                   | 18,200              | 45,500 |  |
|                                                     | 8-12                                                   | 6-9                         | 3,500                               | 6,300              | 8,400                | 10,500                   | 12,600                   | 16,800              | 42,000 |  |
|                                                     | 13-17                                                  | 10-13                       | 3,200                               | 5,800              | 7,900                | 9,800                    | 11,600                   | 15,800              | 39,600 |  |
|                                                     | 18-25                                                  | 14-18                       | 3,000                               | 5,500              | 7,400                | 9,200                    | 11,000                   | 14,800              | 36,800 |  |
|                                                     | 26-35                                                  | 19-25                       | 2,700                               | 4,800              | 6,300                | 8,100                    | 9,600                    | 12,600              | 32,200 |  |
| Registers: Low Wall, High Wall<br>or Baseboard:     | 36-45                                                  | 26-35                       | 2,300                               | 4,200              | 5,700                | 7,200                    | 8,400                    | 11,400              | 28,200 |  |
|                                                     | 46-55                                                  | 36-45                       | 1,900                               | 3,400              | 4,500                | 5,800                    | 6,800                    | 9,000               | 22,800 |  |
|                                                     | .....                                                  | 46-55                       | 1,800                               | 3,300              | 4,300                | 5,400                    | 6,600                    | 8,600               | 21,500 |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
| Registers: Floor, Warm Air                          | Up to 7                                                | Up to 5                     | 3,500                               | 6,100              | 8,200                | 10,300                   | 12,200                   | 16,400              | 41,000 |  |
|                                                     | 8-12                                                   | 6-9                         | 3,200                               | 5,700              | 7,600                | 9,500                    | 11,400                   | 15,200              | 38,300 |  |
|                                                     | 13-17                                                  | 10-13                       | 2,900                               | 5,300              | 7,100                | 8,900                    | 10,600                   | 14,200              | 35,800 |  |
|                                                     | 18-25                                                  | 14-18                       | 2,700                               | 5,000              | 6,700                | 8,300                    | 10,000                   | 13,400              | 33,400 |  |
|                                                     | 26-35                                                  | 19-25                       | 2,500                               | 4,400              | 5,700                | 7,400                    | 8,800                    | 11,400              | 29,000 |  |
| Registers: Floor, Return Air                        | 36-45                                                  | 26-35                       | 2,100                               | 3,800              | 5,100                | 6,500                    | 7,800                    | 10,200              | 25,800 |  |
|                                                     | 46-55                                                  | 36-45                       | 1,900                               | 3,400              | 4,500                | 5,800                    | 6,800                    | 9,000               | 22,800 |  |
|                                                     | .....                                                  | 46-55                       | 1,500                               | 2,800              | 3,500                | 4,700                    | 5,600                    | 7,000               | 17,500 |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
|                                                     | .....                                                  | .....                       | .....                               | .....              | .....                | .....                    | .....                    | .....               | .....  |  |
| Trunk Duct Increase, Inches                         | Combination Number                                     | 41                          | 42                                  | 43                 | 44                   | 45                       | 46                       | 47                  |        |  |
|                                                     | Stacks <sup>b</sup> No.                                | 1                           | 1                                   | 1                  | 1                    | 2                        | 2                        | —                   |        |  |
|                                                     | Size                                                   | 10x3 3/4                    | 10x3 3/4                            | 12x3 3/4           | 14x3 3/4             | 10x3 3/4                 | 12x3 3/4                 | —                   |        |  |
|                                                     | Rectangular Branch Size                                | 3x8                         | 4x8                                 | 5x8                | 6x8                  | 8x8                      | 10x8                     | 15x8                |        |  |
|                                                     | Round Branch Size (Diam.)                              | 5                           | 6                                   | 7                  | 8                    | 9                        | 10                       | 12                  |        |  |
| Registers: Low Wall, High Wall<br>or Baseboard:     | Number of Joist Spaces and<br>Minimum Depth—Return Air | 1 at 3                      | 1 at 3                              | 1 at 4             | 1 at 5               | 1 at 6<br>or 2 at 3      | 1 at 7<br>or 2 at 4      | 1 at 9<br>or 2 at 5 |        |  |
|                                                     | Registers: Low Wall, High Wall<br>or Baseboard:        | 10x6                        | 10x6                                | 12x6               | 14x6                 | (2)10x6<br>or<br>(1)24x6 | (2)12x6<br>or<br>(1)30x6 | —                   |        |  |
|                                                     | Registers: Floor, Warm Air                             | 8x10                        | 8x10                                | 9x12               | 9x12<br>or<br>longer | 10x12                    | 12x14                    | —                   |        |  |
|                                                     | Registers: Floor, Return Air                           | 6x10<br>or<br>4x14          | 6x10<br>or<br>4x14                  | 6x12<br>or<br>6x14 | 6x14                 | 6x30                     | 6x30                     | 8x30                |        |  |
|                                                     | Trunk Duct Increase, Inches                            | 1                           | 2                                   | 3                  | 4                    | 5                        | 7                        | 12                  |        |  |

<sup>a</sup> Uninsulated ducts in heated spaces and insulated ducts in unheated spaces.

<sup>b</sup> Note: For return air a 14x3 3/4 in. stud space may be used instead of 10x3 3/4 in. stack. Where 12x3 3/4 in. stack is required, a 14x3 3/4 in. stud space may be used only when inside of stud space is smooth and without protruding plaster keys. The number of joist spaces for combination 47 is based on 2x8 joists. One space may be used with 2x10 joists.

The limiting factor for a duct combination is the stack capacity.

This simplified method is applicable to structures having heat losses not in excess of approximately 120,000 Btu per hour. The capacities shown in Tables 1 and 2 are based upon the most reliable data pertaining to friction losses and temperature drops in ducts. They are also based upon a 100 deg temperature rise of the air, and a static pressure available for overcoming friction losses in the external duct system alone of 0.20 in. water gage. The use of this method assumes that the fan in the fan-furnace assembly will be capable not only of overcoming the resistance of the external duct system alone, but also the resistances imposed by the blower inlet, the filter, and the furnace casing.

Tables 1 and 2 are applicable for the selection of both warm air and return air branches. A depth of 8 in. has been adopted as the standard for trunk ducts, and where a branch joins the trunk the required increase shown in the last line of Table 1 or Table 2 refers to an 8-in. trunk duct.

Where two branches form a trunk the farthest branch is considered to be the trunk and its equivalent width (for 8-in. depth) is increased as required.

#### DESIGN PROCEDURE FOR LARGE SYSTEMS<sup>4</sup>

For buildings having a heat loss in excess of 120,000 Btu per hour, the design procedure<sup>4</sup> given in Manual 9 of the *NWAA & ACA*, may be used. Work sheets 9a, 9b, and 9c are available to simplify calculations.<sup>4</sup> The procedure consists of:

1. Calculation of design heat losses from individual spaces in the structure. The calculation of these losses is explained in Chapter 12.
2. Location of registers and return intakes on floor plan, showing types of registers, with distance from register to opposite wall and deflection of registers desired.
3. Laying out a proposed duct system for both warm air and return air sides of the system, and including details of types of fittings and the actual and equivalent lengths of each branch line from bonnet to register, without sizes. (See Fig. 4, Groups 1 through 6, for equivalent length of fittings.)
4. Determination of bonnet temperature.

If the rating sheet for a furnace-blower unit specifies a fixed value of bonnet temperature, locate this temperature in the left-hand column of Table 3. If not specified, use the following procedure: Use Table 3 for buildings having a heat loss between 120,000 and 350,000 Btu per hr, or Table 4 for buildings having a heat loss greater than 350,000 Btu per hr. Select *shortest actual length*, including vertical risers and read downward in nearest column in Tables 3 or 4 until lower heavy diagonal line is reached, but do not cross line. Run horizontally to first column of table and note *bonnet temperature*. Also select *longest actual length* including vertical risers, and read downward in nearest column in Tables 3 or 4 until upper heavy diagonal line is just crossed. Run horizontally to left to obtain value for *bonnet temperature* in first column. Select as the design bonnet temperature any value between these two limits.

5. Determination of air volume to be delivered through each register and the respective register air temperatures.

Using Tables 3 or 4 and the design bonnet temperature selected, find the values of cfm per 1000 Btu for each duct length, and the corresponding register temperature.

6. Selection of register sizes and pressure losses to produce necessary throw, for the air volumes handled.

Use Tables 5 or 6 to obtain required free area and pressure loss of register.

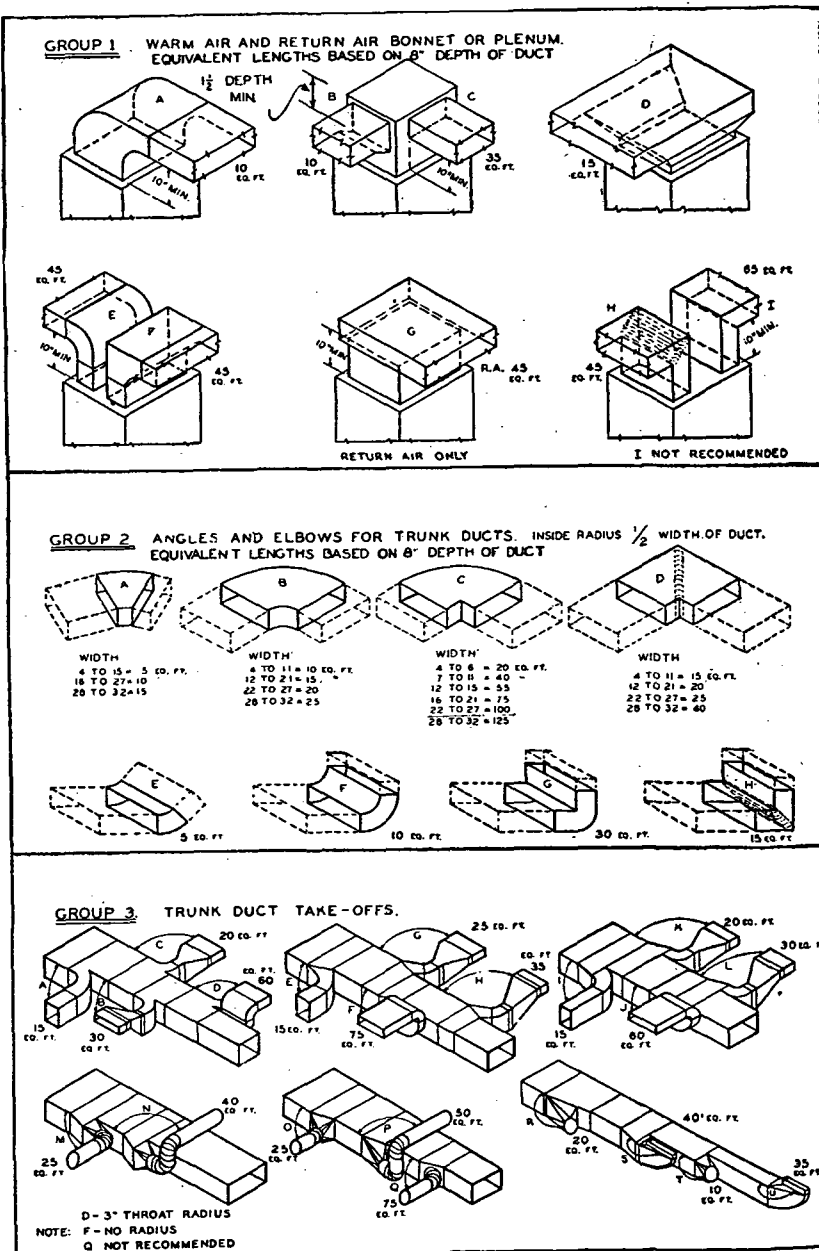


FIG. 4. EQUIVALENT LENGTH OF FITTINGS

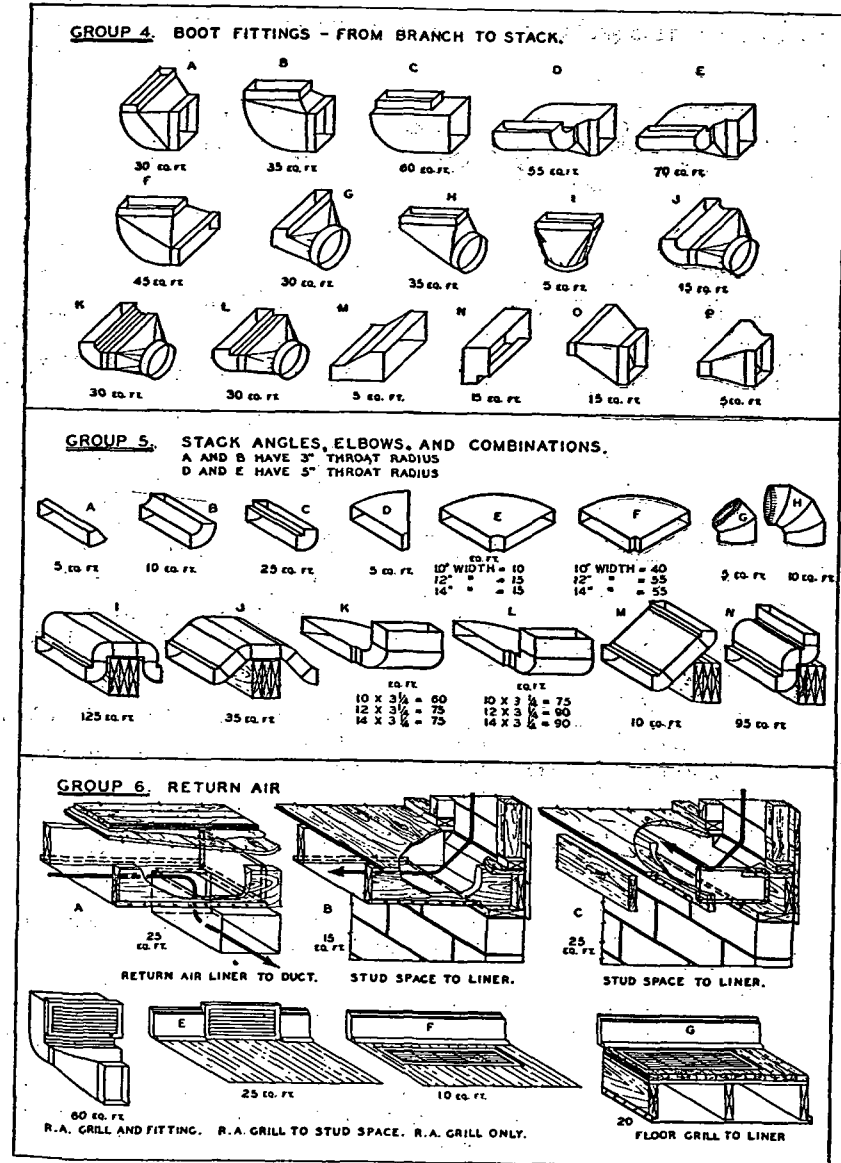


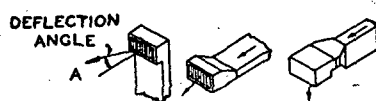
FIG. 4. EQUIVALENT LENGTH OF FITTINGS (Continued)

## 7. Design of duct system.

## A. Warm air branches.

- Use Table 7 to select maximum bonnet pressure *usually* required for the trunk carrying the maximum volume of air (cfm). If the maximum

GROUP 7. REGISTERS (INCLUDING LOSSES IN STACKHEAD AND VELOCITY PRESSURE).



25 EQ. FT.  
FL. REG. & BOX  
ONLY

TABLE 4A. EQUIVALENT LENGTH FOR REGISTERS

| Deflection Angle A                        | 0°            | 15° | 22° | 30° | 45° |
|-------------------------------------------|---------------|-----|-----|-----|-----|
| Baseboard, High or Low Sidewall Registers | Eq. Ft.<br>35 | 40  | 45  | 60  | 115 |
| Floor Registers with Box only             | 25            |     |     |     |     |

For 2-way deflection registers, add the vertical and horizontal deflection angles together and multiply by 0.7. Select closest angle A in Table 4A. For diffuser type registers see manufacturers' catalogs.

FIG. 4. EQUIVALENT LENGTH OF FITTINGS (Concluded)

bonnet pressure is not high enough to accommodate the pressure loss through the registers, use a higher bonnet pressure. If the register pressure is critically large, it may be necessary to reduce it by either using two registers in place of one, or using smaller deflection angles.

- two registers in place of one, or using smaller registers.
      - a. Obtain actual duct loss by subtracting total register pressure loss, as determined from Tables 5 or 6, from maximum bonnet pressure.
      - c. Obtain the pressure drop in each duct per 100 ft by use of Table 8.
      - d. Determine duct size by means of air friction chart (such as Fig. 1, or Fig. 2, Chapter 32), volume (cfm), and pressure drop per 100 ft of duct.
    - B. *Return air branches.*
      - a. Select a low value of actual duct loss obtained from step b under item A for the suction loss of return duct system.
      - b. Proceed in sizing return air branches by the same method described for the warm air branches.
    - C. *Trunk ducts for warm air and return air sides of system.*
      - a. Add air volumes of branches to be handled by each trunk duct.
      - b. The friction loss per 100 ft of trunk duct is determined by taking the smaller of the two values for friction loss for the two ducts meeting at the junction.
      - c. Determine trunk duct size by using an air friction chart, volume (cfm), and pressure drop per 100 ft of trunk duct.
  8. *Selection of Blower.*
    - A. Determine total cfm air delivery (the sum of all branch cfm values).
    - B. Determine static pressure requirement.
      - a. For furnace-blower combination units it is the sum of bonnet pressure and suction pressure.
      - b. For blowers separately selected from the furnace it is the sum of bonnet pressure, suction pressure, filter loss, casing loss, losses through air washers, coils, and other devices.
  9. *Selection of Furnace.*
    - A. Determine register delivery (the sum of room Btu losses).
    - B. Determine bonnet capacity.  
 $\text{Bonnet capacity} = (\text{total cfm}) \times (\text{temperature rise}) \times 1.089.$
    - C. Determine allowance for pick-up load. For buildings which are heated intermittently, such as churches and auditoriums, it is customary to add from 10 to 25 percent extra furnace capacity for warming of the structure.

TABLE 3. SELECTION OF BONNET TEMPERATURE, REGISTER TEMPERATURE AND REGISTER DELIVERY (CFM)<sup>a, b</sup>  
(For Buildings Having a Heat Loss between 180,000 and 350,000 BTU/Hr.)  
Register Delivery Volume in CFM per 1000 BTU per Hr.

| TEMP. OF BOR.<br>NET F. |                  | LINEAR DISTANCE FROM BORNET TO REGISTER, IN FEET |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|-------------------------|------------------|--------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                         |                  | 10                                               | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  | 110  | 120  | 130  | 140  | 150  | 160  | 170  | 180  | 190  | 200  | 210  | 220  | 230  | 240  |      |
| 110                     | 108 <sup>a</sup> | 107                                              | 106  | 104  | 103  | 102  | 101  | 100  | 99   | 98   | 97   | 96   | 95   | 94   | 93   | 92   | 91   | 90   | 89   | 88   | 87   | 86   | 85   | 84   | 83   | 82   |
| 22                      | 23 <sup>b</sup>  | 23 <sup>b</sup>                                  | 24.2 | 25.4 | 26.0 | 26.6 | 27.3 | 28.0 | 28.8 | 29.6 | 30.5 | 31.5 | 32.3 | 33.3 | 34.6 | 35.9 | 37.3 | 38.6 | 39.9 | 41.3 | 42.7 | 44.1 | 45.5 | 46.9 | 48.3 | 49.7 |
| 120                     | 118              | 116                                              | 114  | 112  | 111  | 109  | 108  | 106  | 105  | 104  | 102  | 101  | 100  | 99   | 98   | 97   | 96   | 95   | 94   | 93   | 92   | 91   | 90   | 89   | 88   | 87   |
| 18.4                    | 19.0             | 19.6                                             | 20.3 | 21.1 | 21.6 | 22.5 | 23.1 | 24.2 | 24.8 | 26.0 | 28.6 | 27.3 | 28.0 | 28.8 | 29.6 | 30.5 | 31.5 | 32.3 | 33.3 | 34.6 | 35.9 | 37.3 | 38.6 | 39.9 | 41.3 | 42.7 |
| 130                     | 128              | 126                                              | 123  | 121  | 119  | 117  | 115  | 113  | 111  | 110  | 108  | 107  | 105  | 104  | 103  | 102  | 101  | 99   | 98   | 97   | 96   | 95   | 94   | 93   | 92   | 91   |
| 15.9                    | 16.4             | 16.9                                             | 17.6 | 18.1 | 18.7 | 19.3 | 20.0 | 20.7 | 21.6 | 22.1 | 23.1 | 23.6 | 24.8 | 25.4 | 26.0 | 26.6 | 27.3 | 28.6 | 29.6 | 30.5 | 31.5 | 32.3 | 33.3 | 34.6 | 35.9 | 37.3 |
| 140                     | 137              | 134                                              | 131  | 129  | 128  | 124  | 122  | 120  | 118  | 116  | 114  | 112  | 110  | 109  | 107  | 106  | 105  | 103  | 102  | 101  | 100  | 99   | 98   | 97   | 96   | 95   |
| 14.0                    | 14.6             | 15.1                                             | 15.7 | 16.2 | 16.9 | 17.3 | 17.9 | 18.4 | 19.0 | 19.6 | 20.3 | 21.1 | 22.1 | 22.5 | 23.6 | 24.2 | 24.8 | 26.0 | 27.3 | 28.6 | 29.6 | 30.5 | 31.5 | 32.3 | 33.3 | 34.6 |
| 150                     | 147              | 143                                              | 140  | 137  | 134  | 131  | 129  | 127  | 124  | 122  | 120  | 118  | 116  | 114  | 112  | 110  | 109  | 107  | 106  | 105  | 103  | 102  | 101  | 100  | 99   | 98   |
| 12.6                    | 12.9             | 13.5                                             | 14.0 | 14.6 | 15.1 | 15.7 | 16.2 | 16.6 | 17.3 | 17.9 | 18.5 | 18.4 | 19.6 | 20.3 | 21.1 | 22.1 | 22.5 | 23.6 | 24.2 | 24.8 | 26.0 | 27.3 | 28.6 | 29.6 | 30.5 | 31.5 |
| 160                     | 156              | 152                                              | 149  | 145  | 142  | 139  | 136  | 133  | 130  | 128  | 126  | 123  | 121  | 119  | 117  | 115  | 113  | 112  | 110  | 108  | 107  | 106  | 105  | 103  | 102  | 101  |
| 11.4                    | 11.8             | 12.3                                             | 12.7 | 13.2 | 13.7 | 14.2 | 14.8 | 15.3 | 15.9 | 16.4 | 16.9 | 17.6 | 18.1 | 18.7 | 19.3 | 20.0 | 20.7 | 21.1 | 22.1 | 22.5 | 23.6 | 24.2 | 24.8 | 26.0 | 27.3 | 28.0 |
| 170                     | 166              | 161                                              | 157  | 153  | 150  | 146  | 143  | 140  | 137  | 134  | 131  | 128  | 126  | 124  | 122  | 120  | 118  | 116  | 114  | 112  | 110  | 109  | 107  | 106  | 105  | 103  |
| 10.5                    | 10.8             | 11.3                                             | 11.7 | 12.2 | 12.6 | 13.1 | 13.5 | 14.0 | 14.6 | 15.1 | 15.7 | 16.4 | 16.9 | 17.3 | 17.9 | 18.4 | 19.0 | 19.6 | 20.3 | 21.1 | 22.1 | 22.5 | 23.6 | 24.2 | 25.4 | 26.0 |
| 180                     | 175              | 170                                              | 166  | 161  | 157  | 153  | 150  | 146  | 143  | 140  | 137  | 135  | 131  | 128  | 126  | 124  | 122  | 120  | 118  | 116  | 114  | 112  | 110  | 109  | 107  | 106  |
| 9.7                     | 10.0             | 10.5                                             | 10.8 | 11.3 | 11.7 | 12.2 | 12.6 | 13.1 | 13.5 | 14.0 | 14.6 | 14.9 | 15.7 | 16.4 | 16.9 | 17.3 | 17.9 | 18.4 | 19.0 | 19.6 | 20.3 | 21.1 | 22.1 | 22.5 | 23.6 | 24.2 |
| 190                     | 184              | 179                                              | 174  | 169  | 165  | 160  | 156  | 153  | 149  | 145  | 142  | 139  | 136  | 133  | 130  | 128  | 126  | 124  | 122  | 120  | 118  | 116  | 115  | 113  | 111  | 110  |
| 9.1                     | 9.4              | 9.8                                              | 10.1 | 10.6 | 10.9 | 11.4 | 11.8 | 12.2 | 12.7 | 13.2 | 13.7 | 14.2 | 14.7 | 15.3 | 15.9 | 16.4 | 16.9 | 17.3 | 17.9 | 18.4 | 19.0 | 19.6 | 20.0 | 20.7 | 21.1 | 22.1 |
| 200                     | 193              | 187                                              | 182  | 176  | 171  | 167  | 163  | 158  | 154  | 151  | 147  | 144  | 140  | 138  | 135  | 132  | 129  | 127  | 125  | 122  | 120  | 118  | 116  | 115  | 113  | 112  |
| 8.6                     | 8.9              | 9.2                                              | 9.6  | 9.9  | 10.4 | 10.7 | 11.1 | 11.6 | 12.1 | 12.4 | 12.9 | 13.4 | 14.0 | 14.4 | 14.9 | 15.5 | 16.2 | 16.6 | 17.2 | 17.9 | 18.4 | 19.0 | 19.6 | 20.0 | 20.7 | 21.1 |

\* Register temperature, Fahrenheit. (Use upper value in each group).

<sup>b</sup> Register delivery volume in cubic feet per minute per 1000 Btu. (Use lower value in each group).

Register delivery volumes in column 1 for zero length of duct.

TABLE 4. SELECTION OF BONNET TEMPERATURE, REGISTER TEMPERATURE AND REGISTER DELIVERY (CFM)<sup>a, b</sup>  
(For Buildings Having a Heat Loss Greater than 50,000 BTU/Hr.)  
Register Delivery Volume in CFM per 1000 BTU per Hr.

| BONNET TEMP. °F. | LINEAR DISTANCE FROM BONNET TO REGISTER, IN FEET |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|------------------|--------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                  | 10                                               | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  | 110  | 120  | 130  | 140  | 150  | 160  | 170  | 180  | 190  |
| 140              | 138*                                             | 136  | 134  | 132  | 130  | 128  | 127  | 126  | 125  | 124  | 123  | 121  | 120  | 119  | 118  | 117  | 116  | 115  | 114  |
| 14.0°            | 14.4*                                            | 14.8 | 15.1 | 15.5 | 15.8 | 16.4 | 16.8 | 17.2 | 17.3 | 17.6 | 18.1 | 18.4 | 18.7 | 19.0 | 19.3 | 19.6 | 20.0 | 20.3 | 20.7 |
| 150              | 148                                              | 146  | 143  | 141  | 139  | 137  | 135  | 133  | 131  | 129  | 128  | 127  | 126  | 124  | 123  | 122  | 120  | 119  | 118  |
| 12.6             | 12.8                                             | 13.1 | 13.5 | 13.9 | 14.2 | 14.6 | 14.9 | 15.3 | 15.7 | 16.2 | 16.6 | 17.0 | 17.3 | 17.6 | 17.9 | 18.3 | 18.7 | 19.0 | 19.3 |
| 160              | 158                                              | 155  | 152  | 150  | 147  | 145  | 143  | 140  | 138  | 136  | 134  | 132  | 130  | 128  | 127  | 126  | 125  | 124  | 123  |
| 11.4             | 11.6                                             | 12.0 | 12.3 | 12.6 | 12.9 | 13.2 | 13.5 | 14.0 | 14.4 | 14.8 | 15.1 | 15.5 | 15.9 | 16.4 | 16.8 | 17.2 | 17.6 | 18.1 | 18.4 |
| 170              | 167                                              | 164  | 161  | 158  | 155  | 152  | 150  | 147  | 145  | 143  | 140  | 138  | 136  | 134  | 132  | 130  | 128  | 127  | 126  |
| 10.5             | 10.7                                             | 11.0 | 11.3 | 11.6 | 12.0 | 12.3 | 12.6 | 12.9 | 13.2 | 13.5 | 14.0 | 14.4 | 14.8 | 15.1 | 15.5 | 15.9 | 16.4 | 16.8 | 17.2 |
| 180              | 177                                              | 173  | 170  | 167  | 164  | 161  | 158  | 155  | 152  | 150  | 147  | 145  | 143  | 140  | 138  | 136  | 134  | 132  | 130  |
| 9.7              | 9.9                                              | 10.2 | 10.5 | 10.7 | 11.0 | 11.3 | 11.6 | 12.0 | 12.3 | 12.6 | 12.9 | 13.2 | 13.5 | 14.0 | 14.4 | 14.8 | 15.1 | 15.5 | 15.9 |
| 190              | 186                                              | 182  | 178  | 175  | 172  | 168  | 165  | 162  | 159  | 156  | 153  | 151  | 148  | 146  | 143  | 141  | 139  | 137  | 135  |
| 9.1              | 9.3                                              | 9.6  | 9.8  | 10.0 | 10.3 | 10.7 | 11.0 | 11.3 | 11.6 | 12.0 | 12.3 | 12.6 | 12.9 | 13.2 | 13.5 | 14.0 | 14.4 | 14.8 | 15.1 |
| 200              | 196                                              | 191  | 187  | 183  | 179  | 176  | 172  | 169  | 166  | 163  | 160  | 157  | 154  | 151  | 149  | 147  | 144  | 142  | 140  |
| 8.6              | 8.8                                              | 9.0  | 9.2  | 9.5  | 9.8  | 9.9  | 10.3 | 10.6 | 10.8 | 11.1 | 11.4 | 11.7 | 12.1 | 12.4 | 12.7 | 12.9 | 13.3 | 13.7 | 14.0 |

\* Register temperature, Fahrenheit. (Use upper value in each group).  
b Register delivery volume in cubic feet per minute per 1000 Btu. (Use lower value in each group).

## Forced Warm Air Systems

TABLE 5. DETERMINATION OF FREE AREA AND TOTAL PRESSURE LOSS OF REGISTER  
FOR 22 DEG DEFLECTION OF AIR<sup>a, b, c, d, e</sup>  
Register Free Area in Square Inches (Upper value in each group)  
Pressure Loss in Inches of Water (Lower value in each group)

| CFM      | RESIDENTIAL USE                         |                | CFM         | RESIDENTIAL USE          |                | CFM         | DISTANCE FROM REGISTER TO OPPOSITE WALL |             |             |             |             |             |             |             |             |  |  |  |
|----------|-----------------------------------------|----------------|-------------|--------------------------|----------------|-------------|-----------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--|--|--|
|          | REG. SIZE OR EQUIV-ALENT                | PRES-SURE LOSS |             | REG. SIZE OR EQUIV-ALENT | PRES-SURE LOSS |             | CFM                                     |             |             |             |             |             |             |             |             |  |  |  |
|          |                                         |                |             |                          |                |             |                                         | 31-34       | 35-39       | 40-49       | 50-59       | 60-69       | 70-79       | 80-89       |             |  |  |  |
|          |                                         |                |             |                          |                |             |                                         |             |             |             | A'          |             | B'          |             |             |  |  |  |
| Up to 59 | 10 x 4<br>10 x 6                        | .01<br>.01     | 100-119     | 12 x 6<br>14 x 4         | .02<br>.02     | 700-739     | 243<br>0.02                             | 186<br>0.03 | 127<br>0.06 | 85<br>0.11  |             |             |             |             |             |  |  |  |
| 60-69    | 10 x 6<br>12 x 4                        | .01<br>.02     | 120-129     | 12 x 6<br>14 x 6         | .02<br>.02     | 740-779     | 271<br>0.02                             | 208<br>0.03 | 141<br>0.05 | 94<br>0.10  |             |             |             |             |             |  |  |  |
| 70-99    | 10 x 6<br>12 x 6                        | .02<br>.02     | 130-169     | 14 x 6                   | .02            | 780-819     |                                         | 230<br>0.02 | 157<br>0.05 | 105<br>0.09 |             |             |             |             |             |  |  |  |
|          |                                         |                | 170-189     | 14 x 8                   | .02            | 820-859     |                                         | 254<br>0.02 | 173<br>0.04 | 115<br>0.08 |             |             |             |             |             |  |  |  |
| CFM      | DISTANCE FROM REGISTER TO OPPOSITE WALL |                |             |                          |                |             |                                         |             |             |             |             |             |             |             |             |  |  |  |
|          | Up to 18                                | 19-21          | 22-24       | 25-27                    | 28-30          | 31-34       | 35-39                                   | 40-49       | 50-59       |             |             |             |             |             |             |  |  |  |
|          |                                         | A              |             |                          |                |             |                                         |             |             |             |             |             |             |             |             |  |  |  |
| 190-209  | 68<br>0.02                              | 49<br>0.03     | 38<br>0.05  | 29<br>0.08               | 24<br>0.11     | 19<br>0.16  |                                         |             |             |             |             |             |             |             |             |  |  |  |
| 210-229  | 82<br>0.02                              | 60<br>0.03     | 45<br>0.04  | 35<br>0.06               | 28<br>0.10     | 23<br>0.13  |                                         |             |             |             |             |             |             |             |             |  |  |  |
| 230-249  |                                         | 71<br>0.02     | 54<br>0.04  | 42<br>0.06               | 34<br>0.08     | 28<br>0.11  | 22<br>0.17                              |             |             |             |             |             |             |             |             |  |  |  |
| 250-269  |                                         | 84<br>0.02     | 63<br>0.03  | 49<br>0.05               | 40<br>0.07     | 32<br>0.10  | 25<br>0.16                              |             |             |             |             |             |             |             |             |  |  |  |
| 270-299  |                                         | 100<br>0.02    | 78<br>0.03  | 60<br>0.04               | 48<br>0.06     | 39<br>0.09  | 30<br>0.13                              |             |             |             |             |             |             |             |             |  |  |  |
| 300-339  |                                         |                | 96<br>0.02  | 73<br>0.04               | 60<br>0.05     | 48<br>0.07  | 37<br>0.11                              |             |             |             |             |             |             |             |             |  |  |  |
| 340-379  |                                         |                | 122<br>0.02 | 95<br>0.03               | 78<br>0.04     | 61<br>0.06  | 47<br>0.09                              | 33<br>0.18  |             |             |             |             |             |             |             |  |  |  |
| 380-419  |                                         |                |             | 117<br>0.02              | 94<br>0.03     | 75<br>0.05  | 58<br>0.08                              | 39<br>0.15  |             |             |             |             |             |             |             |  |  |  |
| 420-459  |                                         |                |             | 142<br>0.02              | 113<br>0.03    | 91<br>0.04  | 70<br>0.06                              | 47<br>0.13  |             |             |             |             |             |             |             |  |  |  |
| 460-499  |                                         |                |             | 168<br>0.02              | 135<br>0.03    | 108<br>0.04 | 83<br>0.06                              | 56<br>0.11  |             |             |             |             |             |             |             |  |  |  |
| 500-539  |                                         |                |             |                          | 159<br>0.02    | 126<br>0.03 | 97<br>0.05                              | 66<br>0.10  |             |             |             |             |             |             |             |  |  |  |
| 540-579  |                                         |                |             |                          | 185<br>0.02    | 147<br>0.03 | 113<br>0.04                             | 77<br>0.08  |             |             |             |             |             |             |             |  |  |  |
| 580-619  |                                         |                |             |                          | 212<br>0.02    | 169<br>0.03 | 130<br>0.04                             | 88<br>0.08  | 51<br>0.18  |             |             |             |             |             |             |  |  |  |
| 620-659  |                                         |                |             |                          |                | 192<br>0.02 | 147<br>0.03                             | 100<br>0.07 | 59<br>0.15  |             |             |             |             |             |             |  |  |  |
| 660-699  |                                         |                |             |                          |                | 217<br>0.02 | 166<br>0.03                             | 113<br>0.06 | 75<br>0.13  |             |             |             |             |             |             |  |  |  |
|          |                                         |                |             |                          |                |             |                                         |             |             | 1460-1500   | 536<br>0.02 | 356<br>0.03 | 256<br>0.06 | 182<br>0.10 | 129<br>0.19 |  |  |  |

<sup>a</sup> If register selected based on distance from register to opposite wall is unsatisfactory on account of size or pressure loss, it is permissible to shift one or more spaces left or right in the tables to obtain a more suitable register. If requirements fall in blank space, select two registers in place of one and divide CFM capacity between the two registers.  
<sup>b</sup> Total pressure (static plus velocity) loss is based on FLAT FACE ADJUSTABLE BAR TYPE and does NOT include stackhead.  
<sup>c</sup> Values on the right of line A and A' should not be used in applications such as churches, auditoriums, and concert halls.  
<sup>d</sup> Values on right of line B and B' should not be used in applications such as residential work, motion picture theaters, court rooms and schools.  
<sup>e</sup> For floor and baseboard registers where a velocity of approximately 300 FPM is used, the free area =  $\frac{\text{CFM} \times 144}{300}$  or approximately,  $\frac{\text{CFM}}{2}$ . Assume a pressure loss of 0.01.

TABLE 6. DETERMINATION OF FREE AREA AND TOTAL PRESSURE LOSS OF REGISTER FOR NO DEFLECTION OF AIR<sup>a,b,c,d,e</sup>

Register Free Air in Square Inches (Upper value in each group)  
Pressure Loss in Inches of Water Column (Lower value in each group)

| CFM                   | DISTANCE FROM REGISTER TO OPPOSITE WALL |            |             |             |                 |                 | CFM        | DISTANCE FROM REGISTER TO OPPOSITE WALL |             |             |                  |                  |             |             |       |
|-----------------------|-----------------------------------------|------------|-------------|-------------|-----------------|-----------------|------------|-----------------------------------------|-------------|-------------|------------------|------------------|-------------|-------------|-------|
|                       | 19-21                                   | 22-24      | 25-27       | 28-30       | 31-34           | 35-39           |            | 40-49                                   | 50-59       | 60-69       | 35-39            | 40-49            | 50-59       | 60-69       | 70-79 |
| 190 <sup>d</sup> -209 | 62<br>0.02                              | 47<br>0.03 | 37<br>0.04  | 30<br>0.06  | A<br>24<br>0.09 | B<br>18<br>0.15 |            | 660-699                                 | 210<br>0.02 | 143<br>0.03 | A'<br>95<br>0.07 | B'<br>69<br>0.12 | 49<br>0.22  |             |       |
| 210-229               | 76<br>0.02                              | 58<br>0.02 | 45<br>0.04  | 36<br>0.05  | 29<br>0.08      | 22<br>0.12      |            | 700-739                                 | 236<br>0.02 | 160<br>0.03 | 107<br>0.06      | 77<br>0.11       | 54<br>0.21  |             |       |
| 230-249               |                                         | 69<br>0.02 | 53<br>0.03  | 43<br>0.04  | 34<br>0.07      | 26<br>0.11      |            | 740-779                                 | 262<br>0.02 | 179<br>0.03 | 119<br>0.06      | 86<br>0.10       | 61<br>0.18  |             |       |
| 250-269               |                                         | 81<br>0.02 | 63<br>0.03  | 50<br>0.04  | 40<br>0.06      | 31<br>0.09      | 21<br>0.18 | 780-819                                 | 291<br>0.02 | 198<br>0.03 | 132<br>0.05      | 95<br>0.09       | 67<br>0.17  |             |       |
| 270-299               |                                         | 93<br>0.02 | 73<br>0.02  | 59<br>0.03  | 47<br>0.05      | 36<br>0.08      | 24<br>0.16 | 820-859                                 | 320<br>0.02 | 218<br>0.03 | 145<br>0.05      | 105<br>0.08      | 74<br>0.15  |             |       |
| 300-339               |                                         |            | 95<br>0.02  | 77<br>0.03  | 61<br>0.04      | 46<br>0.06      | 32<br>0.12 | 860-899                                 | 352<br>0.02 | 240<br>0.02 | 160<br>0.04      | 115<br>0.08      | 81<br>0.14  |             |       |
| 340-379               |                                         |            | 120<br>0.02 | 97<br>0.02  | 77<br>0.03      | 59<br>0.05      | 40<br>0.10 | 900-939                                 | 385<br>0.01 | 262<br>0.02 | 175<br>0.04      | 126<br>0.07      | 89<br>0.13  |             |       |
| 380-419               |                                         |            |             | 119<br>0.02 | 95<br>0.03      | 73<br>0.04      | 50<br>0.08 | 940-979                                 | 419<br>0.01 | 285<br>0.02 | 190<br>0.04      | 137<br>0.07      | 97<br>0.12  |             |       |
| 420-459               |                                         |            |             | 149<br>0.02 | 114<br>0.03     | 88<br>0.04      | 60<br>0.07 | 980-1019                                | 455<br>0.01 | 309<br>0.02 | 206<br>0.04      | 148<br>0.06      | 105<br>0.11 |             |       |
| 460-499               |                                         |            |             | 171<br>0.02 | 136<br>0.03     | 105<br>0.03     | 71<br>0.06 | 1020-1059                               | 493<br>0.01 | 335<br>0.02 | 223<br>0.03      | 161<br>0.06      | 113<br>0.11 |             |       |
| 500-539               |                                         |            |             | 160<br>0.02 | 123<br>0.03     | 84<br>0.05      |            | 1060-1099                               | 530<br>0.01 | 361<br>0.02 | 241<br>0.03      | 173<br>0.06      | 123<br>0.10 |             |       |
| 540-579               |                                         |            |             | 186<br>0.02 | 143<br>0.02     | 97<br>0.05      | 65<br>0.09 | 1100-1139                               | 571<br>0.01 | 388<br>0.02 | 258<br>0.03      | 186<br>0.05      | 132<br>0.09 | 93<br>0.17  |       |
| 580-619               |                                         |            |             | 213<br>0.02 | 164<br>0.02     | 111<br>0.04     | 74<br>0.08 | 1140-1179                               |             | 416<br>0.02 | 277<br>0.03      | 199<br>0.05      | 141<br>0.08 | 100<br>0.16 |       |
| 620-659               |                                         |            |             |             | 180<br>0.02     | 127<br>0.04     | 85<br>0.07 | 1180-1219                               |             | 446<br>0.02 | 297<br>0.03      | 214<br>0.04      | 151<br>0.08 | 107<br>0.15 |       |

<sup>a</sup> If register selected based on distance from register to opposite wall is unsatisfactory on account of size or pressure loss, it is permissible to shift one or more spaces left or right in the tables to obtain a more suitable register. If requirements fall in blank space, select two registers in place of one and divide CFM capacity between the two registers.

<sup>b</sup> Total pressure (static plus velocity) loss is based on FLAT FACE ADJUSTABLE BAR TYPE and does NOT include stackhead.

<sup>c</sup> Values on the right of line A and A' should not be used in applications such as churches, auditoriums, and concert halls.

<sup>d</sup> Values on right of line B and B' should not be used in applications such as residential work, motion picture theaters, court rooms and schools.

<sup>e</sup> For floor and baseboard registers where a velocity of approximately 300 FPM is used, the free area =  $\frac{\text{CFM} \times 144}{300}$  or approximately,  $\frac{\text{CFM}}{2}$ . Assume a pressure loss of .01.

For any volume under 190 CFM use Table 5.

A' B'

TABLE 7. SUGGESTED BONNET PRESSURE

Inches of water

| TOTAL CFM THROUGH ANY ONE DUCT | SUGGESTED BONNET PRESSURE IN. WATER | TOTAL CFM THROUGH ANY ONE DUCT | SUGGESTED BONNET PRESSURE IN. WATER |
|--------------------------------|-------------------------------------|--------------------------------|-------------------------------------|
| 800-1000                       | 0.10                                | 3500 to 5000                   | 0.15                                |
| 1000-1200                      | 0.10                                | 5000 to 7500                   | 0.25                                |
| 1200-1800                      | 0.10                                | 7500 to 10,000                 | 0.375                               |
| 1800-2400                      | 0.13                                | 10,000 to 12,000               | 0.500                               |
| 2400 to 3500                   | 0.14                                | 12,000 to 14,000               | 0.750                               |

TABLE 8. PRESSURE DROP IN DUCT

Inches of Water per 100 Feet of Duct Length

| EQUIVALENT LENGTH OF DUCT (Ft) | TOTAL PRESSURE DROP IN DUCT (IN. OF WATER) |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|--------------------------------|--------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                                | 0.04                                       | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 |      |
| 35-44                          | 0.10                                       | 0.13 | 0.15 | 0.18 | 0.20 | 0.23 | 0.25 | 0.28 | 0.30 | 0.33 | 0.35 | 0.38 | 0.40 | 0.43 | 0.45 | 0.48 | 0.50 | 0.52 | 0.54 | 0.56 |
| 45-54                          | 0.09                                       | 0.10 | 0.12 | 0.14 | 0.16 | 0.18 | 0.20 | 0.22 | 0.24 | 0.26 | 0.28 | 0.30 | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 | 0.42 | 0.44 | 0.46 |
| 55-64                          | 0.07                                       | 0.08 | 0.10 | 0.12 | 0.13 | 0.15 | 0.17 | 0.18 | 0.20 | 0.22 | 0.23 | 0.25 | 0.27 | 0.28 | 0.30 | 0.32 | 0.33 | 0.35 | 0.36 | 0.38 |
| 65-74                          | 0.06                                       | 0.07 | 0.09 | 0.10 | 0.11 | 0.13 | 0.14 | 0.16 | 0.17 | 0.19 | 0.20 | 0.21 | 0.23 | 0.24 | 0.27 | 0.28 | 0.29 | 0.31 | 0.32 | 0.33 |
| 75-84                          | 0.05                                       | 0.06 | 0.08 | 0.09 | 0.10 | 0.11 | 0.13 | 0.14 | 0.15 | 0.16 | 0.18 | 0.19 | 0.20 | 0.21 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 |
| 85-94                          | 0.05                                       | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 |
| 95-104                         | 0.04                                       | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.23 |
| 105-114                        | 0.04                                       | 0.05 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 |
| 115-129                        | 0.03                                       | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 |
| 130-149                        | 0.03                                       | 0.04 | 0.04 | 0.05 | 0.06 | 0.07 | 0.07 | 0.08 | 0.09 | 0.09 | 0.10 | 0.11 | 0.11 | 0.12 | 0.13 | 0.14 | 0.14 | 0.15 | 0.16 | 0.17 |
| 150-169                        | 0.03                                       | 0.03 | 0.04 | 0.04 | 0.05 | 0.06 | 0.06 | 0.07 | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.13 | 0.14 | 0.14 |
| 170-189                        | 0.02                                       | 0.03 | 0.03 | 0.04 | 0.04 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.11 | 0.11 | 0.12 | 0.13 | 0.13 |
| 190-214                        | 0.02                                       | 0.02 | 0.03 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 |
| 215-239                        | 0.02                                       | 0.02 | 0.03 | 0.03 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.11 |
| 240-264                        | 0.02                                       | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 |
| 265-289                        | 0.01                                       | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 |
| 290-324                        | 0.01                                       | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 |
| 325-374                        | 0.01                                       | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.07 |
| 375-424                        | 0.01                                       | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 |
| 425-474                        | 0.01                                       | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 |
| 475-524                        | 0.01                                       | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.05 |
| 525-574                        | 0.01                                       | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 |
| 575-625                        | 0.01                                       | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 |

| EQUIVALENT LENGTH OF DUCT (Ft) | TOTAL PRESSURE DROP IN DUCT (IN. OF WATER) |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |  |
|--------------------------------|--------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|--|
|                                | 0.21                                       | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 |  |
| 35-44                          | 0.53                                       | 0.55 | 0.58 | 0.60 | 0.63 | 0.65 | 0.68 | 0.70 | 0.73 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 | 1.00 | 1.13 | 1.25 | 1.40 | 1.55 |  |
| 45-54                          | 0.42                                       | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 | 0.54 | 0.56 | 0.58 | 0.60 | 0.64 | 0.68 | 0.72 | 0.76 | 0.80 | 0.90 | 1.00 | 1.10 | 1.20 |  |
| 55-64                          | 0.35                                       | 0.37 | 0.39 | 0.40 | 0.42 | 0.43 | 0.45 | 0.47 | 0.48 | 0.50 | 0.53 | 0.57 | 0.60 | 0.64 | 0.67 | 0.75 | 0.83 | 0.93 | 1.05 |  |
| 65-74                          | 0.30                                       | 0.32 | 0.33 | 0.34 | 0.36 | 0.37 | 0.39 | 0.40 | 0.42 | 0.43 | 0.46 | 0.49 | 0.52 | 0.54 | 0.57 | 0.64 | 0.72 | 0.81 | 0.92 |  |
| 75-84                          | 0.26                                       | 0.28 | 0.29 | 0.30 | 0.31 | 0.33 | 0.34 | 0.35 | 0.36 | 0.38 | 0.40 | 0.43 | 0.45 | 0.48 | 0.50 | 0.56 | 0.63 | 0.72 | 0.83 |  |
| 85-94                          | 0.23                                       | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.31 | 0.32 | 0.33 | 0.36 | 0.38 | 0.40 | 0.42 | 0.45 | 0.50 | 0.56 | 0.64 | 0.74 |  |
| 95-104                         | 0.21                                       | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.32 | 0.33 | 0.36 | 0.38 | 0.40 | 0.45 | 0.50 | 0.58 | 0.68 |  |
| 105-114                        | 0.19                                       | 0.20 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.31 | 0.33 | 0.35 | 0.37 | 0.41 | 0.46 | 0.54 | 0.64 |  |
| 115-129                        | 0.18                                       | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.23 | 0.23 | 0.24 | 0.25 | 0.27 | 0.28 | 0.30 | 0.32 | 0.33 | 0.38 | 0.47 | 0.56 | 0.66 |  |
| 130-149                        | 0.15                                       | 0.16 | 0.16 | 0.17 | 0.18 | 0.19 | 0.19 | 0.20 | 0.21 | 0.21 | 0.23 | 0.24 | 0.26 | 0.27 | 0.29 | 0.32 | 0.36 | 0.43 | 0.51 |  |
| 150-169                        | 0.13                                       | 0.14 | 0.14 | 0.15 | 0.16 | 0.16 | 0.17 | 0.18 | 0.18 | 0.19 | 0.20 | 0.21 | 0.23 | 0.24 | 0.25 | 0.28 | 0.31 | 0.35 | 0.41 |  |
| 170-189                        | 0.12                                       | 0.12 | 0.13 | 0.13 | 0.14 | 0.15 | 0.15 | 0.16 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.25 | 0.28 | 0.32 | 0.38 |  |
| 190-214                        | 0.11                                       | 0.11 | 0.12 | 0.12 | 0.13 | 0.13 | 0.14 | 0.14 | 0.15 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.23 | 0.25 | 0.29 | 0.34 |  |
| 215-239                        | 0.09                                       | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.20 | 0.22 | 0.26 | 0.30 | 0.35 |  |
| 240-264                        | 0.08                                       | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.18 | 0.20 | 0.24 | 0.28 | 0.33 |  |
| 265-289                        | 0.08                                       | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.18 | 0.20 | 0.23 |  |
| 290-324                        | 0.07                                       | 0.07 | 0.08 | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.13 | 0.13 | 0.15 | 0.17 | 0.20 | 0.23 |  |
| 325-374                        | 0.06                                       | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.11 | 0.11 | 0.11 | 0.13 | 0.14 | 0.16 | 0.18 |  |
| 375-424                        | 0.05                                       | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 |  |
| 425-474                        | 0.05                                       | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 |  |
| 475-524                        | 0.04                                       | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 |  |
| 525-574                        | 0.04                                       | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 |  |
| 575-625                        | 0.04                                       | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 |  |

| EQUIVALENT LENGTH OF DUCT (Ft) | TOTAL PRESSURE DROP IN DUCT (IN. OF WATER) |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|--------------------------------|--------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                                | 0.21                                       | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 |
| 35-44                          | 0.53                                       | 0.55 | 0.58 | 0.60 | 0.63 | 0.65 | 0.68 | 0.70 | 0.73 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 | 1.00 | 1.13 | 1.25 | 1.37 | 1.50 | 1.63 |
| 45-54                          | 0.42                                       | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 | 0.54 | 0.56 | 0.58 | 0.60 | 0.64 | 0.68 | 0.72 | 0.76 | 0.80 | 0.90 | 1.00 | 1.13 | 1.25 | 1.37 |
| 55-64                          | 0.35                                       | 0.37 | 0.39 | 0.40 | 0.42 | 0.43 | 0.46 | 0.47 | 0.48 | 0.50 | 0.53 | 0.57 | 0.60 | 0.64 | 0.67 | 0.75 | 0.83 | 0.93 | 1.03 | 1.13 |
| 65-74                          | 0.30                                       | 0.32 | 0.33 | 0.34 | 0.36 | 0.37 | 0.39 | 0.40 | 0.42 | 0.43 | 0.46 | 0.49 | 0.52 | 0.54 | 0.57 | 0.64 | 0.72 | 0.81 | 0.91 | 1.01 |
| 75-84                          | 0.26                                       | 0.28 | 0.29 | 0.30 | 0.31 | 0.33 | 0.34 | 0.35 | 0.36 | 0.38 | 0.40 | 0.43 | 0.45 | 0.48 | 0.50 | 0.56 | 0.63 | 0.71 | 0.80 | 0.89 |
| 85-94                          | 0.23                                       | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.31 | 0.32 | 0.33 | 0.36 | 0.38 | 0.40 | 0.42 | 0.45 | 0.50 | 0.56 | 0.63 | 0.71 | 0.80 |
| 95-104                         | 0.21                                       | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.32 | 0.33 | 0.36 | 0.38 | 0.40 | 0.45 | 0.50 | 0.56 | 0.63 | 0.71 |
| 105-114                        | 0.19                                       | 0.20 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.31 | 0.33 | 0.35 | 0.37 | 0.41 | 0.46 | 0.52 | 0.58 | 0.64 |
| 115-129                        | 0.18                                       | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.23 | 0.23 | 0.24 | 0.25 | 0.27 | 0.28 | 0.30 | 0.32 | 0.33 | 0.38 | 0.47 | 0.54 | 0.61 | 0.68 |
| 130-149                        | 0.15                                       | 0.16 | 0.16 | 0.17 | 0.18 | 0.19 | 0.19 | 0.20 | 0.21 | 0.21 | 0.23 | 0.24 | 0.26 | 0.27 | 0.29 | 0.32 | 0.36 | 0.42 | 0.49 | 0.55 |
| 150-169                        | 0.13                                       | 0.14 | 0.14 | 0.15 | 0.16 | 0.16 | 0.17 | 0.18 | 0.18 | 0.19 | 0.20 | 0.21 | 0.23 | 0.24 | 0.25 | 0.28 | 0.31 | 0.36 | 0.42 | 0.48 |
| 170-189                        | 0.12                                       | 0.12 | 0.13 | 0.13 | 0.14 | 0.15 | 0.15 | 0.16 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.25 | 0.28 | 0.33 | 0.39 | 0.45 |
| 190-214                        | 0.11                                       | 0.11 | 0.12 | 0.12 | 0.13 | 0.13 | 0.14 | 0.14 | 0.15 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.23 | 0.25 | 0.30 | 0.36 | 0.42 |
| 215-239                        | 0.09                                       | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.13 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.20 | 0.22 | 0.27 | 0.32 | 0.37 |
| 240-264                        | 0.08                                       | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.19 | 0.21 | 0.25 | 0.30 | 0.35 |
| 265-289                        | 0.08                                       | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.18 | 0.20 | 0.24 | 0.28 |
| 290-324                        | 0.07                                       | 0.07 | 0.08 | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.13 | 0.13 | 0.15 | 0.17 | 0.20 | 0.24 | 0.28 |
| 325-374                        | 0.06                                       | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.11 | 0.13 | 0.14 | 0.17 | 0.20 | 0.24 |
| 375-424                        | 0.05                                       | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.11 | 0.13 | 0.15 | 0.18 | 0.20 |
| 425-474                        | 0.05                                       | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.11 | 0.13 | 0.15 | 0.17 |
| 475-524                        | 0.04                                       | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | 0.11 | 0.13 | 0.15 |
| 525-574                        | 0.04                                       | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.13 |
| 575-625                        | 0.04                                       | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 |



### AUTOMATIC CONTROLS

Air stratification, high bonnet temperatures, excessive flue gas temperatures, and heat overrun or lag in a properly designed system, can be largely eliminated through proper care in the planning and installation of the control system.<sup>6</sup> Best results are obtained when the fan is operated as continuously as possible, coupled with frequent, short cycles of burner operation. Controls usually employed are:

1. A *room thermostat* located in the occupied space at a point where there is good air circulation and where the temperature is representative of the area being controlled. It is the operating control which initiates the starting and stopping of the burner. It is frequently of the timed, two-position type. Refer to Chapter 39 for more information on types of room thermostats.
2. A *fan thermostat* located in the bonnet of the furnace to start the fan at a bonnet temperature between 110 and 130 F and stop the fan at about 15 deg below the cut-in point. The lower settings are used for high sidewall register installations and the higher settings for baseboard register installations. For most satisfactory performance these settings should be as low as is feasible without resulting in drafts.
3. A *high limit control*, also in the bonnet of the furnace, to stop the burner independently of the room thermostat if the air temperature exceeds 175 F. The fan thermostat and high limit control are sometimes combined into a single unit.
4. A *humidistat* to regulate the moisture supplied to the rooms on systems which are equipped with humidifying means. This may be of the room type, usually located adjacent to the room thermostat, or it may be of the insertion type located in the main return air duct.
5. Primary and limit controls for the various types of gas burners, oil burners and coal burners (stokers) should be provided as required, and are discussed in Chapter 39.

### ADJUSTMENT OF SYSTEM

More even room temperatures will result if the controls are adjusted to produce long period fan operation. This is accomplished in automatically-fired forced warm air heating systems when the control arrangement is of the type where the room thermostat controls the fire, and the blower control (fan switch) controls the blower operation. This procedure as outlined in detail in Manual 6 of the *National Warm Air Heating and Air Conditioning Association*, is as follows:<sup>7</sup>

1. Adjust the fuel input in proper relation to the heat loss of the structure.
2. Determine the temperature rise through the furnace.
3. Adjust the air volume to produce a temperature rise through the furnace of about 100 deg.
4. If adjustable, set the fan switch differential to a minimum of about 15 deg.
5. Adjust the fan switch cut-out point as low as practicable.
6. Balance the system by adjusting dampers to produce even temperature distribution between rooms.
7. Set the room thermostat at the desired room temperature.

Close control of room temperature is facilitated by the use of a room thermostat having a narrow operating differential. The heat anticipating thermostat is an example of such a device.

### WARM AIR CEILING PANEL SYSTEMS

Warm air ceiling panel heating systems utilize a false ceiling suspended 3¼ in. from the ceiling joists which have previously been covered on the bottom with sheets of plasterboard. Special hangers are used to suspend

the false ceiling or heating panel from the joists. Steel supporting rods are installed through these hangers and metal lath is attached to the rods. The lath is then plastered to a thickness of ¾ in., making a completely sealed air space above the ceiling. Warm air is delivered to this sealed space through a standard warm air duct, installed in the usual manner. The air is then circulated over the entire ceiling being guided by sheet-metal baffles. After the air has passed over the ceiling, it is returned to the furnace through a return air duct for reheating. The system is closed, and no air is introduced into the heated space from the panel. (See also Chapter 24, Panel Heating.)

Because a warm air ceiling panel system involves a different type of ceiling construction, its installation is practically limited to new construction. Only automatically-fired and thermostatically-controlled furnace-blower units may be used with this system. The standard automatic heating controls consisting of a room thermostat, temperature limit control, blower control (fan switch), and primary control are all that are re-

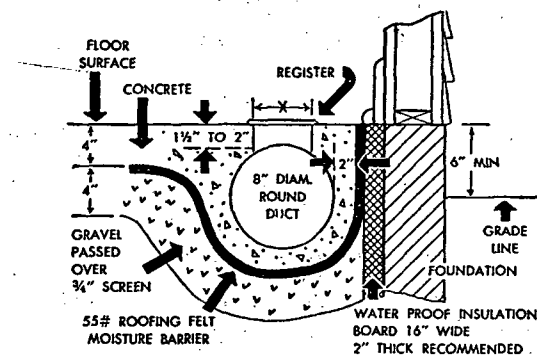


FIG. 5. CROSS-SECTION OF SLAB CONSTRUCTION CONTAINING PERIMETER DUCT<sup>8</sup>

quired. While warm air ceiling panel heating has particular advantages in one-story utility room houses, it can be just as effectively installed in one- and two-story houses with basements.

Complete design and installation procedure is given<sup>8</sup> in Manual 7-A of the *National Warm Air Heating and Air Conditioning Association*.

### WARM AIR PERIMETER SYSTEMS

Perimeter heating is a method of heating residential and commercial buildings, with or without basements, in which warm air is (a) conveyed under the floor to warm the floor surface and (b) introduced into the rooms, preferably under the windows, at or near the floor, and delivered upward in a diffused pattern blanketing the outside walls. The return air is collected through one or more grilles located high on the interior sidewalls or in the ceiling. Suggested procedures<sup>10</sup> for the design and installation of warm air perimeter heating systems are given in Manuals 4 and 10 and in the accompanying work sheets<sup>11</sup> of the *National Warm Air Heating and Air Conditioning Association*.

The furnace may be either the down-flow or the conventional up-flow

type. For basementless houses the down-flow type is preferred since it requires a minimum amount of floor area and ductwork, and eliminates the need for a duct to bring the warm air down from the top of the furnace, or a duct to bring the return air down to the blower inlet.

Several arrangements of perimeter ducts may be used to heat slabs on ground construction, but the most common is the type having a complete loop of a continuous duct around the edge of the slab, supplied by radial feeders extending from the furnace sub-floor plenum to the perimeter duct. A schematic cross-section of the slab construction, with the perimeter duct installed, is shown in Fig. 5.

The slab should be constructed on a well-drained site where drainage is away from the slab, and where there is no standing water at any time of the year. With slab construction, a suitable porous fill and a waterproof membrane as a moisture barrier beneath the slab are required by the *Federal Housing Administration*. They are highly necessary with warm air perimeter heating. Insulation must be placed between the edge of the slab and the foundation, and must extend completely around the slab to reduce the heat losses from the edge of the slab. Fig. 5 also shows many of the essential features of the slab and under-slab construction.

### SUMMER OPERATION

During hot summer periods a slight cooling effect may sometimes be obtained by the circulation of basement air through the system. This beneficial effect is due to both the increased air movement in the occupied spaces and the small reduction in dry-bulb temperature brought about by passing warm air over the cooler basement walls and floor. In areas of high prevailing dew points, however, this practice may cause objectionable dampness to develop in the basement.

Complete summer air conditioning can be readily combined with forced warm air systems either by using factory-built units incorporating both refrigeration and heating equipment, or in some cases by adapting separate refrigeration equipment or well-water coils to existing warm air systems.

A more complete treatment of residential summer air conditioning is given in Chapter 50.

### REFERENCES

- <sup>1</sup> A Yardstick for Classifying Warm Air Winter Air Conditioning Systems (*National Warm Air Heating and Air Conditioning Association*, Manual 8, 1948).
- <sup>2</sup> Performance of a Forced Warm-Air Heating System as Affected by Changes in Volume and Temperature of Air Recirculated, by A. P. Kratz and S. Konzo (A.S.H.V.E. TRANSACTIONS, Vol. 48, 1942, p. 393).
- <sup>3</sup> Code and Manual for the Design and Installation of Warm Air Winter Air Conditioning Systems (*National Warm Air Heating and Air Conditioning Association*, Manual 7, Fourth Edition, 1953).
- <sup>4</sup> Proposed Design Procedure for Large Mechanical Warm Air Heating Systems, by S. Konzo, R. J. Martin, D. S. Levinson, and R. W. Roose (A.S.H.V.E. TRANSACTIONS, Vol. 53, 1947, p. 177).
- <sup>5</sup> Code and Manual for the Design and Installation of Large Warm Air Winter Air Conditioning Systems (*National Warm Air Heating and Air Conditioning Association*, Manual 9, Fourth Edition, 1950).
- <sup>6</sup> Automatic Controls for Forced-Air Heating Systems, by S. Konzo and A. F. Hubbard (A.S.H.V.E. TRANSACTIONS, Vol. 40, 1934, p. 37).
- <sup>7</sup> Service Manual for Continuous Air Circulation Technicians (*National Warm Air Heating and Air Conditioning Association*, Manual 6, First Edition, 1947).
- <sup>8</sup> Code and Manual for the Design and Installation of Warm Air Ceiling Panel Systems (*National Warm Air Heating and Air Conditioning Association*, Manual 7-A, Third Edition, 1950).
- <sup>9</sup> Warm-Air Perimeter Heating (*National Warm Air Heating and Air Conditioning Association*, Manual 4, Third Edition, 1953).
- <sup>10</sup> Small Pipe Warm Air Perimeter Heating (*National Warm Air Heating and Air Conditioning Association*, Tentative Manual 10, Second Edition, 1953).
- <sup>11</sup> Work Sheets for Warm-Air Perimeter Systems (*National Warm Air Heating and Air Conditioning Association*, Forms 41a, 41b, 42, 43 and 45).

## CHAPTER 21

### STEAM HEATING SYSTEMS

Classification of Steam Heating Systems by Types; One-pipe; Two-pipe; Sub-atmospheric and Orifice Systems; Sizing Piping for Steam Heating Systems; Pressure Reducing Valves; Boiler Connections; Condensate Return Pumps; Vacuum Heating Pumps; Traps; Drips; Connections to Heating Units; Control Valves

STEAM heating systems may be classified according to any one of, or combination of, the following features: (1) piping arrangement, (2) pressure or vacuum conditions obtained in operation, (3) method of returning condensate to the boiler.

1. *By Piping Arrangement.* A steam heating system is known as a *one-pipe system* when a single main serves the dual purpose of supplying steam to the heating unit and conveying condensate from it. Ordinarily, to each heating unit there is but one connection which must serve as both the supply and the return, although separate supply and return connections may be used.

A steam heating system is known as a *two-pipe system* when each heating unit is provided with two piping connections, and when steam and condensate flow in separate mains and branches.

Heating systems may also be described as *up-flow* or *down-flow*, depending on the direction of steam flow in the risers; and as a *dry-return* or a *wet-return*, depending on whether the condensate mains are above or below the water line of the boiler or condensate receiver.

2. *By Pressure or Vacuum Conditions.* Steam heating systems may also be classified as *high pressure*, *low pressure*, *vapor*, and *vacuum* systems, depending on the pressure conditions under which the system is designed to operate.

A system is known as a *high pressure system* when the operating pressures employed are above 15 psig; as a *low pressure system* when pressures vary from 0 to 15 psig; as a *vapor system* when the system operates under both vacuum and low pressure conditions without the use of a vacuum pump; and as a *vacuum system* when the system operates under vacuum and low pressure conditions with the use of vacuum pump.

When automatic controls are employed to vary the pressure conditions in the system in accordance with outside weather conditions, the system may be known as a *sub-atmospheric*, *differential*, or *synchronized* system. These latter classifications are proprietary designations.

When orifices are employed on the inlets to the heating units the system may be known as an *orifice system*.

3. *By Method of Returning Condensate.* When condensate is returned to the boiler by gravity, the system is known as a *gravity return system*. In this system all heating units must be elevated sufficiently above the water line of the boiler, so that the condensate can flow freely to the boiler. Elevation of the heating units above the water line must therefore be sufficient to overcome pressure drops due to flow, as well as pressure differences due to operation.

Referring to Fig. 1 it will be noted that the boiler and wet-return form a U-shaped container, with the boiler steam pressure on the top of the water at one end, and the steam main pressure on the top of the water at the other end. The difference between these two pressures is the *pressure drop* in the system, i.e., the friction and resistance to the flow of steam in passing from the boiler to the far end of the main, and the pressure reduction in consequence of the condensation occurring in the system. The water in the far end will rise sufficiently to overcome this difference in order to balance the pressures, and it will rise far enough to produce a flow through the return pipe and overcome the resistance of check valves, if installed.

If a one-pipe steam system is designed, for example, for a total pressure drop of 1 psi, and utilizes a Hartford return connection instead of a check valve on the return,

the rise in the water level at the far end of the return, due to the difference in steam pressure, would be  $\frac{1}{2}$  of 28 in. (28 in. head being equal to one pound per square inch), or  $3\frac{1}{2}$  in. Adding 3 in. to overcome the resistance of the return main, and 6 in. as a factor of safety for heating up, gives 12 $\frac{1}{2}$  in. as the distance the bottom of the lowest part of the steam main and all heating units must be above the boiler water line. The same system, however, installed and sized for a total pressure drop of  $\frac{1}{2}$  psi, and with a check in the return, would require  $\frac{1}{2}$  of 28 in., or 14 in. for the difference in steam pressure, 3 in. for the flow through the return, 4 in. to operate the check, and 6 in. for a factor of safety, making a total of 27 in. as the required distance. Higher pressure drops would increase the distance accordingly.

When conditions are such that condensate cannot be returned to the boiler by the action of gravity, and either traps or pumps must be employed, the system is known as a *mechanical return system*. There are three general types of mechanical condensate return devices in common use: (a) the alternating return trap, (b) the condensate return pump, and (c) the vacuum return pump.

In systems where pressure conditions in the system vary between that of a gravity return and a forced return system, a boiler return trap or alternating receiver is employed and the system may be known as an *alternating return system*.

When condensate is pumped to the boiler under pressures of the atmosphere or above, the system is known as a *condensate pump return system*.

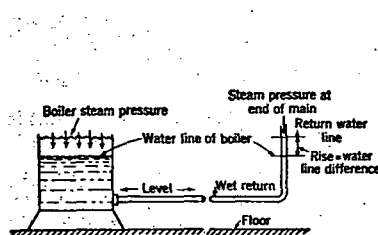


FIG. 1. DIFFERENCE IN STEAM PRESSURE ON WATER IN BOILER AND AT END OF STEAM MAIN

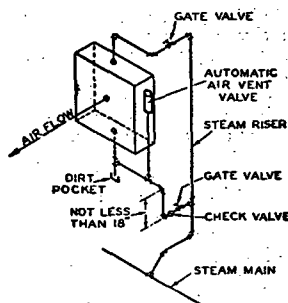


FIG. 2. TYPICAL TWO-PIPE CONNECTIONS TO UNIT HEATERS IN ONE-PIPE AIR-VENT SYSTEMS

When condensate is pumped to the boiler under vacuum conditions, the system is known as a *vacuum pump return system*.

In either the *condensate* or *vacuum pump* systems it is highly desirable to arrange for gravity flow to a receiver and to the pump. The pump then forces condensate into the boiler against its pressure.

### ONE-PIPE SYSTEMS

One-pipe systems, as previously defined, are systems in which steam and condensate flow in the same pipe. Radiators and other heating units, in general, have only one piping connection from main to unit, although it is possible to employ two connections to the same main as indicated in Fig. 2. Unit heaters in one-pipe systems may also have separate connections to the wet-return.

There are several variations in the piping arrangement of a one-pipe system as follows:

1. Up-feed one-pipe systems where the radiators and other heating units are located above the supply mains. The mains in this instance convey both steam and condensate. Such a system is illustrated in Fig. 3. Typical connections to radiator or risers are illustrated in Fig. 4, and method of changing sizes of mains in Fig. 5.

2. Up-feed one-pipe systems where the radiators and other heating units are located above the mains, and the mains are dripped at each radiator connection to a wet-

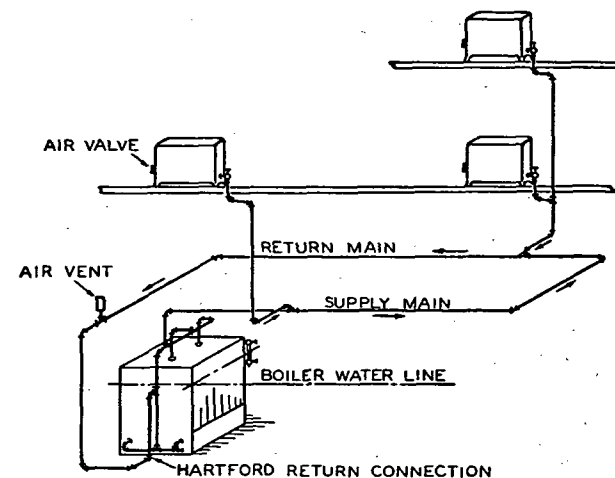


FIG. 3. TYPICAL UP-FEED GRAVITY ONE-PIPE AIR-VENT SYSTEM

return, so that the steam main carries a minimum of the condensate. This system is illustrated in Fig. 6. Typical connections to radiators and risers are illustrated in Fig. 7. Up-feed systems are not recommended for systems higher than four stories.

3. Down-feed one-pipe systems, where the radiators and other heating units are located below the supply main. In this arrangement only risers and connections to heating units convey both steam and condensate, and both are flowing in the same direction. The steam main is kept relatively free of condensate by dripping through the drop risers.

Each radiator or heating unit in a one-pipe system must be supplied with a thermostatic air valve which functions to relieve air from the heating unit under pressure, and to close when steam itself heats the thermostatic element of the valve.

To improve steam circulation in one-pipe systems quick-vent air valves should be provided at the ends and at intermediate points where the steam main is brought to a higher elevation, or where dropped below the water line. It is desirable to install the air-vent valves about a foot ahead of the drips, as indicated in Fig. 6, to prevent possible damage to their mechanisms by water.

Air valves are of two general types, the pressure and the vacuum types. The pressure type permits the inflow of atmospheric air to the system when the steam pressure in the system falls below atmospheric pressure. The vacuum type, which contains a small check valve, prevents the air from flowing back to the system and thereby maintains vacuum conditions in the system, and a consequent evaporation or generation of steam

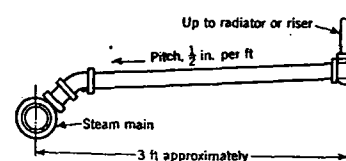


FIG. 4. TYPICAL STEAM RUNOUT WHERE RISERS ARE NOT DRIPPED

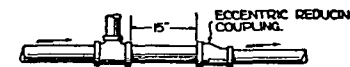


FIG. 5. METHOD OF CHANGING SIZE OF STEAM MAIN WHEN RUNOUTS ARE TAKEN FROM TOP

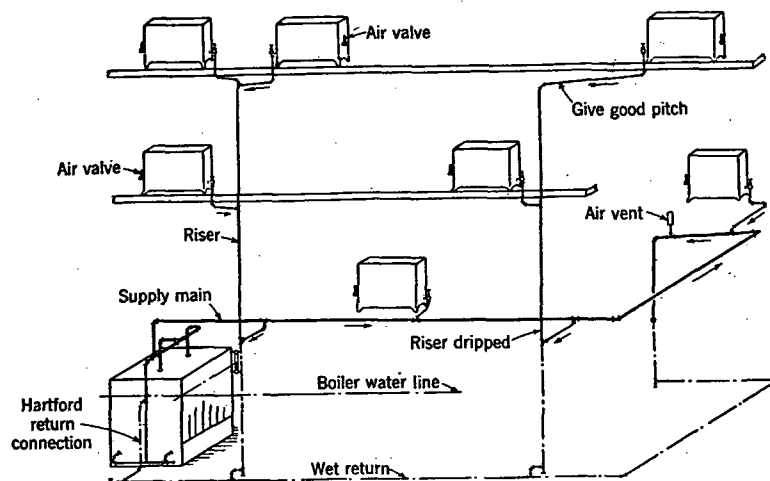


FIG. 6. TYPICAL UP-FEED GRAVITY ONE-PIPE AIR-VENT SYSTEM

or vapor at sub-atmospheric pressures, and at consequent lower temperatures. Systems which use vacuum valves are known as *vapor* or *vacuum one-pipe systems*. The vapor or vacuum systems will maintain a more uniform temperature condition than the pressure systems.

Each heating unit in a one-pipe system may also be provided with a valve on the connection to the unit, although this is not essential except to shut the unit off in case it is not desired for heating. Valves on one-pipe systems must be either fully opened or fully closed. No throttling or modulating position can be maintained since, if a valve is partially closed, condensate will not drain from the unit. This condition is dangerous because it may create a low water condition in the boiler with consequent burning or cracking of the boiler, or create a hazard due to the freezing of the water-logged heating unit itself.

### TWO-PIPE SYSTEMS

Two-pipe systems, as previously defined, are systems in which steam and condensate flow in separate pipes. Two-pipe systems may operate under high pressure, low pressure, vapor, or vacuum conditions. Either the up-flow or the down-flow arrangement of mains may be employed.

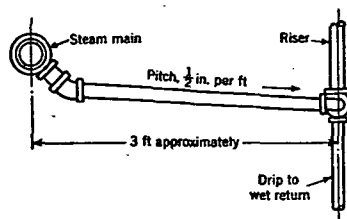


FIG. 7. TYPICAL STEAM RUNOUT WHERE RISERS ARE DRIPPED

### Two-Pipe High Pressure Systems

Two-pipe high pressure systems operate at pressures above 15 psig, usually from 30 to 150 psig. They are usually used in large industrial type buildings, which are equipped with unit heaters or large built-up fan units, or in which high pressure steam is required for process work.

Fig. 8 illustrates a typical high pressure system. Because of the high pressures and the great differential between steam and return mains, it is possible to locate returns above the heating units and lift the condensate to these returns.

The condensate can be flashed into steam in low pressure mains if any are available, or passed through an economizer heater before being discharged to a vented receiver. It is, of course, necessary to provide for the elimination of air from high pressure systems, the same as in low pressure systems.

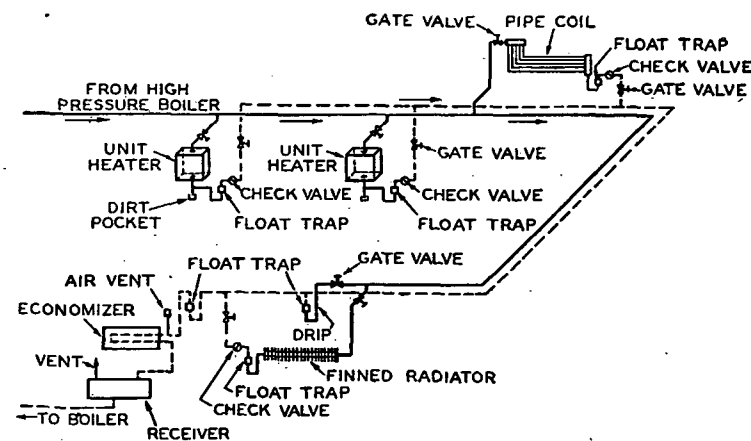


FIG. 8. TYPICAL HIGH PRESSURE HEATING SYSTEM

Return traps used on high pressure systems are usually of the bucket, inverted bucket, float or impulse type.

### Two-Pipe Low Pressure Systems

Low pressure systems operate at pressures of 0 to 15 psig. The piping arrangement of both up-feed and down-feed low pressure systems is identical with those of two-pipe vapor systems described in the following section. The only difference between the two systems is in the type of air valve used. The air valves used in low pressure systems usually do not contain the check discs and hence, the system cannot operate under a vacuum. The low pressure systems are not as popular as the vapor systems, because they have the disadvantage of not holding heat when the rate of steam generation is diminishing. They also have the disadvantage of corroding to a greater extent than vapor systems, due to the continued presence of new air in the system.

Low pressure systems have the advantage, however, of returning condensate to the boiler readily and not retaining it in the piping, as may be possible in vapor systems when the system pressure exceeds the operating

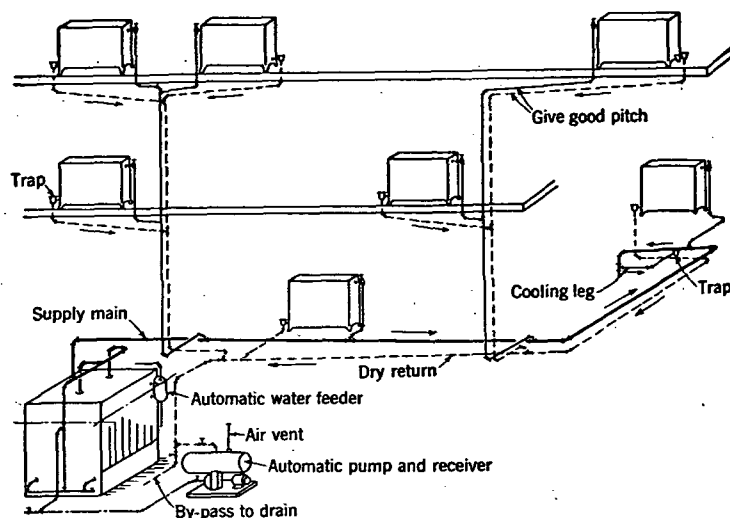


FIG. 9. TYPICAL INSTALLATION USING CONDENSATE PUMP

range of the average vapor system. Fig. 9 illustrates a typical low pressure system with condensate pump.

### Two-Pipe Vapor Systems

Two-pipe vapor systems operate at pressures varying from 20 in. vacuum or more (depending upon the tightness with which the system is assembled) to 15 psig without the use of a vacuum pump. A typical two-pipe up-feed vapor system is shown in Fig. 10, and a typical two-pipe down-feed system is illustrated in Fig. 11. The method of dripping drop risers in a down-feed system is illustrated in Fig. 12. Radiators discharge their condensate and air through thermostatic traps to the dry-return main. Air is eliminated,

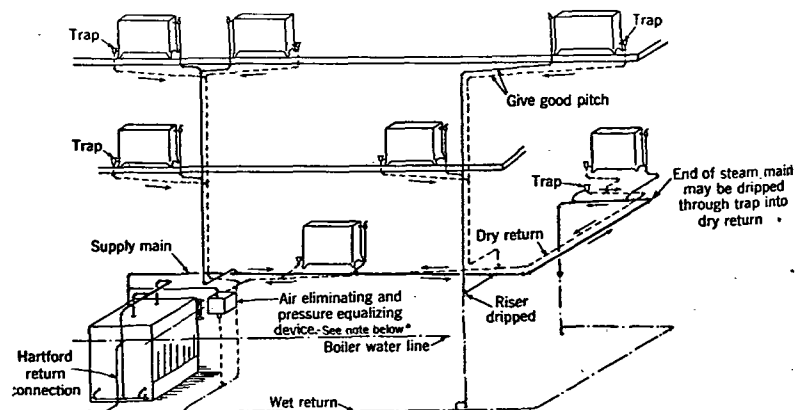


FIG. 10. TYPICAL UP-FEED TWO-PIPE SYSTEM WITH AUTOMATIC RETURN TRAP\*

\* Proper piping connections are essential with special appliances for pressure equalizing and air elimination.

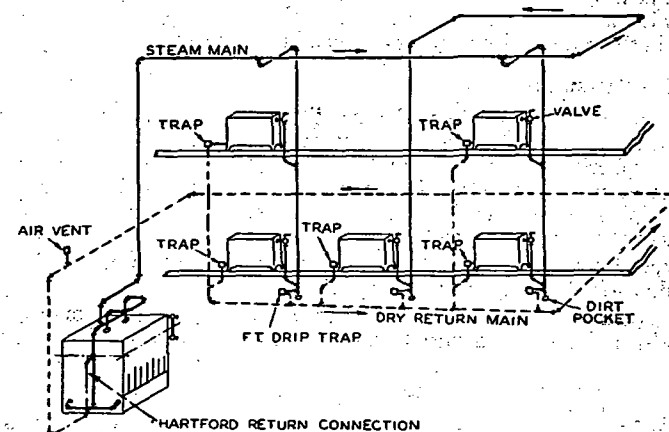


FIG. 11. TYPICAL DOWN-FEED TWO-PIPE SYSTEM

when the system is under pressure, at the ends of the supply and return mains just before they drop to the wet return. The vent valves are of the float rather than float and thermostatic type since there should be no steam in the return main so long as the thermostatic traps on the radiators or convectors are operating properly. The float element of the valve closes the valve when, due to pressure differences, water rises to the point of overflow in the main. The vent valves are also provided with a small check disc which closes to prevent the inflow of air to the system when the pressure drops below atmospheric pressure. This enables the system to operate under vacuum conditions at lower steam temperatures for a period of four to eight hours, depending on the tightness of the system.

Vapor systems may also be provided with an automatic return trap or alternating receiver which automatically returns condensate to the boiler when the boiler is steaming under pressure conditions which would prevent the return of condensate by gravity. The typical connections for an automatic return trap are illustrated in Fig. 13.

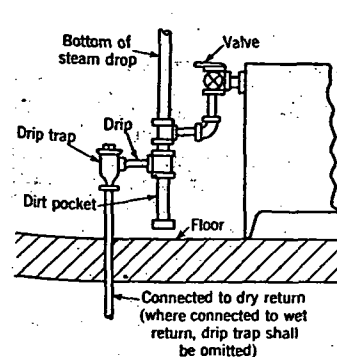


FIG. 12. DETAIL OF DRIP CONNECTIONS AT BOTTOM OF DOWN-FEED STEAM DROP

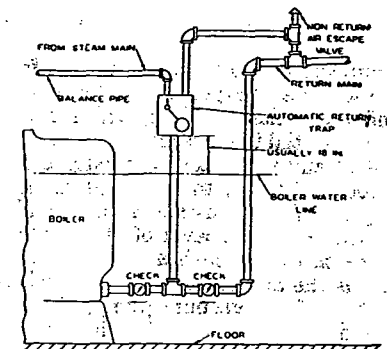


FIG. 13. TYPICAL CONNECTIONS FOR AUTOMATIC RETURN TRAP

Each heating unit in a vapor system, as in all two-pipe systems, is provided with a graduated or modulating valve which permits the control of heat in the radiator by varying the opening of the valve.

### Two-Pipe Vacuum Systems

Vacuum systems operate under conditions of both low pressure and vacuum, but employ the use of a vacuum pump to insure maintenance of sub-atmospheric pressures in the return piping for all operating conditions. The system may operate transiently with sub-atmospheric pressure in the supply piping during the time the rate of steam generation is equivalent to or less than the total connected load.

A typical two-pipe up-feed vacuum system is illustrated in Fig. 14, and a down-feed arrangement in Fig. 15.

The return risers are connected in the basement into a common return main which slopes downward toward the vacuum pump. The vacuum

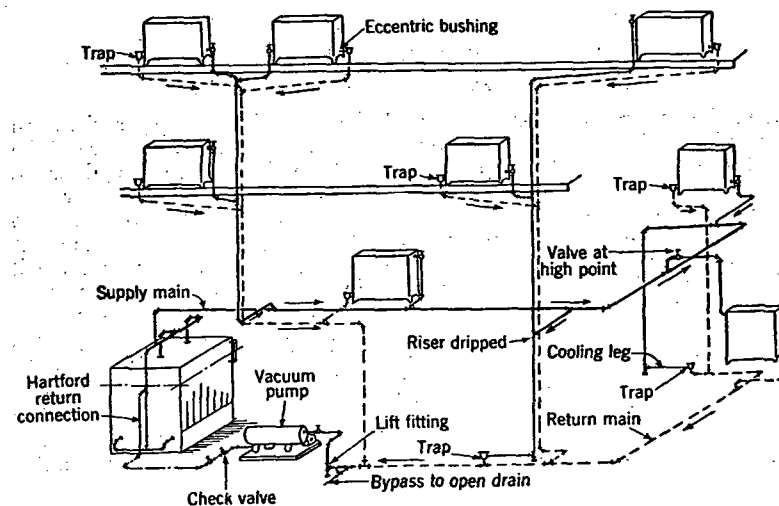


FIG. 14. TYPICAL UP-FEED VACUUM PUMP SYSTEM

pump withdraws the air and water from the system, separates the air from the water and expels it to atmosphere, and pumps the water back to the boiler or other receiver, which may be a feed-water heater or hot well. It is essential that no connection be made from the supply side to the return side at any point except through a trap. The desirable practice demands a return flowing to the vacuum pump by an uninterrupted downward slope. In some instances local conditions make it necessary to drop the return below the level of the vacuum pump inlet before the pump can be reached. In such an event one of the advantages of the vacuum system is the ability to raise the condensate to a considerable height, by the suction of the vacuum pump, by means of a lift connection or fitting inserted in the return. The height the condensate can be raised depends on the amount of vacuum maintained. It is preferable to limit lift connections to a single lift at the vacuum pump. A still more preferable arrangement is the use of an accumulator tank, or receiver tank, with a

float control for the pump at the low point of the return main, located adjacent to the vacuum pump.

When the vertical lift is considerable, several lift fittings should be used in steps as shown in Fig. 16. This permits a given lift to be secured with a somewhat lower vacuum than where the vertical distance is served by a single lift. Where several lifts are present in a given system at different locations, the lifting cannot occur until the entire system is filled with steam. A lift connection for location close to the pump, where the size may be above the commercial stock sizes, is shown in Fig. 17. It is desirable that means be provided for manually draining the low point of the lift fittings to eliminate danger of freezing.

### TWO-PIPE SUB-ATMOSPHERIC SYSTEMS

Sub-atmospheric systems are similar to vacuum systems but, in contrast, provide control of building temperature by variation of the heat

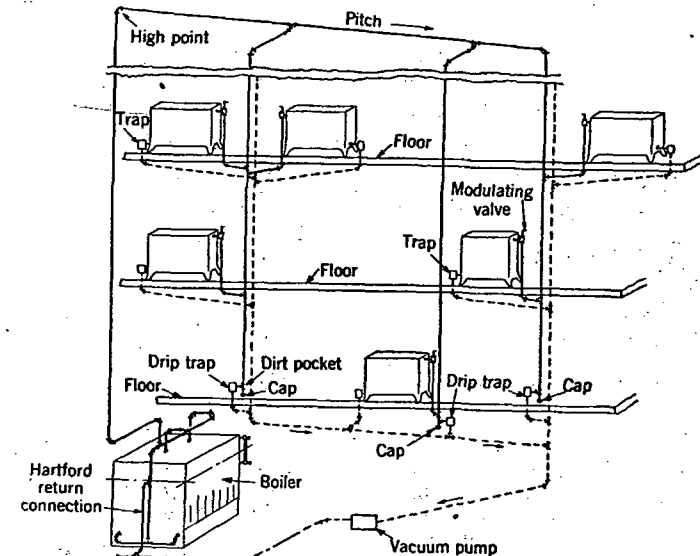


FIG. 15. TYPICAL DOWN-FEED VACUUM SYSTEM

output from the radiators. The radiator heat emission is controlled by varying the pressure, temperature and specific volume of steam in circulation. These systems differ from the ordinary vacuum system in that they maintain a controllable partial vacuum on both the supply and return sides of the system, instead of only on the return side. In the vacuum system, steam pressure above that of the atmosphere exists in the supply mains and radiators practically at all times. In the sub-atmospheric system, atmospheric pressure or higher exists in the steam supply piping and radiators only during severe weather. Under average winter temperature the steam is under partial vacuum which in mild weather may reach as high as 25 in. Hg, after which further reduction in heat output is obtained by restricting the quantity of steam.

The rate of steam supply is controlled by a valve in the steam main or by thermostatically controlling the rate of steam production in the boiler.

The control valve may be of the automatic *modulating* or *floating* type governed thermostatically from selected control points in the building, or it may be a special pressure reducing valve which will maintain the desired sub-atmospheric pressures by continuous flow into the heating main. In some systems radiator supply valves include adjustable orifices, or are equipped with regulating orifice plates. The sizes of orifices used are larger than for other types of orifice systems because, for equal radiator sizes, the volume flowing is larger. Orifices are omitted on some systems. Radiator traps and drips are designed to operate at any pressure from 15 psig to 26 in. Hg. A vacuum pump capable of operating at high vacuum is preferable to promote accuracy in the distribution of steam throughout the system, particularly in mild weather. This vacuum is partially self-induced by the condensation of the steam in the system under conditions of restricted supply used for reduction of the radiator heat emission.

The returns must grade downward constantly and uninterruptedly from the radiator return outlets to the inlet of the receiver of the vacuum pump.

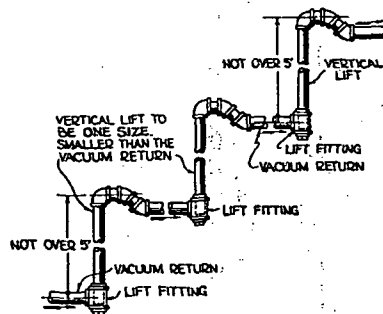


FIG. 16. METHOD OF MAKING LIFTS ON VACUUM SYSTEMS WHEN DISTANCE IS OVER 5 FT

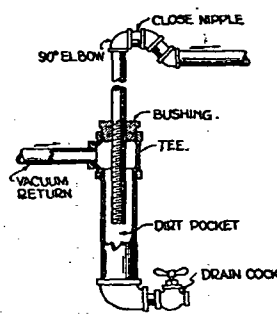


FIG. 17. DETAIL OF MAIN RETURN LIFT AT VACUUM PUMP

One radical difference between this and the ordinary vacuum system is that no lifts should be made in the return line, except at the vacuum pump. The receivers are placed at a lower level than the pump, and equipped with float control so that the pump may operate as a return pump under night conditions. The system may be operated in the same manner as the ordinary vacuum system when desired.

Steam for heating domestic hot water should be taken from the boiler header back of the control valve so that pressures sufficiently high for heating the water may be maintained on the heater. The sub-atmospheric method of heating can be used for the heating coils of ventilating and air conditioning systems. The flexible control of heat output secured by this method materially reduces the required size of by-pass around the heaters. Some applications of sub-atmospheric systems are proprietary.

### TWO-PIPE ORIFICE SYSTEMS

Orifice steam heating systems may have piping arrangements identical with vacuum systems. Some of these omit the radiator thermostatic traps, but use thermostatic or combination float and thermostatic traps on all drip points. A return condensate pump with receiver vented to

atmosphere, a return line vacuum pump, or a return trap, is generally used to return the condensate to the boiler or place of similar disposition, such as a feed-water heater or hot well. The heat emission from the radiators is controlled by varying the pressure differential maintained.

The principle on which these systems operate is based on the fact that the steam flow through an orifice will vary with square root of pressure drop when the ratio of the absolute pressures on the two sides of the orifice exceeds 58 percent. If the absolute pressure on the outlet side is less than 58 percent of the absolute pressure on the inlet side, no further increase in flow will be obtained as a result of the increased pressure difference. If an orifice is so designed in size as to exactly fill a radiator with 2 psig on one side and  $\frac{1}{2}$  psig on the other, the absolute pressure relation is

$$\frac{14.7 + 0.25}{14.7 + 2.0} = 0.90 \text{ or } 90 \text{ percent.}$$

Should the steam pressure be dropped to  $\frac{1}{2}$  psig on the supply pipe, the pressure on each side of the orifice would be balanced and no steam flow would take place. From this it will be apparent that if an orifice of a given diameter will fill a given radiator with steam when there is a given pressure on the main, reducing this steam main pressure will permit filling various desired portions of the radiator down to the point where the main pressure equals the back pressure in the radiator, provided the supply pipe pressures may be controlled sufficiently close. If orifices are designed on a similar basis for a given system and proportioned to the heating capacity of the radiators they serve, all radiators will heat proportionately to the steam pressure. The range of pressure variation is limited by the permissible noise level of the steam flowing under the pressure difference required for maximum heat output. The control of the steam supply is obtained by a valve placed in the steam main, which maintains a determined pressure, and by varying the vacuum in the return lines. The valves are frequently set manually from a remote location, guided by temperature indicating stations in the building; or thermostatically controlled from a thermostat on the roof, which automatically measures the differential of outside and inside temperatures. Since the range through which the pressures may be varied is usually from 0 to 4 psig, the control should be capable of maintaining close regulation to maintain the desired space temperatures, particularly in mild weather.

A recommended orifice schedule is shown in Table 1. Some systems use orifices not only in radiator inlets, but also at different points in the steam supply piping for the purpose of balancing the system to a greater extent. In this manner the difference between the initial and terminal pressure in the steam main may be compensated to a great extent. For example, if the initial pressure is 3 psig and the pressure at the end of the main is 2 psig, an orifice could be used in each branch for the purpose of obtaining a more uniform pressure throughout the system. Such a provision may be particularly useful in this system for branches close to the boiler where the drop in the main has not yet been produced. Some orifice systems are proprietary.

### SIZING PIPING FOR STEAM HEATING SYSTEMS

The functions of the piping system are the distribution of the steam, the return of the condensate and, in systems where no local air vents are provided, the removal of the air. The distribution of the steam should be rapid, uniform and without noise, and the release of air should be facili-



tated as much as possible, as an air bound system will not heat readily nor properly. In designing the piping arrangement, it is desirable to maintain equivalent resistances in the supply and return piping to and from a radiator. Arranging the piping so the total distance from the boiler to the radiator is the same as the return piping distance from the heating unit back to the boiler, tends to obtain such a result. The

TABLE 1. ORIFICE CAPACITIES FOR LOW PRESSURE STEAM SYSTEMS  
This table is based on data from actual tests\*

| ORIFICE<br>DIAMETER<br>64THS OF<br>AN INCH | 6 IN. HG<br>DIFFERENTIAL | 5 IN. HG<br>DIFFERENTIAL | 4 IN. HG<br>DIFFERENTIAL | 2 IN. HG<br>DIFFERENTIAL | 1 IN. HG<br>DIFFERENTIAL |
|--------------------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Capacity Expressed in Square Feet E D R    |                          |                          |                          |                          |                          |
| 7                                          | 18-23                    | 16-21                    | 15-19                    | 10-13                    | 8-11                     |
| 8                                          | 23-29                    | 21-27                    | 19-25                    | 13-17                    | 11-14                    |
| 9                                          | 29-36                    | 27-33                    | 25-30                    | 17-21                    | 14-17                    |
| 10                                         | 36-44                    | 33-40                    | 30-37                    | 21-26                    | 17-20                    |
| 11                                         | 44-52                    | 40-48                    | 37-44                    | 26-31                    | 20-24                    |
| 12                                         | 52-62                    | 48-57                    | 44-51                    | 31-37                    | 24-28                    |
| 13                                         | 62-72                    | 57-66                    | 51-59                    | 37-43                    | 28-32                    |
| 14                                         | 72-83                    | 66-76                    | 59-67                    | 43-49                    | 32-37                    |
| 15                                         | 83-94                    | 76-86                    | 67-76                    | 49-56                    | 37-42                    |
| 16                                         | 94-106                   | 86-97                    | 76-86                    | 56-64                    | 42-47                    |
| 17                                         | 106-119                  | 97-109                   | 86-97                    | 64-72                    | 47-52                    |
| 18                                         | 119-133                  | 109-122                  | 97-108                   | 72-80                    | 52-58                    |
| 19                                         | 133-148                  | 122-135                  | 108-120                  | 80-88                    | 58-64                    |
| 20                                         | 148-163                  | 135-149                  | 120-133                  | 88-98                    | 64-71                    |
| 21                                         | 163-179                  | 149-164                  | 133-145                  | 98-107                   |                          |
| Capacity Expressed in Pounds per Hour      |                          |                          |                          |                          |                          |
| 7                                          | 4.5-5.8                  | 4.0-5.3                  | 3.8-4.8                  | 2.5-3.3                  | 2.0-2.8                  |
| 8                                          | 5.8-7.3                  | 5.3-6.8                  | 4.8-6.3                  | 3.3-4.3                  | 2.8-3.5                  |
| 9                                          | 7.3-9.0                  | 6.8-8.3                  | 6.3-7.5                  | 4.3-5.3                  | 3.5-4.3                  |
| 10                                         | 9.0-11.0                 | 8.3-10.0                 | 7.5-9.3                  | 5.3-6.5                  | 4.3-5.0                  |
| 11                                         | 11.0-13.0                | 10.0-12.0                | 9.3-11.0                 | 6.5-7.8                  | 5.0-6.0                  |
| 12                                         | 13.0-15.5                | 12.0-14.3                | 11.0-12.8                | 7.8-9.3                  | 6.0-7.0                  |
| 13                                         | 15.5-18.0                | 14.3-16.5                | 12.8-14.8                | 9.3-10.8                 | 7.0-8.0                  |
| 14                                         | 18.0-20.8                | 16.5-19.0                | 14.8-16.8                | 10.8-12.3                | 8.0-9.3                  |
| 15                                         | 20.8-23.5                | 19.0-21.5                | 16.8-19.0                | 12.3-14.0                | 9.3-10.5                 |
| 16                                         | 23.5-26.5                | 21.5-24.3                | 19.0-21.5                | 14.0-16.0                | 10.5-11.8                |
| 17                                         | 26.5-29.8                | 24.3-27.3                | 21.5-24.3                | 16.0-18.0                | 11.8-13.0                |
| 18                                         | 29.8-33.3                | 27.3-30.5                | 24.3-27.0                | 18.0-20.0                | 13.0-14.5                |
| 19                                         | 33.3-37.0                | 30.5-33.8                | 27.0-30.0                | 20.0-22.0                | 14.5-16.0                |
| 20                                         | 37.0-40.8                | 33.8-37.3                | 30.0-33.3                | 22.0-24.5                | 16.0-17.8                |
| 21                                         | 40.8-44.8                | 37.3-41.0                | 33.3-36.3                | 24.5-26.8                |                          |

Note.—The radiator orifice plates recommended in this table are made of brass stampings 0.023 in. thick cup-shaped to be inserted in radiator valve unions.  
\* Flow of Steam Through Orifices into Radiators, by S. S. Sanford and C. B. Sprenger (A.S.H.V.E. Transactions, Vol. 37, 1931, p. 371).

condensate which occurs in steam piping as well as in radiators must be drained to prevent impeding the ready flow of the steam and air. The effect of back pressure in the returns and excessive re-vaporization, such as occurs where condensate is released from pressures considerably higher than the vacuum or pressure in the return, must be avoided.

It is important that steam piping systems distribute steam not only at full design load, but during excess and partial loads. Usually the average winter steam demand is less than half of the demand at the design outside

temperature. Moreover, in rapidly warming up a system even in moderate weather, the load on the steam main and returns may exceed the maximum operating load for severe weather, due to the necessity of raising the temperature of the metal in the system to the steam temperature, and the building to the design indoor temperature. Investigations of the return of condensate have revealed that as high as 143 percent of the design condensation rate may exist under conditions of actual operation.

The piping design of a heating system is greatly influenced by its operating characteristics. Heating systems do not operate under constant conditions, as conditions change continually, due to variation in load. As the system is being filled with steam, the pressures existing in various locations may be different from those which exist for appreciable periods at other locations, although at equilibrium conditions the pressures are approximately the same. In designing piping it is of especial importance to arrange the system to preclude trouble caused by such pressure differences. The systems which readily release the air, permit uniform

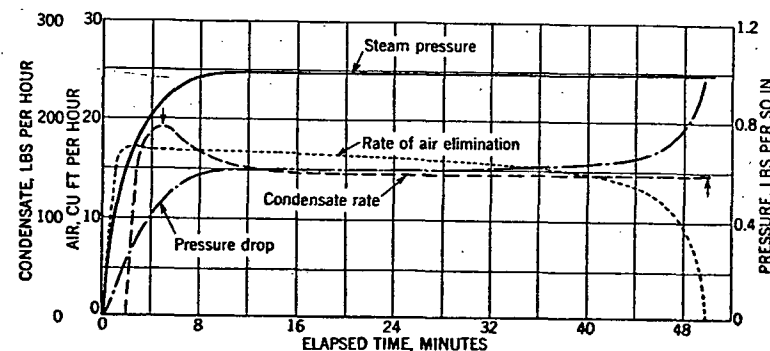


FIG. 18. RELATION BETWEEN ELAPSED TIME, STEAM PRESSURE, CONDENSATE AND AIR ELIMINATION RATES

pressures to be attained in much shorter time intervals than those which are sluggish. Results are given in Fig. 18 from investigations<sup>1</sup> to determine the rate of condensate and air return from a two-pipe gravity heating system. Variations in the steam pressure during the warming-up period, when the rate of air elimination and condensation is high, are clearly indicated in these curves.

It is evident that the condensate flow during the initial warming-up period reaches a peak, which is greater than the constant condensing rate eventually reached when the pressure becomes uniform. Moreover, the peak condensing rate is obtained when the system steam pressure is lower than that existing during a period of constant condensing rate. It will also be noted that the peak rate of air elimination does not coincide with the higher condensing rate.

#### Steam Flow

The rate of flow of dry steam or steam with a small amount of water flowing in the same direction, is in accordance with the general laws of gas flow, and is a function of the length and diameter of the pipe, the density of the steam, and the pressure drop through the pipe. This relationship

TABLE 2. FLOW OF STEAM IN PIPES

$P$  = loss in pressure in pounds per square inch.  
 $D$  = inside diameter of pipe in inches.  
 $L$  = length of pipe in feet.  
 $d$  = weight of 1 cu ft of steam.  
 $W$  = pounds of steam per hour.

$$W = 5220 \sqrt{\frac{Pd^4}{(1 + \frac{3.6}{D})L}}$$

$$P = 0.000000367 \left(1 + \frac{3.6}{D}\right) \frac{W^2 L}{dD^5}$$

| PRESSURE LOSS IN OUNCES | Col. 1                     | PIPE SIZE                                                                                                                                                                                                                                                                                            |                          | INTERNAL AREA OF PIPE SQ INCHES | Col. 2                                 | AVG STEAM PRESS. PSIG | Col. 3     | LENGTH OF PIPE IN FEET | Col. 4                 |       |
|-------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|---------------------------------|----------------------------------------|-----------------------|------------|------------------------|------------------------|-------|
|                         | $5220\sqrt{\frac{P}{100}}$ | Nominal                                                                                                                                                                                                                                                                                              | Actual Internal Diameter |                                 | $\sqrt{\frac{D^5}{1 + \frac{3.6}{D}}}$ |                       | $\sqrt{d}$ |                        | $\sqrt{\frac{100}{L}}$ |       |
| 0.25                    | 65.28                      | 1                                                                                                                                                                                                                                                                                                    | 1.049                    | 0.864                           | 0.536                                  | -1.0a                 | 0.187      | 20                     | 2.240                  |       |
| 0.50                    | 92.28                      | 1¼                                                                                                                                                                                                                                                                                                   | 1.380                    | 1.496                           | 1.178                                  | -0.5a                 | 0.190      | 40                     | 1.580                  |       |
| 1.00                    | 130.5                      | 1½                                                                                                                                                                                                                                                                                                   | 1.610                    | 2.036                           | 1.828                                  | 0.0                   | 0.193      | 60                     | 1.290                  |       |
| 2                       | 184.6                      | 2                                                                                                                                                                                                                                                                                                    | 2.067                    | 3.356                           | 3.710                                  | 0.3                   | 0.195      | 80                     | 1.120                  |       |
| 3                       | 226.0                      | 2½                                                                                                                                                                                                                                                                                                   | 2.469                    | 4.788                           | 6.109                                  | 1.3                   | 0.201      | 100                    | 1.000                  |       |
| 4                       | 261.0                      | 3                                                                                                                                                                                                                                                                                                    | 3.068                    | 7.393                           | 11.183                                 | 2.3                   | 0.207      | 120                    | 0.912                  |       |
| 5                       | 291.8                      | 3½                                                                                                                                                                                                                                                                                                   | 3.548                    | 9.887                           | 16.705                                 | 5.3                   | 0.223      | 140                    | 0.841                  |       |
| 6                       | 319.7                      | 4                                                                                                                                                                                                                                                                                                    | 4.026                    | 12.730                          | 23.631                                 | 10.3                  | 0.248      | 160                    | 0.793                  |       |
| 7                       | 345.3                      | 4½                                                                                                                                                                                                                                                                                                   | 4.506                    | 15.947                          | 32.134                                 | 15.3                  | 0.270      | 180                    | 0.741                  |       |
| 8                       | 369.1                      | 5                                                                                                                                                                                                                                                                                                    | 5.047                    | 20.006                          | 43.719                                 | 20.3                  | 0.290      | 200                    | 0.710                  |       |
| 10                      | 412.7                      | 6                                                                                                                                                                                                                                                                                                    | 6.065                    | 28.886                          | 71.762                                 | 30.3                  | 0.326      | 250                    | 0.632                  |       |
| 12                      | 452.0                      | 7                                                                                                                                                                                                                                                                                                    | 7.023                    | 38.743                          | 106.278                                | 40.3                  | 0.358      | 300                    | 0.578                  |       |
| 14                      | 488.3                      | 8                                                                                                                                                                                                                                                                                                    | 7.981                    | 50.027                          | 149.382                                | 50.3                  | 0.388      | 350                    | 0.538                  |       |
| 16                      | 522.0                      | 9                                                                                                                                                                                                                                                                                                    | 8.941                    | 62.786                          | 201.833                                | 60.3                  | 0.415      | 400                    | 0.500                  |       |
| 20                      | 583.6                      | 10                                                                                                                                                                                                                                                                                                   | 10.020                   | 78.854                          | 272.592                                | 75.3                  | 0.452      | 450                    | 0.477                  |       |
| 24                      | 639.3                      | 12                                                                                                                                                                                                                                                                                                   | 12.000                   | 113.098                         | 437.503                                | 100.3                 | 0.507      | 500                    | 0.447                  |       |
| 28                      | 690.5                      | 14                                                                                                                                                                                                                                                                                                   | 13.250                   | 137.880                         | 566.693                                | 125.3                 | 0.557      | 600                    | 0.407                  |       |
| 32                      | 738.2                      | 16                                                                                                                                                                                                                                                                                                   | 15.250                   | 182.655                         | 816.872                                | 150.3                 | 0.603      | 700                    | 0.378                  |       |
| 40                      | 825.4                      | Column 1 × 2 × 3 × 4 = lb of steam per hour that will flow through a straight pipe for a given condition.<br><br>Example 1: 1 oz drop - 2 in. pipe - 1.3 lb press. - 100 ft equivalent length:<br><br>130.5 × 3.710 × 0.201 × 1 = 97.2 lb per hour.<br>97.2 × 45 = 388.8 sq ft equivalent radiation. |                          |                                 |                                        |                       | 175.3      | 0.645                  | 800                    | 0.354 |
| 48                      | 904.1                      |                                                                                                                                                                                                                                                                                                      |                          |                                 |                                        |                       | 200.3      | 0.685                  | 900                    | 0.333 |
| 80                      | 1167.2                     |                                                                                                                                                                                                                                                                                                      |                          |                                 |                                        |                       |            |                        | 1000                   | 0.316 |
| 160                     | 1650.7                     |                                                                                                                                                                                                                                                                                                      |                          |                                 |                                        |                       |            |                        | 1200                   | 0.289 |
| 320                     | 2334.5                     |                                                                                                                                                                                                                                                                                                      |                          |                                 |                                        |                       |            |                        | 1500                   | 0.258 |
| 480                     | 2859.1                     |                                                                                                                                                                                                                                                                                                      |                          |                                 |                                        |                       |            |                        | 2000                   | 0.224 |

<sup>a</sup> Pounds per square inch gage = 2.04 in. Vacuum, Mercury Column.

<sup>b</sup> The factor 4 is the approximate equivalent in square feet of steam radiation of 1 lb of steam per hour.

has been established by Babcock in the formula given at the top of Table 2. In Columns 1, 2, 3, and 4 of this table, the numerical values of the factors for different pressure losses, pipe diameters, steam densities and lengths of pipe have been worked out in convenient form so that the steam flowing in any pipe may be calculated by multiplying together the proper factors in each column, as shown in the example at the bottom of the table.

### Pipe Sizes

The determination of pipe sizes for a given load in steam heating depends on the following principal factors:

1. The initial pressure and the total pressure drop which may be allowed between the source of supply and at the end of the return system.
2. The maximum velocity of steam allowable for quiet and dependable operation of the system, taking into consideration the direction of condensate flow.
3. The equivalent length of the run from the boiler or source of steam supply to the farthest heating unit.
4. The direction of flow of the condensate, whether against or with the steam.

### Initial Pressure and Pressure Drop

Theoretically, there are several factors to be considered such as initial pressure and pressure required at the end of the line, but it is most important that: (1) the total pressure drop does not exceed the initial gage pressure of the system, and in actual practice it should never exceed one-half of the initial gage pressure; (2) the pressure drop is not so great as to cause excessive velocities; (3) there is a constant initial pressure, except on systems specially designed for varying initial pressures, such as the sub-atmospheric, which normally operate under controlled partial vacua and orifice and vapor systems, which at times operate under such partial vacua as may be obtained due to the condition of the fire; and (4) the rise in water due to pressure drop does not exceed the difference in level, for gravity return systems, between the lowest point on the steam main, the heating units, or the dry-return, and the boiler water line.

The present tendency in steam heating unmistakably points toward a constant lowering of initial pressures, even to those below atmospheric, and to the use of reasonably small pressure drops because a system designed in this manner will operate under higher pressures without difficulty. When a system designed for a relatively high initial pressure and a relatively high pressure drop is operated at a lower pressure, it is likely to be noisy and have poor circulation.

The total pressure drop should never exceed one-half of the initial gage pressure when condensate is flowing in the same direction as the steam. Where the condensate must flow counter to the steam, the governing factor is the velocity permissible without interfering with the condensate flow. A.S.H.A.E. Research Laboratory experiments limit this to the capacities given in Table 3 for horizontal pipes at varying grades.

### Maximum Velocity

The capacity of a steam pipe in any part of a steam system depends upon the quantity of condensate present, the direction in which the condensate is flowing, and the pressure drop in the pipe. Where the quantity of condensate is limited and is flowing in the same direction as the steam, only the pressure drop need be considered. When the condensate must flow against the steam, even in limited quantity, the velocity of the steam must not exceed limits above which the disturbance between the steam and

the counter-flowing water may produce objectionable sounds, such as water hammer, or may result in the retention of water in certain parts of the system until the steam flow is reduced sufficiently to permit the water to pass. The velocity at which such disturbances take place is a function of (1) the pipe size, whether the pipe runs horizontally or vertically; (2) the pitch of the pipe if it runs horizontally; (3) the quantity of condensate flowing against the steam; and (4) freedom of the piping from water pockets which under certain conditions act as a restriction in pipe size.

#### Reaming Important

Three factors of uncertainty always exist in determining the capacity of any steam pipe. The first is variation in manufacture, which apparently cannot be avoided. The second is the care used in reaming the ends of the pipe after cutting. The effect of both of these factors increases as the

TABLE 3. COMPARATIVE CAPACITY OF STEAM LINES AT VARIOUS PITCHES FOR STEAM AND CONDENSATE FLOWING IN OPPOSITE DIRECTIONS\*  
Pitch of Pipe in Inches per 10 Ft. Velocity in Ft per Sec

| PITCH OF PIPE                           | 1/4 IN.  |           | 1/2 IN.  |           | 1 IN.    |           | 1 1/2 IN. |           | 2 IN.    |           | 3 IN.    |           | 4 IN.    |           | 5 IN.    |           |
|-----------------------------------------|----------|-----------|----------|-----------|----------|-----------|-----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|
| Pipe Size Inches                        | Capacity | Max. Vel. | Capacity | Max. Vel. | Capacity | Max. Vel. | Capacity  | Max. Vel. | Capacity | Max. Vel. | Capacity | Max. Vel. | Capacity | Max. Vel. | Capacity | Max. Vel. |
| Capacity Expressed in Square Feet E D R |          |           |          |           |          |           |           |           |          |           |          |           |          |           |          |           |
| 3/4                                     | 25.0     | 12        | 30.3     | 14        | 37.3     | 18        | 40.4      | 19        | 42.5     | 20        | 46.1     | 21        | 47.5     | 22        | 49.3     | 23        |
| 1                                       | 45.8     | 12        | 52.6     | 15        | 63.0     | 17        | 70.0      | 20        | 75.2     | 22        | 83.0     | 23        | 87.9     | 25        | 90.2     | 26        |
| 1 1/4                                   | 104.9    | 18        | 117.2    | 20        | 133.0    | 23        | 144.5     | 25        | 154.0    | 27        | 165.0    | 28        | 172.6    | 29        | 178.2    | 31        |
| 1 1/2                                   | 142.6    | 18        | 159.0    | 21        | 181.0    | 23        | 196.5     | 25        | 209.3    | 27        | 224.0    | 28        | 234.8    | 30        | 242.6    | 31        |
| 2                                       | 236.0    | 19        | 263.5    | 20        | 299.5    | 23        | 325.5     | 25        | 346.5    | 27        | 371.5    | 28        | 388.4    | 29        | 401.1    | 30        |
| Capacity Expressed in Pounds per Hour   |          |           |          |           |          |           |           |           |          |           |          |           |          |           |          |           |
| 3/4                                     | 6.3      | 12        | 7.6      | 14        | 9.3      | 18        | 10.1      | 19        | 10.6     | 20        | 11.5     | 21        | 11.9     | 22        | 12.3     | 23        |
| 1                                       | 11.5     | 12        | 13.2     | 15        | 15.8     | 17        | 17.5      | 20        | 18.8     | 22        | 20.8     | 23        | 22.0     | 25        | 22.6     | 26        |
| 1 1/4                                   | 26.2     | 18        | 29.3     | 20        | 33.3     | 23        | 36.1      | 25        | 38.5     | 27        | 41.3     | 28        | 43.2     | 29        | 44.6     | 31        |
| 1 1/2                                   | 35.7     | 18        | 39.8     | 21        | 45.3     | 23        | 49.1      | 25        | 52.3     | 27        | 56.0     | 28        | 58.7     | 30        | 60.7     | 31        |
| 2                                       | 59.0     | 19        | 65.9     | 20        | 74.9     | 23        | 81.4      | 25        | 86.6     | 27        | 92.4     | 28        | 97.1     | 29        | 100.3    | 30        |

\* Data from THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS Research Laboratory.

pipe size decreases. According to A.S.H.A.E. Research Laboratory tests, either of these factors may affect the capacity of a 1-in. pipe as much as 20 percent. The third factor is the uniformity in grading the pipe line. All of the capacity tables given in this chapter include a factor of safety. However, the factor of safety referred to does not cover abnormal defects or constrictions, nor does it cover pipe not properly reamed.

#### Equivalent Length of Run

All tables for the flow of steam in pipes, based on pressure drop, must allow for the friction offered by the pipe, as well as for the additional resistance of the fittings and valves. These resistances generally are stated in terms of straight pipe; in other words, a certain fitting will produce a drop in pressure equivalent to so many feet of straight run of the same size of pipe. Table 4 gives the number of feet of straight pipe usually allowed for the more common types of fittings and valves. In all pipe sizing tables in this chapter the *length of run* refers to the *equivalent*

*length of run* as distinguished from the *actual length* of pipe in feet. The length of run is not usually known at the outset; hence, it may be necessary to assume some pipe size at the start. Such an assumption frequently is considerably in error, and a more common and practical method is to assume the length of run and to check this assumption after the pipes are sized. For this purpose the length of run usually is taken as double the actual length of pipe.

#### TABLES FOR PIPE SIZING FOR LOW PRESSURE SYSTEMS\*

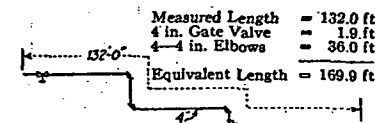
Tables 5, 6, and 7 are based on the actual inside diameters of the pipe and the condensation of 1/4 lb (4 oz) of steam per square foot of equivalent direct radiation (*abbreviated EDR*) per hour. The drops indicated are

TABLE 4. LENGTH IN FEET OF PIPE TO BE ADDED TO ACTUAL LENGTH OF RUN—OWING TO FITTINGS—TO OBTAIN EQUIVALENT LENGTH

| SIZE OF PIPE INCHES | LENGTH IN FEET TO BE ADDED TO RUN |                 |             |              |              |
|---------------------|-----------------------------------|-----------------|-------------|--------------|--------------|
|                     | Standard Elbow                    | Side Outlet Tee | Gate Valve* | Globe Valve* | Angle Valve* |
| 1/2                 | 1.3                               | 3               | 0.3         | 14           | 7            |
| 3/4                 | 1.8                               | 4               | 0.4         | 18           | 10           |
| 1                   | 2.2                               | 5               | 0.5         | 23           | 12           |
| 1 1/4               | 3.0                               | 6               | 0.6         | 29           | 15           |
| 1 1/2               | 3.5                               | 7               | 0.8         | 34           | 18           |
| 2                   | 4.3                               | 8               | 1.0         | 46           | 22           |
| 2 1/2               | 5.0                               | 11              | 1.1         | 54           | 27           |
| 3                   | 6.5                               | 13              | 1.4         | 66           | 34           |
| 3 1/2               | 8                                 | 15              | 1.6         | 80           | 40           |
| 4                   | 9                                 | 18              | 1.9         | 92           | 45           |
| 5                   | 11                                | 22              | 2.2         | 112          | 56           |
| 6                   | 13                                | 27              | 2.8         | 136          | 67           |
| 8                   | 17                                | 35              | 3.7         | 180          | 92           |
| 10                  | 21                                | 45              | 4.6         | 230          | 112          |
| 12                  | 27                                | 53              | 5.5         | 270          | 132          |
| 14                  | 30                                | 63              | 6.4         | 310          | 152          |

\* Valve in full open position.

Example of length in feet of pipe to be added to actual length of run.



drops in pressure per 100 ft of equivalent length of run. The pipe is assumed to be well reamed and without unusual or noticeable defects.

Table 5 may be used for sizing piping for steam heating systems by pre-determining the allowable or desired pressure drop per 100 equivalent feet of run, and reading from the column for that particular pressure drop. This applies to all steam mains on both one-pipe and two-pipe systems, vapor systems, and vacuum systems. Columns B to G, inclusive, are used where the steam and condensate flow in the same direction, while Columns H and I are for cases where the steam and condensate flow in opposite directions, as in risers and runouts that are not dripped. Columns J, K, and L are for one-pipe systems and cover riser, radiator valve and vertical connection sizes, and radiator and runout sizes, all of which are based on the

TABLE 5. STEAM PIPE CAPACITIES FOR LOW PRESSURE SYSTEMS  
(Reference to this table will be by column letter A through L)

This table is based on pipe size data developed through the research investigations of  
THE AMERICAN SOCIETY OF HEATING AND AIR-CONDITIONING ENGINEERS.

| CAPACITIES OF STEAM MAINS AND RISERS      |                                                 |                                            |                                            |                                            |                        |                                              | SPECIAL CAPACITIES FOR ONE-PIPE SYSTEMS ONLY |                                            |                              |                                 |                      |
|-------------------------------------------|-------------------------------------------------|--------------------------------------------|--------------------------------------------|--------------------------------------------|------------------------|----------------------------------------------|----------------------------------------------|--------------------------------------------|------------------------------|---------------------------------|----------------------|
| PIPE SIZE IN.                             | DIRECTION OF CONDENSATE FLOW IN PIPE LINE       |                                            |                                            |                                            |                        |                                              | Supply Risers Up-Feed                        | Radi-ator Valves and Vertical Con-nections | Radi-ator and Riser Run-outs |                                 |                      |
|                                           | With the Steam in One-Pipe and Two-Pipe Systems |                                            |                                            |                                            |                        |                                              |                                              |                                            |                              | Against the Steam Two-Pipe Only |                      |
|                                           | $\frac{1}{8}$ psi or $\frac{1}{8}$ Oz Drop      | $\frac{1}{4}$ psi or $\frac{1}{4}$ Oz Drop | $\frac{1}{2}$ psi or $\frac{1}{2}$ Oz Drop | $\frac{3}{4}$ psi or $\frac{3}{4}$ Oz Drop | $1$ psi or $1$ Oz Drop | $1\frac{1}{2}$ psi or $1\frac{1}{2}$ Oz Drop |                                              |                                            |                              | Vertical                        | Horizontal           |
|                                           |                                                 |                                            |                                            |                                            |                        |                                              |                                              |                                            |                              |                                 |                      |
| A                                         | B                                               | C                                          | D                                          | E                                          | F                      | G                                            | H <sup>a</sup>                               | I <sup>a</sup>                             | J <sup>b</sup>               | K                               | L <sup>c</sup>       |
| Capacity Expressed in Square Feet E D R   |                                                 |                                            |                                            |                                            |                        |                                              |                                              |                                            |                              |                                 |                      |
| $\frac{1}{8}$                             | —                                               | —                                          | 30                                         | —                                          | —                      | —                                            | 30                                           | —                                          | 25                           | —                               | —                    |
| 1                                         | 39                                              | 46                                         | 56                                         | 79                                         | 111                    | 157                                          | 56                                           | 34                                         | 45                           | 28                              | 28                   |
| 1 $\frac{1}{4}$                           | 87                                              | 100                                        | 122                                        | 173                                        | 245                    | 346                                          | 122                                          | 75                                         | 98                           | 62                              | 62                   |
| 1 $\frac{1}{2}$                           | 134                                             | 155                                        | 190                                        | 269                                        | 380                    | 538                                          | 190                                          | 108                                        | 152                          | 93                              | 93                   |
| 2                                         | 273                                             | 315                                        | 386                                        | 546                                        | 771                    | 1,091                                        | 386                                          | 195                                        | 288                          | 169                             | 169                  |
| 2 $\frac{1}{2}$                           | 449                                             | 518                                        | 635                                        | 898                                        | 1,270                  | 1,800                                        | 635                                          | 395                                        | 464                          | —                               | 260                  |
| 3                                         | 822                                             | 948                                        | 1,160                                      | 1,650                                      | 2,330                  | 3,290                                        | 1,130                                        | 700                                        | 800                          | —                               | 475                  |
| 3 $\frac{1}{2}$                           | 1,230                                           | 1,420                                      | 1,740                                      | 2,460                                      | 3,470                  | 4,910                                        | 1,550                                        | 1,150                                      | 1,140                        | —                               | 745                  |
| 4                                         | 1,740                                           | 2,010                                      | 2,460                                      | 3,480                                      | 4,910                  | 6,950                                        | 2,040                                        | 1,700                                      | 1,520                        | —                               | 1,110                |
| 5                                         | 3,210                                           | 3,710                                      | 4,550                                      | 6,430                                      | 9,090                  | 12,900                                       | 4,200                                        | 3,150                                      | —                            | —                               | 2,180                |
| 6                                         | 5,280                                           | 6,100                                      | 7,460                                      | 10,550                                     | 14,900                 | 21,100                                       | 7,200                                        | 5,600                                      | —                            | —                               | —                    |
| 8                                         | 11,000                                          | 12,700                                     | 15,500                                     | 21,970                                     | 31,070                 | 43,900                                       | 15,000                                       | 12,000                                     | —                            | —                               | —                    |
| 10                                        | 20,000                                          | 23,100                                     | 28,300                                     | 40,100                                     | 56,700                 | 80,200                                       | 28,000                                       | 23,000                                     | —                            | —                               | —                    |
| 12                                        | 32,000                                          | 37,100                                     | 45,500                                     | 64,300                                     | 91,000                 | 129,000                                      | 46,000                                       | 38,000                                     | —                            | —                               | —                    |
| 16                                        | 61,000                                          | 69,700                                     | 84,800                                     | 121,000                                    | 170,000                | 242,000                                      | 88,000                                       | 76,000                                     | —                            | —                               | —                    |
| Capacity Expressed in Pounds per Hour     |                                                 |                                            |                                            |                                            |                        |                                              |                                              |                                            |                              |                                 |                      |
| $\frac{1}{8}$                             | —                                               | —                                          | 8                                          | —                                          | —                      | —                                            | 8                                            | —                                          | 6                            | —                               | 7                    |
| 1                                         | 10                                              | 12                                         | 14                                         | 20                                         | 28                     | 40                                           | 14                                           | 9                                          | 11                           | 7                               | 7                    |
| 1 $\frac{1}{4}$                           | 22                                              | 25                                         | 31                                         | 43                                         | 61                     | 87                                           | 31                                           | 19                                         | 20                           | 16                              | 16                   |
| 1 $\frac{1}{2}$                           | 34                                              | 39                                         | 48                                         | 67                                         | 95                     | 135                                          | 48                                           | 27                                         | 38                           | 23                              | 23                   |
| 2                                         | 68                                              | 79                                         | 97                                         | 137                                        | 193                    | 273                                          | 97                                           | 49                                         | 72                           | 42                              | 42                   |
| 2 $\frac{1}{2}$                           | 112                                             | 130                                        | 159                                        | 225                                        | 318                    | 449                                          | 159                                          | 99                                         | 116                          | —                               | 65                   |
| 3                                         | 206                                             | 237                                        | 291                                        | 411                                        | 581                    | 822                                          | 282                                          | 175                                        | 200                          | —                               | 119                  |
| 3 $\frac{1}{2}$                           | 307                                             | 355                                        | 434                                        | 614                                        | 869                    | 1,230                                        | 387                                          | 288                                        | 286                          | —                               | 186                  |
| 4                                         | 435                                             | 503                                        | 614                                        | 869                                        | 1,230                  | 1,740                                        | 511                                          | 425                                        | 380                          | —                               | 278                  |
| 5                                         | 806                                             | 928                                        | 1,140                                      | 1,610                                      | 2,270                  | 3,210                                        | 1,050                                        | 788                                        | —                            | —                               | 545                  |
| 6                                         | 1,320                                           | 1,520                                      | 1,870                                      | 2,640                                      | 3,730                  | 5,280                                        | 1,800                                        | 1,400                                      | —                            | —                               | —                    |
| 8                                         | 2,750                                           | 3,170                                      | 3,880                                      | 5,490                                      | 7,770                  | 11,000                                       | 3,750                                        | 3,000                                      | —                            | —                               | —                    |
| 10                                        | 5,010                                           | 5,790                                      | 7,090                                      | 10,000                                     | 14,200                 | 20,000                                       | 7,000                                        | 5,700                                      | —                            | —                               | —                    |
| 12                                        | 8,040                                           | 9,290                                      | 11,400                                     | 16,100                                     | 22,700                 | 32,200                                       | 11,500                                       | 9,500                                      | —                            | —                               | —                    |
| 16                                        | 15,100                                          | 17,400                                     | 21,200                                     | 30,300                                     | 42,400                 | 60,500                                       | 22,000                                       | 19,000                                     | —                            | —                               | —                    |
| All Horizontal Mains and Down-Feed Risers |                                                 |                                            |                                            |                                            |                        |                                              | Up-Feed Risers                               | Mains and Un-drilled Run-outs              | Up-Feed Risers               | Radi-ator Con-nections          | Run-outs Not Drilled |

Note.—Steam at an average pressure of 1 psig is used as a basis for calculating capacities. All drops shown are in psi per 100 ft of equivalent run—based on pipe properly reamed.

<sup>a</sup> Do not use Column H for drops of 1/24 or 1/32 psi; substitute Column C or Column B as required.

<sup>b</sup> Do not use Column J for drops of 1/32 psi except on sizes 3 in. and over; below 3 in. substitute Column B.

<sup>c</sup> Pitch of horizontal runouts to risers and radiators should be not less than 1/2 in. per ft. Where this pitch cannot be obtained, runouts over 8 ft in length should be one pipe size larger than called for in Table 5.

critical velocities of the steam to permit the counter flow of condensate without noise.

Return piping may be sized with the aid of Tables 6 and 7 where pipe capacities for wet, dry, and vacuum return lines are shown for the pressure drops per 100 ft corresponding to the drops in Table 5. *It is customary to use the same pressure drop on both the steam and return sides of a system.*

**Example 2:** What pressure drop should be used for the steam piping of a system if the measured length of the longest run is 500 ft, and the initial pressure is not to be over 2-psig?

**Solution:** It will be assumed, if the measured length of the longest run is 500 ft., that when the allowance for fittings is added, the equivalent length of run will not exceed 1,000 ft. Then, with the pressure drop not over one-half of the initial pressure, the drop could be 1 psi or less. With a pressure drop of 1 psi and a length of run of 1,000 ft, the drop per 100 ft would be  $\frac{1}{10}$  psi, while if the total drop were  $\frac{1}{2}$  psi, the drop per 100 ft would be  $\frac{1}{20}$  psi. In the first instance the pipe could be sized according to Column D for  $\frac{1}{10}$  psi per 100 ft, and in the second case, the pipe could be sized according to Column C for  $\frac{1}{20}$  psi. On completion of the sizing, the drop could be checked by taking the longest line and actually calculating the equivalent length of run from the pipe sizes determined. If the calculated drop is less than that assumed, the pipe size is all right; if it is more, it is probable that there are an unusual number of fittings involved, and either the lines must be straightened or the column for the next lower drop must be used, and the lines resized. Ordinarily, resizing will be unnecessary.

#### TABLES FOR PIPE SIZING FOR HIGH PRESSURE SYSTEMS

Many of the recent installations of heating systems for large industrial type buildings have been designed for the use of high pressure steam, that is, without the use of pressure reducing valves. Such systems usually involve the use of unit heaters or large built-up fan units with blast heating coils. Pressures on these systems vary from 30 to 150 psi. Temperatures are controlled by a modulating or throttling type thermostatic valve controlled by the air temperature in the room, fan inlet or outlet.

Tables 8 to 11 may be used for the sizing of steam and return piping for systems of 30 and 150 psi pressure at various pressure drops. These tables are based on Babcock's formula, and have been used as the basis of design for a number of years.

#### SIZING PIPING FOR ONE-PIPE GRAVITY SYSTEMS

Gravity one-pipe air-vent systems, in which the equivalent length of run does not exceed 200 ft, should be sized by means of Tables 5, 6 and 7 as follows:

1. For the steam main and dripped runouts to risers where the steam and condensate flow in the same direction, use  $\frac{1}{8}$ -psi drop (Column D).
2. Where the riser runouts are not dripped and the steam and condensate flow in opposite directions, and also in the radiator runouts where the same condition occurs, use Column L.
3. For up-feed steam risers carrying condensate back from the radiators, use Column J.
4. For down-feed systems, the main risers of which do not carry any radiator condensate, use Column H.
5. For the radiator valve size and the stub connection, use Column K.
6. For the dry-return main, use Column U.
7. For the wet-return main, use Column T.

On systems exceeding an equivalent length of 200 ft., it is suggested that the total drop be not over  $\frac{1}{2}$  psi. The return piping sizes should correspond with the drop used on the steam side of the system. Thus, where  $\frac{1}{10}$ -psi drop is being used, the steam main and dripped runouts would be

TABLE 6. RETURN PIPE CAPACITIES FOR LOW PRESSURE SYSTEMS  
Capacity Expressed in Square Feet of Equivalent Direct Radiation

(Reference to this table will be by column letter M through EE)  
through the research investigations of THE AMERICAN SOCIETY OF HEATING AND AIR-CONDITIONING ENGINEERS.

[illegible][illegible]

TABLE 7. RETURN PIPE CAPACITIES FOR LOW PRESSURE SYSTEMS

Capacity Expressed in Pounds per Hour

(Reference to this table will be made by column letter *M* through *EE*)

This table is based on pipe size data developed through the research investigations of THE AMERICAN SOCIETY OF HEATING AND AIR-CONDITIONING ENGINEERS.

| CAPACITY OF RETURN MAINS AND RISERS |                                                            |       |       |                                                            |       |        |                                                |       |        |                                                |       |       |                                                |        |       |                                                |       |        |
|-------------------------------------|------------------------------------------------------------|-------|-------|------------------------------------------------------------|-------|--------|------------------------------------------------|-------|--------|------------------------------------------------|-------|-------|------------------------------------------------|--------|-------|------------------------------------------------|-------|--------|
| MAINS                               |                                                            |       |       |                                                            |       |        |                                                |       |        |                                                |       |       |                                                |        |       |                                                |       |        |
| Pipe<br>Size<br>Inches              | $\frac{1}{8}$ Psi or $\frac{1}{4}$ Oz.<br>Drop per 100 Ft. |       |       | $\frac{1}{4}$ Psi or $\frac{1}{2}$ Oz.<br>Drop per 100 Ft. |       |        | $\frac{1}{2}$ Psi or 1 Oz.<br>Drop per 100 Ft. |       |        | $\frac{1}{4}$ Psi or 2 Oz.<br>Drop per 100 Ft. |       |       | $\frac{1}{8}$ Psi or 4 Oz.<br>Drop per 100 Ft. |        |       | $\frac{1}{4}$ Psi or 8 Oz.<br>Drop per 100 Ft. |       |        |
|                                     | Wet                                                        | Dry   | Vac.  | Wet                                                        | Dry   | Vac.   | Wet                                            | Dry   | Vac.   | Wet                                            | Dry   | Vac.  | Wet                                            | Dry    | Vac.  | Wet                                            | Dry   | Vac.   |
| $\frac{3}{4}$ "                     | .....                                                      | ..... | ..... | .....                                                      | ..... | .....  | .....                                          | ..... | .....  | .....                                          | ..... | ..... | .....                                          | .....  | ..... | .....                                          | ..... | .....  |
| 1"                                  | 125                                                        | 62    | ..... | 145                                                        | 71    | 42     | .....                                          | 80    | 175    | 100                                            | ..... | 250   | 103                                            | 142    | ..... | 350                                            | 115   | 200    |
| $1\frac{1}{4}$ "                    | 213                                                        | 130   | ..... | 248                                                        | 149   | 244    | .....                                          | 168   | 300    | 175                                            | ..... | 425   | 217                                            | 249    | ..... | 600                                            | 241   | 350    |
| $1\frac{1}{2}$ "                    | 338                                                        | 206   | ..... | 393                                                        | 236   | 388    | .....                                          | 265   | 475    | 340                                            | ..... | 675   | 340                                            | 674    | ..... | 950                                            | 378   | 600    |
| 2"                                  | 700                                                        | 470   | ..... | 810                                                        | 535   | 815    | .....                                          | 575   | 1,000  | 1,000                                          | ..... | 1,400 | 740                                            | 1,420  | ..... | 2,000                                          | 825   | 950    |
| $2\frac{1}{2}$ "                    | 1,180                                                      | 760   | ..... | 1,580                                                      | 868   | 1,360  | .....                                          | 950   | 1,680  | 1,680                                          | ..... | 2,350 | 1,230                                          | 2,380  | ..... | 3,350                                          | 1,360 | 2,000  |
| 3"                                  | 1,880                                                      | 1,460 | ..... | 2,130                                                      | 1,560 | 2,180  | .....                                          | 1,750 | 2,680  | 2,350                                          | ..... | 3,750 | 2,250                                          | 3,800  | ..... | 5,350                                          | 2,500 | 3,350  |
| $3\frac{1}{2}$ "                    | 2,750                                                      | 1,970 | ..... | 3,300                                                      | 2,200 | 3,250  | .....                                          | 4,000 | 3,500  | 3,250                                          | ..... | 5,500 | 3,250                                          | 5,680  | ..... | 8,000                                          | 3,580 | 5,350  |
| 4"                                  | 3,880                                                      | 2,930 | ..... | 4,580                                                      | 3,350 | 4,500  | .....                                          | 5,500 | 3,750  | 3,750                                          | ..... | 7,750 | 4,830                                          | 7,810  | ..... | 11,000                                         | 5,380 | 8,000  |
| 5"                                  | .....                                                      | ..... | ..... | .....                                                      | ..... | 7,880  | .....                                          | ..... | 9,680  | .....                                          | ..... | ..... | 13,700                                         | 11,000 | ..... | 19,400                                         | ..... | 27,300 |
| 6"                                  | .....                                                      | ..... | ..... | .....                                                      | ..... | 12,600 | .....                                          | ..... | 15,500 | .....                                          | ..... | ..... | 22,000                                         | .....  | ..... | 31,000                                         | ..... | 43,800 |

[illegible]

TABLE 8. STEAM PIPE CAPACITIES FOR 30 PSIG STEAM SYSTEMS\*  
Capacity Expressed in Pounds per Hour  
(Steam and Condensate Flowing in Same Direction)

| PIPE SIZE<br>INCHES | DROP IN PRESSURE—POUNDS PER 100 FT IN LENGTH |        |        |        |        |         |
|---------------------|----------------------------------------------|--------|--------|--------|--------|---------|
|                     | 1/8                                          | 1/4    | 3/8    | 1/2    | 1      | 2       |
| 3/4                 | 15                                           | 22     | 31     | 38     | 45     | 63      |
| 1                   | 31                                           | 46     | 63     | 77     | 89     | 125     |
| 1 1/4               | 69                                           | 100    | 141    | 172    | 199    | 281     |
| 1 1/2               | 107                                          | 154    | 219    | 267    | 309    | 437     |
| 2                   | 217                                          | 313    | 444    | 543    | 627    | 886     |
| 2 1/2               | 358                                          | 516    | 730    | 924    | 1,030  | 1,460   |
| 3                   | 651                                          | 940    | 1,330  | 1,630  | 1,880  | 2,660   |
| 3 1/2               | 979                                          | 1,410  | 2,000  | 2,450  | 2,830  | 4,000   |
| 4                   | 1,390                                        | 2,000  | 2,830  | 3,460  | 4,000  | 5,660   |
| 5                   | 2,560                                        | 3,640  | 5,230  | 6,400  | 7,390  | 10,500  |
| 6                   | 4,210                                        | 6,030  | 8,590  | 10,400 | 12,100 | 17,200  |
| 8                   | 8,750                                        | 12,600 | 17,900 | 21,900 | 25,300 | 35,100  |
| 10                  | 16,300                                       | 23,500 | 33,200 | 40,600 | 46,900 | 66,400  |
| 12                  | 25,900                                       | 36,900 | 52,300 | 64,000 | 74,000 | 104,500 |

\* Note: Steam at an average pressure of 30 psig is used as the basis for calculating the above table.

sized from Column C; radiator runouts and undrilled riser runouts from Column L; up-feed risers from Column J; the main riser on a down-feed system from Column C (it will be noted that if Column H is used the drop would exceed the limit of  $\frac{1}{4}$  psi); the dry return from Column R; and the wet-return from Column Q.

With a  $\frac{1}{4}$ -psi drop the sizing would be the same as for  $\frac{1}{4}$  psi, except that the steam main and dripped runouts would be sized from Column B, the main riser on a down-feed system from Column B, the dry-return from Column O, and the wet-return from Column N.

#### Notes on Gravity One-Pipe Air-Vent Systems

1. Pitch of mains should not be less than  $\frac{1}{4}$  in. in 10 ft.
2. Pitch of horizontal runouts to risers and radiators should not be less than  $\frac{1}{4}$  in. per foot. Where this pitch cannot be obtained, runouts over 8 ft in length should be one size larger than called for in the table.
3. In general, it is not desirable to have a main less than 2 in. The diameter of the far end of the supply main should not be less than half its diameter at its largest part.

TABLE 9. STEAM PIPE CAPACITIES FOR 150 PSIG STEAM SYSTEMS\*  
Capacity Expressed in Pounds per Hour  
(Steam and Condensate Flowing in Same Direction)

| PIPE SIZE<br>INCHES | DROP IN PRESSURE—PSI PER 100 FT IN LENGTH |        |        |         |         |         |         |
|---------------------|-------------------------------------------|--------|--------|---------|---------|---------|---------|
|                     | 1/8                                       | 1/4    | 3/8    | 1/2     | 1       | 2       | 5       |
| 3/4                 | 29                                        | 41     | 58     | 71      | 82      | 116     | 184     |
| 1                   | 58                                        | 82     | 117    | 143     | 165     | 233     | 369     |
| 1 1/4               | 130                                       | 185    | 262    | 320     | 370     | 523     | 827     |
| 1 1/2               | 203                                       | 287    | 407    | 497     | 575     | 813     | 1,290   |
| 2                   | 412                                       | 583    | 825    | 1,010   | 1,170   | 1,650   | 2,600   |
| 2 1/2               | 683                                       | 959    | 1,360  | 1,650   | 1,920   | 2,710   | 4,290   |
| 3                   | 1,240                                     | 1,750  | 2,490  | 3,020   | 3,500   | 4,940   | 7,820   |
| 3 1/2               | 1,890                                     | 2,630  | 3,720  | 4,550   | 5,250   | 7,420   | 11,700  |
| 4                   | 2,630                                     | 3,720  | 5,260  | 6,430   | 7,430   | 10,500  | 16,600  |
| 5                   | 4,860                                     | 6,880  | 9,730  | 11,900  | 13,800  | 19,500  | 30,800  |
| 6                   | 7,960                                     | 11,300 | 16,000 | 19,500  | 22,600  | 31,900  | 50,400  |
| 8                   | 16,600                                    | 23,500 | 33,200 | 40,600  | 47,000  | 66,400  | 105,000 |
| 10                  | 30,800                                    | 43,400 | 61,700 | 75,600  | 87,300  | 123,000 | 195,000 |
| 12                  | 48,600                                    | 68,800 | 97,300 | 119,000 | 138,000 | 194,000 | 307,500 |

\* Note: Steam at an average pressure of 150 psig is used as the basis for calculating the above table.

TABLE 10. RETURN PIPE CAPACITIES FOR 30 PSIG STEAM SYSTEMS\*  
Capacity Expressed in Pounds per Hour

| PIPE SIZE<br>INCHES | DROP IN PRESSURE—POUNDS PER 100 FT IN LENGTH |        |        |        |        |
|---------------------|----------------------------------------------|--------|--------|--------|--------|
|                     | 1/8                                          | 1/4    | 3/8    | 1/2    | 1      |
| 3/4                 | 115                                          | 170    | 245    | 308    | 365    |
| 1                   | 230                                          | 340    | 490    | 615    | 730    |
| 1 1/4               | 485                                          | 710    | 1,025  | 1,290  | 1,530  |
| 1 1/2               | 790                                          | 1,160  | 1,670  | 2,100  | 2,500  |
| 2                   | 1,580                                        | 2,360  | 3,400  | 4,300  | 5,050  |
| 2 1/2               | 2,650                                        | 3,900  | 5,600  | 7,100  | 8,400  |
| 3                   | 4,850                                        | 7,100  | 10,300 | 12,900 | 15,300 |
| 3 1/2               | 7,200                                        | 10,600 | 15,300 | 19,200 | 22,800 |
| 4                   | 10,200                                       | 15,000 | 21,600 | 27,000 | 32,300 |
| 5                   | 19,000                                       | 27,800 | 40,300 | 55,500 | 60,000 |
| 6                   | 31,000                                       | 45,500 | 65,500 | 83,000 | 98,000 |

\* Note: The above table is based on steam at pressures of 0 to 4 psig.

4. Supply mains, runouts to risers, or risers, should be dripped where necessary.
5. Where supply mains are decreased in size they should be dripped, or be provided with eccentric couplings, flush on bottom.

*Example 3:* Size the one-pipe gravity steam system shown in Fig. 19 assuming that this is all there is to the system, or that the riser and main shown involve the longest run on the system.

*Solution:* The total length of run actually shown is 215 ft. If the equivalent length of run is taken at double this, it will amount to 430 ft, and with a total drop of  $\frac{1}{4}$  psi the drop per 100 ft will be slightly less than  $\frac{1}{4}$  psi. It would be well in this case to use  $\frac{1}{4}$  psi, and this would result in the theoretical sizes indicated in Table 12. These theoretical sizes, however, should be modified by not using a wet-return less than 2 in., while the main supply, g-h, if from the uptake of a boiler, should be made the full size of the main, or 3 in. Also the portion of the main k-m should be made 2 in. if the wet-return is made 2 in.

#### SIZING PIPING FOR ONE-PIPE VAPOR SYSTEMS

Piping for one-pipe vapor systems is sized so as to permit only a few ounces pressure drop in the system. Otherwise, the method follows that outlined for sizing one-pipe gravity systems.

TABLE 11. RETURN PIPE CAPACITIES FOR 150 PSIG STEAM SYSTEMS\*  
Capacity Expressed in Pounds per Hour

| PIPE SIZE<br>INCHES | DROP IN PRESSURE—PSI PER 100 FT IN LENGTH |        |        |         |         |
|---------------------|-------------------------------------------|--------|--------|---------|---------|
|                     | 1/8                                       | 1/4    | 3/8    | 1/2     | 1       |
| 3/4                 | 156                                       | 232    | 360    | 465     | 560     |
| 1                   | 313                                       | 462    | 690    | 910     | 1,120   |
| 1 1/4               | 650                                       | 960    | 1,500  | 1,950   | 2,330   |
| 1 1/2               | 1,070                                     | 1,580  | 2,460  | 3,160   | 3,800   |
| 2                   | 2,160                                     | 3,300  | 4,950  | 6,400   | 7,700   |
| 2 1/2               | 3,600                                     | 5,350  | 8,200  | 10,700  | 12,800  |
| 3                   | 6,500                                     | 9,600  | 15,000 | 19,500  | 23,300  |
| 3 1/2               | 9,600                                     | 14,400 | 22,300 | 28,700  | 34,500  |
| 4                   | 13,700                                    | 20,500 | 31,600 | 40,500  | 49,200  |
| 5                   | 25,600                                    | 38,100 | 58,500 | 76,000  | 91,500  |
| 6                   | 42,000                                    | 62,500 | 96,000 | 125,000 | 150,000 |

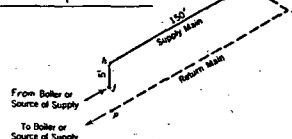
\* Note: The above table is based on steam at pressures of 1 to 20 psig.



TABLE 12. PIPE SIZES FOR ONE-PIPE UP-FEED SYSTEM SHOWN IN FIG. 19

| PART OF SYSTEM             | SECTION OF PIPE | RADIATION SUPPLIED EDR Sq Ft | THEORETICAL PIPE SIZE (INCHES) | PRACTICAL PIPE SIZE (INCHES) |
|----------------------------|-----------------|------------------------------|--------------------------------|------------------------------|
| Branches to radiators..... |                 | 100                          | 2                              | 2                            |
| Branches to radiators..... |                 | 50                           | 1½                             | 1½                           |
| Riser.....                 | a to b          | 200                          | 2                              | 2                            |
| Riser.....                 | b to c          | 300                          | 2½                             | 2½                           |
| Riser.....                 | c to d          | 400                          | 2½                             | 2½                           |
| Riser.....                 | d to e          | 500                          | 3                              | 3                            |
| Riser.....                 | e to f          | 600                          | 3                              | 3                            |
| Runout to riser.....       | f to g          | 600                          | 3½                             | 3½                           |
| Supply main.....           | g to h          | 600                          | 3                              | 3                            |
| Branch to supply main..... | h to i          | 600                          | 2½                             | 3                            |
| Dry return main.....       | f to k          | 600                          | 1½                             | 2                            |
| Wet return main.....       | k to m          | 600                          | 1                              | 2                            |
| Wet return main.....       | m to n          | 600                          | 1                              | 2                            |
| Wet return main.....       | n to p          | 600                          | 1                              | 2                            |

FIG. 19. RISER, SUPPLY MAIN AND RETURN MAIN OF ONE-PIPE SYSTEM



## SIZING PIPING FOR TWO-PIPE HIGH PRESSURE SYSTEMS

Steam supply piping for two-pipe high pressure can be sized for greater pressure drops than that of the return piping. For a system using steam at 30 psig, the total pressure drop can be 5 to 10 psi, and for 150 psig systems, 25 to 30 psi.

It has been observed that the maximum total pressure in the returns of a 30-psig system is about 5 psig, and that of a 150-psig system is about 20 psig. The pressure in the return mains is, of course, caused by the discharge of traps and flashing of condensate into steam because the return line pressure is below that corresponding to the saturation temperature of the condensate. The usual practice in the sizing of high pressure returns has been to size on the basis of ¼ psi per 100 ft of pipe for 30-psig systems, and 1 psi per 100 ft for 150-psig systems. This is an average figure which corresponds generally to several of the previously published tables for the design of high pressure return piping.

## Notes on Two-Pipe High Pressure Systems

- Pitch of mains should not be less than ¼ in. in 10 ft.
- Pitch of horizontal runouts to risers and heating units should not be less than ¼ in. per ft.

## SIZING PIPING FOR TWO-PIPE LOW PRESSURE SYSTEMS

Piping for two-pipe low pressure systems is sized in the same manner as for two-pipe vapor systems, except that the pressure drop throughout the system can be based on ½ psi to 1 psi drop.

## SIZING PIPING FOR TWO-PIPE VAPOR SYSTEMS

While many manufacturers of patented vapor heating accessories have their own schedules for pipe sizing, an inspection of these sizing tables indicates that in general as small a drop as possible is recommended. The reasons for this are: (1) to have the condensate return to the boiler by

gravity; (2) to obtain a more uniform distribution of steam throughout the system, especially when it is desirable to carry a moderate or low fire; and (3) to prevent large variations in pressure which would nullify the value of graduated valves on radiators.

For small vapor systems where the equivalent length of run does not exceed 200 ft, it is recommended that the main and any runouts to risers that may be dripped, should be sized from Column D, Table 5, while riser runouts not dripped and radiator runouts should employ Column I. The up-feed steam risers should be taken from Column H. On the returns, the risers should be sized from Tables 6 and 7, Column U (lower portion), and the mains from Column U (upper portion). It should again be noted that the pressure drop in the steam side of the system is kept the same as on the return side, except where the flow in the riser is concerned.

On a down-feed system, the main vertical riser should be sized from Column H, but the down-feed risers can be taken from Column D, although it so happens that the values in Columns D and H for small systems correspond. This will not hold true in larger systems.

For vapor systems over 200 ft of equivalent length, the drop should not exceed ½ psi to ¾ psi, if possible. Thus, for a 400 ft equivalent run the drop per 100 ft should be not over ½ psi divided by 4, or ¼ psi. In this case the steam mains would be sized from Column B, the radiator and undripped riser runouts from Column I; the risers from Column B, because Column H gives a drop in excess of ¾ psi. On a down-feed system, Column B would have to be used for both the main riser and the smaller risers feeding the radiators in order not to increase the drop over ¾ psi. The return risers would be sized from the lower portion of Column O and the dry return main from the upper portion of the same column, while any wet returns would be sized from Column N. The same pressure drop is applied on both the steam and the return sides of the system.

## Notes on Vapor Systems

- Pitch of mains should not be less than ¼ in. in 10 ft.
- Pitch of horizontal runouts to risers and radiators should not be less than ¼ in. per ft. Where this pitch cannot be obtained, runouts over 8 ft in length should be one size larger than called for in the table.
- In general it is not desirable to have a supply main smaller than 2 in.
- When necessary, supply main, supply risers, or runouts to supply risers should be dripped separately into a wet-return, or may be connected into the dry-return through a thermostatic drip trap.

## SIZING PIPING FOR TWO-PIPE VACUUM SYSTEMS

Vacuum, atmospheric, sub-atmospheric and orifice systems are usually employed in large installations and have total drops varying from ½ to ¾ psi. Systems in which the maximum equivalent length does not exceed 200 ft preferably employ the smaller pressure drop, while systems over 200 ft equivalent length of run, more frequently are designed for the higher drop, owing to the relatively greater saving in pipe sizes. For example, a system with 1200 ft longest equivalent length of run would employ a drop per 100 ft of ½ psi divided by 12, or ¼ psi. In this case, the steam main would be sized from Column C, Table 5, and the risers also from Column C (Column H could be used as far as critical velocity is concerned; but the drop would exceed the limit of ¼ psi). Riser runouts, if dripped, would use Column C but, if undripped, would use Column I; radiator runouts, Column I; return risers, lower part of Column S, Tables 6 and 7; return runouts to radiators, one pipe size larger than the radiator trap connections.



### Notes on Vacuum Systems

1. It is not generally considered good practice to exceed  $\frac{1}{2}$  psi drop per 100 ft of equivalent run, nor to exceed 1 psi total pressure drop in any system.
2. Pitch of mains should not be less than  $\frac{1}{4}$  in. in 10 ft.
3. Pitch of horizontal runouts to risers and radiators should not be less than  $\frac{1}{4}$  in. per ft. Where this pitch cannot be obtained, runouts over 8 ft in length should be one size larger than called for in the table.
4. In general, it is not considered desirable to have a supply main smaller than 2 in.
5. When necessary, the supply main, supply riser, or runout to a supply riser should be dripped separately through a trap into the vacuum return. A connection should not be made between the steam and return sides of a vacuum system without interposing a trap to prevent the steam from entering the return line.
6. Lifts should be avoided if possible, but when they cannot be eliminated they should be made in the manner described in this chapter.
7. No lifts can be used in orifice and atmospheric systems. In sub-atmospheric systems the lift must be at the vacuum pump.

### SIZING PIPING FOR INDIRECT HEATING UNITS

Pipe connections and mains for indirect heating units are sized according to the quantity of steam condensed by each unit. The condensation per unit depends upon the entering temperature and the air velocity, and may be obtained from manufacturers' rating tables. Where two or more units are placed in series, the entering air temperature for any unit will be the leaving temperature for the preceding unit.

When the amount of condensation has been obtained for each unit, the pipe sizes should be based on the length of run and the pressure drop desired, as in the case of radiators. It is generally desirable to place the indirect heating units on a separate piping system rather than to connect them to the piping which supplies direct radiation. For type of connections see section on Connections to Heating Units.

### PRESSURE REDUCING VALVES

While the illustrations given in Figs. 2 to 17 inclusive, indicate the various systems to be supplied by separate boiler plants, it is also possible to have steam supplied at high pressure by a boiler plant remotely located. In this case steam is supplied directly to the system or through a pressure reducing valve. Condensate can either be returned to the boiler plant or wasted to the sewer. The general arrangement of the systems fed through a pressure reducing valve will not vary from those illustrated with a boiler supply.

When high pressure steam is being supplied and lower steam pressures are required for heating, for domestic hot water, for utility services, etc., one or more pressure reducing valves (pressure regulators) are required.

These are used in two classes of service, one where the steam must be shut off tight to prevent the low pressure building up at time of no load, and the other where the low pressure lines will condense enough steam to offset normal leakage through the valve. In the latter case, double seated valves may be used in a manner that reduces the work required of the diaphragm in closing the valve and consequently, the size of the diaphragm. These valves also control the low pressures more closely under conditions of varying high pressures.

Valves that shut off all steam are called *dead end* type. They are single seated, and some of them have pilot operation that provides close control of the reduced pressure. If a thermostatically controlled valve is installed

after, and near, a reducing valve in such a manner as to cut off the passage of steam, the dead end type should be used.

It is common practice, when the initial steam pressure is 100 psig or higher, to install two-stage reduction. If the radiation served is cast-iron, the ASME code requires two reducing valves when the inlet pressure exceeds 50 psig. This makes a quieter condition of steam flow, as it is apparent that with one reduction, as for example from 150 to 2 psig, there is a smaller opening with greater velocity across the reducing valve and, consequently, more noise. A two-stage reduction also introduces a source of safety, since if one reducing valve were to build up its discharge pressure, this excess pressure would not be so great as the case might be in a one-stage reduction.

If an installation requires single seated valves and the pilot type cannot be used, it is necessary to use two-stage reduction, as single seated valves require sufficient diaphragm area to overcome the unbalanced pressure underneath the single valve. In many cases the large diameter of diaphragm required would make it impractical in construction. With a two-stage reduction, the diaphragm diameter required would be reduced. If a one-stage reduction is desired, it is necessary to use a pilot controlled pressure reducing valve, where low pressures are to be maintained closely.

In making a two-stage reduction, allowance for expansion of steam on the low pressure side of the valve should be made by increasing the pipe size. This also allows steam flow to be at a more nearly uniform velocity. Separating the valves by a distance up to 20 ft is recommended to reduce excessive hunting action of the first valve.

When the reduced pressure is approximately 15 psig or lower, the weight and lever diaphragm valve gives the best results with minimum maintenance. Above 15 psig, spring loaded diaphragm valves should be used, because of the extra weights required on weight and lever type. Pressure equalizing lines should not be connected too close to the valve. They should be connected into the bottom of the reduced pressure steam main, to allow maximum condensate to exist in the equalizing lines, or the connection can be made into the top of the main if a water accumulator is used to reduce the variation of the head of water on the diaphragm.

Care should be exercised in selecting the size of a reducing valve. The safest method is to consult the manufacturer. It is essential that sizes of piping to and from the reducing valve be such that they will pass the desired amount of steam with the maximum velocity desired. A common error is to make the size of the reducing valve the same size as that of the service, or outlet pipe size. Generally, this will make the reducing valve oversized, and bring about wire-drawing of valve and seat, due to small lift of the valve seat.

On installations where the steam requirements are relatively large and variable in mild weather or reduced demand periods, wire-drawing may occur. To overcome this condition, two reducing valves are installed in parallel, with the sizes selected on a 70 and 30 percent proportion of maximum flow. For example, if 50,000 lb of steam per hour are required, the size of one valve is on the basis of  $0.7 \times 50,000$  lb, or 35,000 lb, and the other on the basis of  $0.3 \times 50,000$  lb, or 15,000 lb. During the mild or reduced demand periods, steam will flow through the smaller valve only. During the remainder of the season, the larger valve is set to control at whatever low pressure is desired, and the smaller one at a somewhat lower pressure. Thus, when steam flow is not at its maximum, the smaller valve is closed, but it opens automatically when the maximum

steam demand occurs, because this maximum demand creates a slight pressure drop in the service line.

The installation of reducing valves in pipe lines requires detailed planning. They should be installed to give ease of access for inspection and repair, and wherever possible, with diaphragm downward, except in cases of pilot operated valves.

There should be a by-pass around each reducing valve of size equal to one-half the size of reducing valve. The globe valve in by-pass line should be of a good type of construction, and must shut off absolutely tight. A steam pressure gage, graduated up to the initial pressure, should be installed on the low pressure side. Safety valves located on the low pressure side should be set 5 psi higher than the final pressure, but may be 10 psi higher than the reduced pressure if this reduced pressure is that of the first stage reduction of a double reduction. Strainers are sometimes installed on the inlet to the reducing valve, but are not required before a

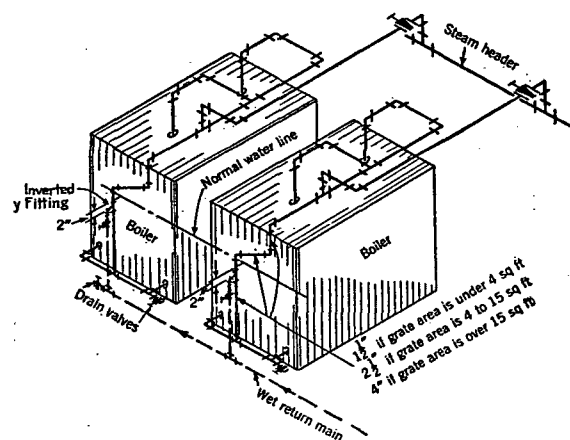


FIG. 20. THE HARTFORD RETURN CONNECTION

second-stage reduction. If a two-stage reduction is made, it is well to install a pressure gage immediately before the reducing valve of the second-stage reduction also. In sizes 3 in. and above, it is advisable to install a drip trap between the two reducing valves.

### BOILER CONNECTIONS

#### Steam

Cast-iron, sectional heating boilers usually have several outlets in the top. Two or more outlets should be used whenever possible to reduce the velocity of the steam in the vertical uptakes from the boiler, and thus to prevent carrying of water into the steam main.

#### Return

Cast-iron boilers are generally provided with return tapplings on both sides, while steel boilers are generally equipped with only one return

tapping. Where two tapplings are provided, both should be used to effect proper circulation through the boiler. The return connection should include either a Hartford return connection or a check valve to prevent the accidental loss of boiler water to the returns, with consequent danger of boiler damage. The Hartford return connection is to be preferred over the check valve, because the latter is apt to stick or not close tightly and, furthermore, because the check valve offers additional resistance to the condensate coming back to the boiler, which in gravity systems would raise the water line in the far end of the wet-return several inches.

In order to prevent the boiler from losing its water under any circumstances, the use of the Hartford return connection is recommended. This connection for a one- or two-boiler installation is shown in Fig. 20. The essential features of construction of a Hartford return connection are: (1) a direct connection (made without valves) between the steam side of the boiler and the return side of the boiler, and (2) a close nipple, or preferably an inverted Y-fitting connection about 2 in. below the normal boiler water line from the return main to the boiler steam and return pressure balance connection. Equalizing pipe connections between the steam and return are given in Fig. 20, based on grate areas, but in no case shall this pipe size be less than the main return piping from the system.

### Sizing Boiler Connections

Little information is available on the sizing of boiler runouts and steam headers. Although some engineers prefer an enlarged steam header to serve as additional steam storage space, there ordinarily is no sudden demand for steam in a steam heating system, except during the heating-up period, at which time a large steam header is a disadvantage rather than an advantage. The boiler header may be sized by first computing the maximum load that must be carried by any portion of the header under any conceivable method of operation, and then applying the same schedule of pipe sizing to the header as is used on the steam mains for the building. The horizontal runouts from the boiler, or boilers, may be sized by calculating the heaviest load that will be placed on the boiler at any time, and sizing the runouts on the same basis as the building mains. The difference in size between the vertical uptakes from the boiler, which should be of same size as the boiler outlet tapping, and the horizontal main or runout, is compensated for by the use of reducing ells.

Return connections to boilers in gravity systems are made the same size as the return main itself. Where the return is split and connected to two tapplings on the same boiler, both connections are made the full size of the return line. Where two or more boilers are in use, the return to each may be sized to carry the full amount of return for the maximum load which that boiler will be required to carry. Where two boilers are used, one of them being a spare, the full size of the return main would be carried to each boiler, but if three boilers are installed, with one spare, the return line to each boiler would require only half of the capacity of the entire system, or, if the boiler capacity were more than one-half the entire system load, the return would be sized on the basis of the maximum boiler capacity. As the return piping around the boiler is usually small and short, it should not be sized to the minimum.

With returns pumped from a vacuum or receiver return pump, the size of the line may be calculated from the water rate on the pump discharge when it is operated, and the line sized for a very small pressure drop. The relative boiler loads should be considered, as in the case of gravity

return connections. Boiler header and piping sizes should be based on the total load.

### CONDENSATE RETURN PUMPS

Condensate return pumps are used for gravity systems when the local conditions do not permit the condensate to return to the boiler under the existing static head. The return of the condensate permits the water to pass repeatedly through the cycle of vaporization, with subsequent condensation and return to the boiler. During such repeated cycles any incrustants or other substances in solution are precipitated and the water de-activated to a considerable extent, so that corrosion of a serious nature is seldom ever encountered where the condensate is repeatedly used. Serious corrosion is more frequently found in systems in which the condensate is wasted, and fresh make-up water is continually being introduced.

A generally accepted condensate pump unit for low pressure heating systems consists of a motor-driven centrifugal pump with receiver and automatic float control. Other types in use include rotary, screw, turbine and reciprocating pumps with steam turbine or motor drive, and direct-acting steam reciprocating pumps.

The receiver capacities of these automatic units should be sized so as not to cause too great a fluctuation of the boiler water line if fed directly to the boiler, and at the same time not so small as to cause too frequent operation of the unit. The usual unit provides storage capacity between stops in the receiver of approximately 1.5 times the amount of condensate returned per minute, and the pump generally has a delivery rate of 3 to 4 times the normal flow. This relation of receiver and pump size to heating system condensing capacity takes account of the peak condensation rate.

A typical installation of a motor driven automatic condensate unit is illustrated in Fig. 9.

### VACUUM HEATING PUMPS

On vacuum systems, where the returns are under a vacuum, and sub-atmospheric systems, where the supply piping, radiation and the returns are under a vacuum, it is necessary to use a vacuum pump to discharge the air and non-condensable gases to atmosphere and to dispose of the condensate. Direct-acting steam-driven reciprocating vacuum pumps are sometimes used where high pressure steam is available, or where the exhaust steam from the pump can be utilized. In general, however, these have been replaced by the automatic motor-driven return line heating pump especially developed for this service. Steam turbine drive is also frequently used where steam at suitable pressures is available, the steam being used afterward for building heating. The usual vacuum pump unit consists of a compact assembly of exhausting unit for withdrawing the air-vapor mixture and discharging the air to atmosphere, and a water removal unit which discharges the condensate to the boiler. They are furnished complete with receiver, separating tank and automatic controls mounted as an integrated unit on one base. There are also special steam turbine driven units which are operated by passing the steam to be used in heating the building through the turbine with only a 2 to 3 psi drop across the turbine required for its operation. Under special conditions such as installations where it is necessary to return the condensate to a high pressure boiler, auxiliary water pumps may be supplied. In some instances separate air and water pumps may be used.

For rating purposes<sup>3</sup> vacuum pumps are classified as *low vacuum* and *high vacuum*. Low vacuum pumps are those rated for maintaining  $5\frac{1}{2}$  in. Hg vacuum on the system, and high vacuum pumps are those rated to maintain vacuums above  $5\frac{1}{2}$  in. Hg.

Manufacturers of vacuum pumps specify that the standard capacity of pumps shall be 0.3 to 0.5 cfm of air removal, and 0.5 gpm of water per 1000 EDR served. This capacity is at  $5\frac{1}{2}$  in. Hg of vacuum, and with condensate at 160 F. The larger air capacity is for smaller systems, and the smaller capacity for the larger systems.

Some manufacturers, however, specify more air capacity than standard where higher vacuums are desired and where air leakage is anticipated.

The vacuum that can be maintained on a system depends upon the relationship of the air leakage rate into the system to the operating air capacity of the hydraulic evacuator when operating at any given return line temperature. The hotter the returns, the lower will be the possible vacuum for a given air leakage rate into the system. It is particularly essential on high vacuum installations to see that the entire system is tight in order to reduce the amount of inward air leakage and, furthermore, to see that relatively higher temperature steam is prevented from entering the vacuum return lines through leaky traps, high pressure drips, etc. It is for this reason that the condensate from equipment using steam at high pressures should not be connected directly to a vacuum return line, but should drain to a flash tank or flash leg through a high pressure trap. The receiver should have an equalizing connection to a low pressure steam main and drain through a low pressure trap to the vacuum return main, as indicated later in this chapter in section on Drips.

### Vacuum Pump Controls

In the ordinary vacuum system, the vacuum pump is controlled by a vacuum regulator which cuts in when the vacuum drops to the lowest point desired, and cuts out when it has been increased to the highest point, these points being varied to suit the particular system or operating conditions. In addition to this vacuum control, a float control is included which will start the pump whenever sufficient condensate accumulates in the receiver, regardless of the vacuum on the system. A selector switch is usually provided to allow operation at night as a condensate pump only, also to give manual or continuous operation when desired.

There are several variations in the control of the vacuum maintained on the system by the pump. In some sub-atmospheric systems where orifices are used, the vacuum pump control maintains a pressure difference between the supply and the return piping, which is held within relatively close limits. There are other sub-atmospheric systems which utilize special temperature-pressure actuated controls for maintaining the desired conditions in the return lines. Where various zones are connected to the same return main, the return vacuum must be controlled to meet the requirements of the zone operating at the lowest steam supply pressure.

### Piston Displacement Vacuum Pumps

Piston displacement return vacuum heating pumps may be either electric or steam driven. Their piston speed in feet per minute should not exceed 20 times the square root of the number of inches in their stroke. They are usually supplied with an air separating tank, open to atmosphere, placed on the discharge side of the pump, and at an elevation sufficiently

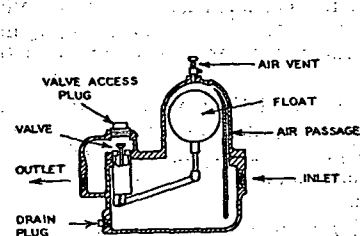


FIG. 21. SINGLE PORT FLOAT TRAP

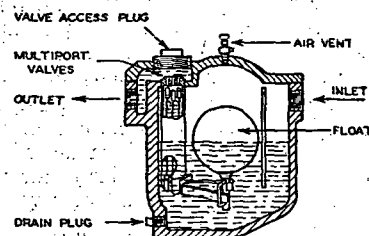


FIG. 22. MULTIPORT FLOAT TRAP

high to allow gravity flow of the condensate to the boiler. If the boiler pressure is too high for such gravity feed, then an additional steam pump for feeding the boiler is desirable. The extra pump is sometimes avoided by using a closed separating tank with a float controlled vent. In both arrangements, the air taken from the system must be discharged against the full discharge pressure of the vacuum pump. In the case of high or medium pressure boilers, it is better to use the atmospheric separator and the second pump.

In figuring the required displacement for such pumps, a value of from 6 to 10 times the volumetric flow of condensate is used for average vacuums and systems.

### STEAM TRAPS

Steam traps, as the name implies, are automatic devices used to trap or hold steam in an apparatus or piping system until it has given up its latent heat, and to allow condensate and air to pass as soon as it accumulates. In general, traps consist of a vessel in which to accumulate the condensate, an orifice through which the condensate is discharged, a valve to close the orifice port, mechanisms to operate the valve, and inlet and outlet openings for the entrance and discharge of the condensate from the trap vessel.

Steam traps are classified according to the type of operating device by which they function. The traps which are available on the market today may be classified as (1) float, (2) thermostatic, (3) float and thermostatic, (4) upright bucket, (5) inverted bucket, (6) flash, (7) impulse, (8) tilting, (9) lifting, and (10) boiler return trap or alternating receiver.

**Float Traps.** Float traps operate by the rise and fall of a float due to a change of condensate level in the trap. When the trap is empty, the float is in its lowest position and the discharge valve is closed. As condensate accumulates in the trap

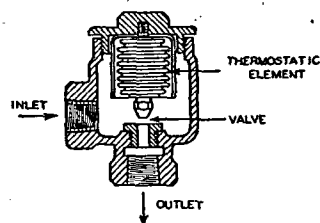


FIG. 23. THERMOSTATIC TRAP BELLows TYPE

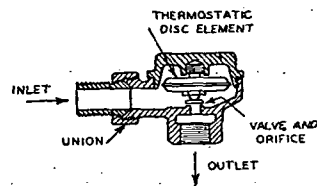


FIG. 24. THERMOSTATIC TRAP DISC TYPE

### Steam Heating Systems

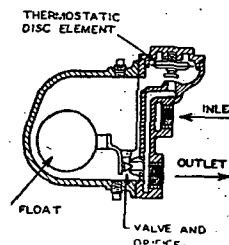


FIG. 25. TYPICAL FLOAT AND THERMOSTATIC TRAP

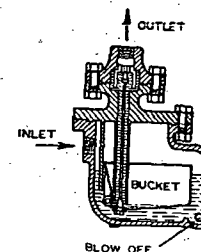


FIG. 26. UPRIGHT BUCKET TRAP

chamber, the float rises and gradually opens the valve, and the pressure of the steam pushes the condensate out of the valve. The discharge from a float trap is generally continuous, since the opening of the valve is proportioned to the flow of condensate through the trap. A gage glass may be used to indicate the height of condensate in the trap chamber. Unless float traps are well made and proportioned, there is danger of considerable steam leakage through the discharge valve due to unequal expansion of the valve and seat, and the sticking of moving parts. Float traps are made in sizes from  $\frac{1}{4}$  to 3 in., and for pressures varying from vacuum conditions to 200 psig. Float traps are used for draining condensate from steam separators, steam headers, blast coils, heating systems, steam water heaters, laundry equipment, sterilizers, and other equipment. When used for draining low pressure systems, float traps should be equipped with a thermostatic air vent (See Float and Thermostatic Traps). Figs 21 and 22 illustrate types of float traps which are in use at the present time.

**Thermostatic Traps.** Thermostatic traps function by means of elements which expand and contract under the influence of heat and cold. Early types of thermostatic traps employed carbon posts and bi-metallic elements for expansion. In general, the modern type of thermostatic trap consists of thin corrugated metal bellows or discs enclosing a hollow chamber. The chamber is either filled with a liquid, or a small amount of a volatile liquid, such as alcohol, is introduced. The liquid expands or becomes a gas when steam comes in contact with the expansive element. The pressure created in either case expands the element and closes the valve of the trap against the escape of steam. When condensate or air comes in contact with the element, it cools and contracts, opening the valve and allowing them to escape.

The discharge from this type of trap is intermittent. Thermostatic traps find their use generally for the draining of condensate from radiators, convectors, pipe coils, drips, unit heaters, water heaters, cooking kettles, and other equipment. Except for radiators and convectors, it is recommended that a strainer be installed on the inlet connection to the trap to prevent dirt, pipe scale, and other foreign substance from entering the trap. A cooling leg of a length of pipe should also be provided ahead of the trap on unit heaters and similar apparatus to cool the condensate in order to help in the trap action. Thermostatic traps are made in sizes from  $\frac{1}{4}$

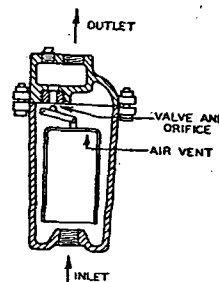


FIG. 27. INVERTED BUCKET TRAP

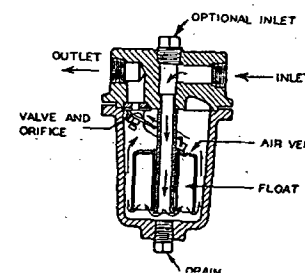


FIG. 28. INVERTED BUCKET TRAP WITH CENTRAL GUIDE

to 2 in., and for pressures ranging from vacuum conditions to 300 psig. Figs. 23 and 24 illustrate types of thermostatic traps which are available at the present time.

**Float and Thermostatic Traps.** This type of trap is a combination of the float trap and the thermostatic trap, and finds its use in the draining of condensate from unit heaters, blast heaters, and coil heaters for water, oil or other liquids where there is apt to be a large volume of condensate which would not permit successful operation of thermostatic traps alone. The function of the float element of this trap is to handle the condensate, and of the thermostatic element to permit the flow of air and to prevent the flow of steam around the float valve. Float and thermostatic traps are made in sizes from  $\frac{1}{4}$  to 2 in. and usually operate under pressures varying from vacuum conditions to 40 psig, although some are made to operate at a maximum pressure of 200 psig. Fig. 25 illustrates a typical float and thermostatic trap.

**Upright Bucket Traps.** In this type of trap, the condensate enters the trap chamber and fills the space between the bucket and the walls of the trap. This causes the bucket to float, and forces the valve against its seat, the valve and its stem usually being fastened to the bucket. When the condensate in the chamber rises above the edges of the bucket, it overflows into it and causes the bucket to sink, thereby withdrawing the valve from its seat. This permits the steam pressure acting on the surface of condensate in the bucket to force the water to the discharge opening. When the bucket is emptied, it rises and closes the valve and another cycle begins. The discharge from this type of trap is intermittent, and it requires a definite differential pressure (usually 1 psi at least) between the inlet and outlet of the trap in order to

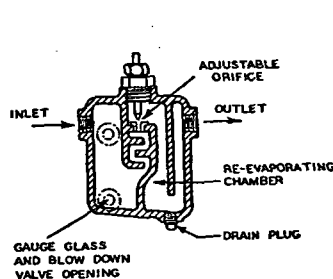


FIG. 29. FLASH TRAP

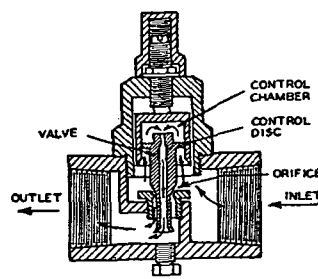


FIG. 30. IMPULSE TRAP

lift the condensate out of the bucket to the return opening. Upright bucket traps are used for draining condensate and air from blast coils, unit heaters, steam mains, laundry equipment, sterilizers, water and oil heaters and other equipment. This type of trap is particularly suited for use where there are pulsating pressures, such as draining steam lines and separators to reciprocating pumps or engines. It is not influenced by pulsations or wide fluctuations of pressure. Upright bucket traps are obtainable in sizes varying from  $\frac{1}{4}$  to 2 in., and for pressures varying from vacuum to 1200 psig. Fig. 26 illustrates an upright bucket trap.

**Inverted Bucket Traps.** In this type of trap, steam, condensate and air enter the trap under the bell or inverted bucket. Steam floats the inverted bucket and closes the valve. Condensate entering the trap enables the inverted bucket to fall, opening the valve. The condensate then discharges through the open valve until steam again enters and displaces the water contained in the bucket, thus restoring its buoyancy. The steam pressure entering through the open valve discharges the trap. Air is eliminated automatically by passing through the small vent hole located in the top of the inverted bucket. Inverted bucket traps for use on low pressure systems, particularly with blast coils or unit heaters, are usually furnished with a large capacity opening equipped with a bi-metallic thermostatic element which closes when heated by steam, and opens when cooled by air and condensate, allowing air to escape from the inverted bucket to the trap outlet. Inverted bucket traps are used for draining condensate and air from blast coils, unit heaters, steam drips, laundry equipment, sterilizers, steam water heaters and other equipment. They are particularly suited for draining condensate from steam lines or equipment where abnormal amounts of air must be discharged, and where there is also foreign matter such as dirt, sludge and oil draining to the trap. The discharge from inverted bucket traps, like that of the upright bucket traps, is intermittent and requires a definite differential pressure between the inlet and the outlet of the trap in order to lift the condensate from the

bottom of the trap to the outlet of same. Inverted bucket traps are made in sizes from  $\frac{1}{4}$  to 3 in., and for pressures varying from vacuum to 2400 psig. Figs. 27 and 28 illustrate some of the types of inverted bucket traps which are available on the market at the present time.

**Flash Traps.** These traps depend on the property of condensate at a high pressure and temperature to flash into steam at a lower pressure. Condensate flows freely through the orifice of the trap due to the pressure difference from inlet to outlet of trap until steam enters the inlet chamber and mixes with the remaining condensate, heating the condensate and causing it to flash, thereby choking the flow through the orifice and allowing more condensate to accumulate in the trap. The discharge from flash type traps is intermittent. There are no moving parts in this type of trap. The orifice, however, is adjustable for the pressure differential required. A gage glass or float indicates whether the trap is operating. These traps can be used for draining condensate from steam water and oil heaters, blast heaters, unit heaters, dryers, vulcanizers, kitchen equipment, laundry equipment, evaporators, steam lines and other equipment, where the pressure differential between steam supply and condensate return does not drop below 5 psi. Flash type traps are made in sizes from  $\frac{1}{4}$  to 3 in., and for pressures varying from vacuum to 450 psig. Fig. 29 illustrates a trap of the flash type.

**Impulse Traps.** These traps are a modification of the flash trap, and depend on the same principle of flash for their operation. In the impulse trap the flashing action

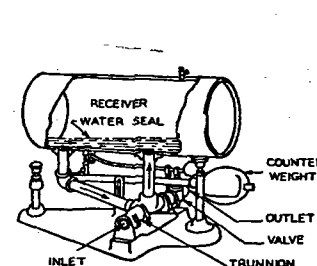


FIG. 31. TILTING TRAP

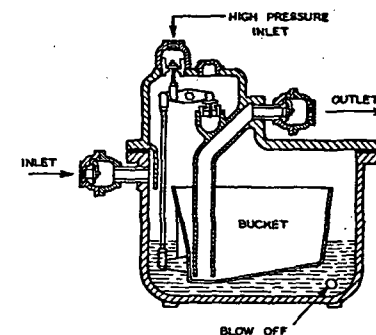


FIG. 32. LIFTING TRAP

is utilized to govern the movement of a valve by causing changes in pressure in a control chamber above the valve. A small portion of condensate, called control flow, by-passes continuously through the control chamber. At low and medium temperatures, the discharge through the center orifice reduces control chamber pressure, and the valve opens for free discharge of air and condensate.

When condensate reaches near-steam temperature, part of the control flow flashes into vapor, due to reduced pressure in control chamber. The increased volume of the condensate-vapor mixture restricts the discharge through the center orifice, and therefore the reduced pressure in control chamber builds up, closes the valve, and shuts off all discharge of hot condensate, except the small amount flowing through center orifice.

Under normal condensate loads, the valve opens and closes at short intervals. Under heavy loads, the valve opens wide and the discharge is heavy and continuous. Impulse traps can be used for draining condensate from steam mains, unit heaters, laundry equipment, kitchen equipment, oil and water heaters, sterilizers, and other equipment where the pressure at the trap outlet is 25 percent or less than that of the inlet pressure. Impulse traps are made in sizes from  $\frac{1}{4}$  to 2 in., and for pressures ranging from one to 600 psig. Fig. 30 illustrates a trap of the impulse type.

**Tilting Traps.** This type of trap as the name implies depends for its operation on the tilting of the trap receiver. When the receiver is in a horizontal position condensate accumulates until the weight of condensate overbalances that of a counterweight, when the receiver tilts. The tilting action opens the discharge valve, and steam pressure pushes the condensate out of the open discharge valve. When the receiver tank is emptied, except for a slight water seal, the receiver drops back to its

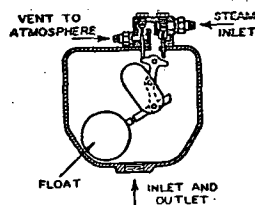


FIG. 33. BOILER RETURN TRAP OR ALTERNATING RECEIVER

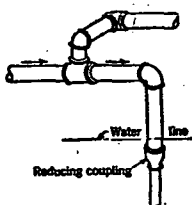


FIG. 34. DRIPPING MAIN WHERE IT RISES TO HIGHER LEVEL

horizontal position and closes the discharge valve, and is again in position to accumulate condensate.

Tilting traps are necessarily intermittent in operation, except that once the trap is in the discharge position, it will discharge condensate continuously as long as the flow of condensate is sufficient to overcome the balance of the counterweight.

This type of trap employs packing around the trunnion and valve stem in order to prevent the loss of steam and condensate. Tilting traps are used for draining laundry and dry cleaning equipment, steam cookers, drips from steam mains, steam separators and purifiers and other equipment. They are made in sizes from 1 to 3 in., and for pressures varying from 0 to 250 psig. Fig. 31 illustrates a type of tilting trap which is in use at the present time.

**Lifting Traps.** This type of trap is an adaptation of the upright bucket trap. It has the added feature of an auxiliary pressure inlet through which steam is introduced at a pressure higher than that of the trap inlet pressure. This high pressure steam forces the condensate to a point above the trap, and against a back pressure higher than that which is possible with normal steam pressure. Lifting traps are made in sizes from one to 3 in., and for pressures ranging from vacuum to 150 psig. Fig. 32 illustrates a trap of the lifting type.

**Boiler Return Trap or Alternating Receiver.** This device is not actually a steam trap in that it is not used to trap or hold steam, but is an adaptation of the lifting trap. It is used for returning condensate to a low pressure boiler, when due to excess pressure, the condensate cannot flow to the boiler by gravity without flooding the return mains, and endangering the boiler by permitting it to go dry. The boiler return trap is a vessel into which condensate alternately collects and is discharged into the boiler by boiler steam pressure. These traps are available in sizes from 1½ to 2½ in., and for pressures varying from 0 to 100 psig. A typical boiler return trap is shown in Fig. 33, and a typical connection to a low pressure heating system is indicated in Fig. 13.

### Steam Trap Installations

The following general rules should govern the installation of traps of all types:

1. A vertical drip as long as possible and a strainer should be installed between the trap and the apparatus it drains. Exceptions to this rule are the installation of ther-

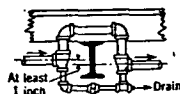


FIG. 35. LOOPING MAIN AROUND BEAM

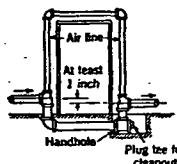


FIG. 36. LOOPING DRY RETURN MAIN AROUND OPENING

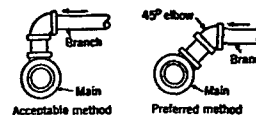


FIG. 37. METHODS OF TAKING BRANCH FROM MAIN

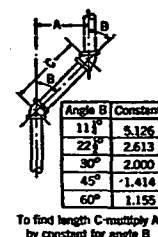


FIG. 38. CONSTANTS FOR DETERMINING LENGTH OF OFFSET PIPE

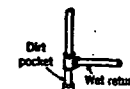


FIG. 39. DIRT POCKET CONNECTION

mostatic traps in radiators, convectors and pipe coils. These, in general, are attached directly to the units without strainers.

2. Whenever it is necessary to maintain in continuous service, apparatus which is to be drained, it is advisable to install a gate valve on each side of the trap, and a valved by-pass around the trap, so that the trap may be removed and repaired and condensate drained through the throttled by-pass valve.

3. Whenever it is necessary to install traps for lift service, as when the condensate must be discharged to a main located above the trap or where the trap must discharge against a definite back pressure, a check valve and a gate valve should be installed on the discharge side of the trap, the check valve to prevent continuous pressure on the discharge side of the valve, and the gate valve to shut off pressure in case the trap is removed for service or repair.

### DRIPS

A steam main in any type of steam heating system may be dropped to a lower level without dripping if the pitch is downward with the direction of steam flow. Any steam main in any heating system can be elevated if dripped. Fig. 34 shows a connection where the steam main is raised and is drained to a wet-return. If the elevation of the low point is above a dry-return, it may be drained through a trap to the dry-return in two-pipe vapor, vacuum and sub-atmospheric systems. Horizontal steam pipes may also be run over obstructions without a change in level, if a small pipe is carried below the obstruction to care for the condensate (Fig. 35). Horizontal return pipes may be carried past doorways and other obstructions by using the scheme illustrated in Fig. 36. It will be noted that the large pipe, in this case, runs below the obstruction, and the smaller one over it.

Branches from steam mains in one-pipe gravity steam systems should use the *preferred connection* shown in Fig. 37, but where radiator condensate does not flow back into the main, the *acceptable method* shown in the same figure may be used. This acceptable method has the advantage of

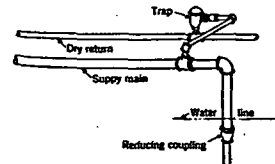


FIG. 40. DRIPPING END OF MAIN INTO WET RETURN

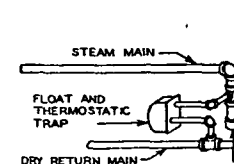


FIG. 41. DRIPPING END OF STEAM MAIN INTO DRY RETURN

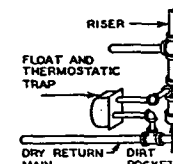


FIG. 42. DRIPPING HEEL OF RISER INTO DRY RETURN



giving a perfect swing joint when connected to the vertical riser or radiator connection, whereas the preferred connection does not give this swing without distorting the angle of the pipe. Runouts are usually made about 5 ft long to provide flexibility for movement in the main.

Offsets in steam and return piping should preferably be made with 90-deg ells, but occasionally fittings of other angles are used, and in such cases the length of the diagonal offset will be found as shown in Fig. 38.

Dirt pockets, desirable on all systems employing thermostatic traps, should be so located as to protect the traps from scale and sludge which

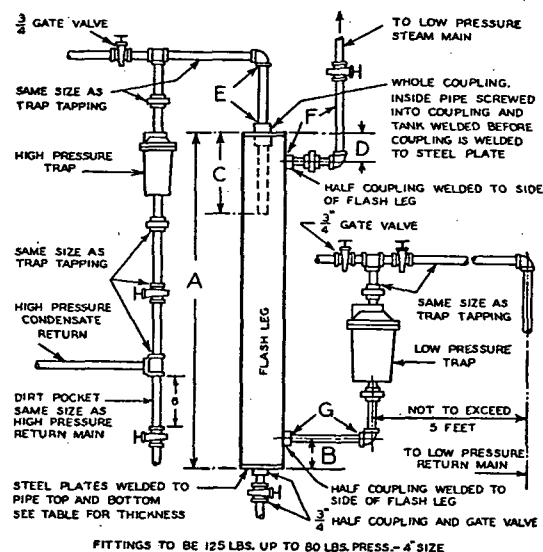


FIG. 43. FLASH LEG INSTALLATION FOR 80 PSI MAXIMUM STEAM WORKING PRESSURE

TABLE 13. DIMENSIONS APPLYING TO FIG. 43

| CON-<br>DENSATE<br>PER HR.,<br>LB AT 70<br>PSI | TRAPS          |                |                     |                |                |                     | FLASH<br>LEG,<br>IPS | A<br>FT. | B<br>IN. | C<br>IN. | D<br>IN. | E<br>IN.       | F<br>IN.       | G<br>IN.      | PLATE<br>THICK-<br>NESS<br>IN. |
|------------------------------------------------|----------------|----------------|---------------------|----------------|----------------|---------------------|----------------------|----------|----------|----------|----------|----------------|----------------|---------------|--------------------------------|
|                                                | HP SIDE        |                |                     | LP SIDE        |                |                     |                      |          |          |          |          |                |                |               |                                |
|                                                | Pipe Size      | Orifice        | Pres. Range,<br>PSI | Pipe Size      | Orifice        | Pres. Range,<br>PSI |                      |          |          |          |          |                |                |               |                                |
| 200                                            | $\frac{1}{2}$  | $\frac{1}{8}$  | 21-80               | $\frac{1}{2}$  | $\frac{1}{8}$  | 0-20                | 4                    | 3        | 6        | 8        | 3        | $\frac{3}{4}$  | $\frac{1}{2}$  | $\frac{3}{4}$ | $\frac{1}{4}$                  |
| 300                                            | $\frac{3}{4}$  | $\frac{1}{4}$  | 31-70               | $\frac{3}{4}$  | $\frac{1}{4}$  | 0-15                | 4                    | 3        | 6        | 8        | 3        | $\frac{1}{2}$  | $\frac{1}{2}$  | $\frac{3}{4}$ | $\frac{1}{4}$                  |
| 700                                            | 1              | $\frac{1}{2}$  | 31-70               | 1              | $\frac{1}{2}$  | 0-15                | 4                    | 3        | 6        | 8        | 3        | $\frac{1}{2}$  | $\frac{1}{2}$  | $\frac{3}{4}$ | $\frac{1}{4}$                  |
| 1500                                           | $1\frac{1}{2}$ | $\frac{3}{4}$  | 61-80               | $1\frac{1}{2}$ | $\frac{3}{4}$  | 0-15                | 5                    | 4        | 6        | 10       | 4        | $\frac{1}{2}$  | $\frac{1}{2}$  | $\frac{3}{4}$ | $\frac{1}{4}$                  |
| 2500                                           | 2              | 1              | 61-80               | 2              | 1              | 0-15                | 8                    | 5        | 6        | 10       | 4        | 1              | 2              | $\frac{1}{2}$ | $\frac{1}{4}$                  |
| 4000                                           | $2\frac{1}{2}$ | $1\frac{1}{4}$ | 61-80               | $2\frac{1}{2}$ | $1\frac{1}{4}$ | 0-15                | 10                   | 6        | 6        | 12       | 5        | $1\frac{1}{4}$ | $2\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{4}$                  |
| 8000                                           | 3              | $1\frac{1}{2}$ | 61-80               | 3              | $1\frac{1}{2}$ | 0-15                | 12                   | 6        | 6        | 12       | 5        | 2              | 3              | 2             | $\frac{1}{4}$                  |
| 15000                                          | $3\frac{1}{2}$ | $1\frac{3}{4}$ | 61-80               | $3\frac{1}{2}$ | $1\frac{3}{4}$ | 0-15                | 16                   | 6        | 8        | 14       | 6        | 3              | 3              | 3             | $\frac{1}{4}$                  |

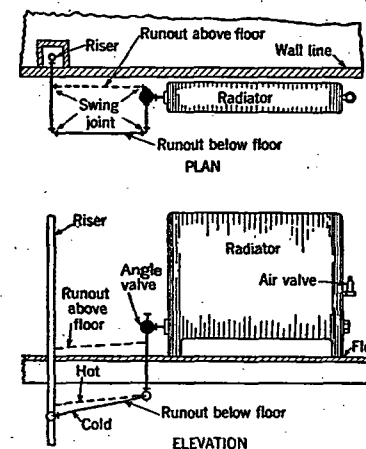


FIG. 44. ONE-PIPE RADIATOR CONNECTIONS

will interfere with their operation. Dirt pockets are usually made 8 in. to 12 in. deep, and serve as receivers for foreign matter which otherwise would be carried into the trap. They are constructed as shown in Fig. 39.

On vapor systems where the end of the steam main is dripped down into the wet-return, the air venting at the end of the main is accomplished by an air vent passing through a thermostatic trap into the dry-return line as shown in Fig. 40. On low pressure or vacuum systems, the ends of the steam mains are dripped and vented into the return through drip traps opening into the return line. A float and thermostatic type trap is recommended for dripping steam mains and risers as indicated in Figs. 41 and 42.

The dripping of high pressure mains, or of equipment using high pressure steam into low pressure or vacuum returns, is generally accomplished by the use of a flash tank or flash leg into which the high pressure trap is arranged to discharge. This tank provides the required space for the flashing from high temperature condensate to low pressure steam to take place. The low pressure steam therein generated is passed directly to the low pressure steam mains, and the condensate is discharged through a second trap to the

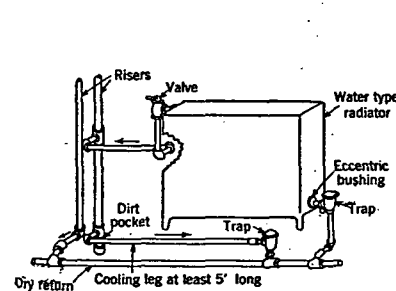


FIG. 45. TWO-PIPE TOP AND BOTTOM OPPOSITE END RADIATOR CONNECTIONS

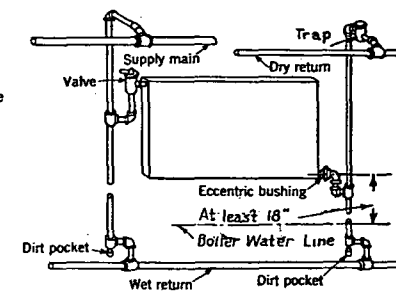


FIG. 46. TWO-PIPE CONNECTIONS TO RADIATOR HUNG ON WALL



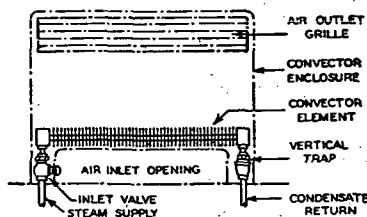


FIG. 47. TYPICAL CONVECTOR CONNECTIONS

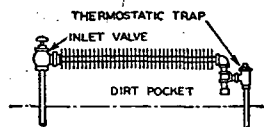


FIG. 48. TYPICAL CONNECTIONS TO FINNED PIPE CONVECTOR

low pressure or vacuum return. A typical arrangement of a flash leg, with sizes required for varying capacities, is given in Fig. 43.

### CONNECTIONS TO HEATING UNITS

Riser, radiator and convector connections must not only be properly pitched at the time they are installed, but must be arranged so that the pitch will be maintained under the strains of expansion and contraction. These connections may be made by swing joints which permit the expansion or contraction to occur under heating and cooling without bending of pipes. To take care of expansion in long risers, either expansion joints of commercial construction or pipe swing joints are used. Anchoring of pipes between expansion joints is desirable.

Two satisfactory methods of making runouts for one-pipe systems for either the up-feed or the down-feed type are shown in Fig. 44. Where the vertical distance is limited and the runouts must run above the floor, the radiator may be set on pedestals or raised by means of high legs. A method of connecting a unit heater to a one-pipe steam heating system is illustrated in Fig. 2.

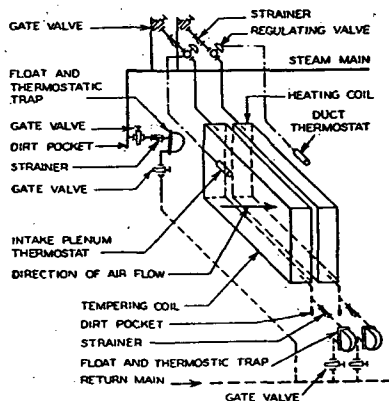


FIG. 49. TYPICAL CONNECTIONS TO FINNED TUBE BLAST HEATING COILS ARRANGED FOR SERIES FLOW OF AIR

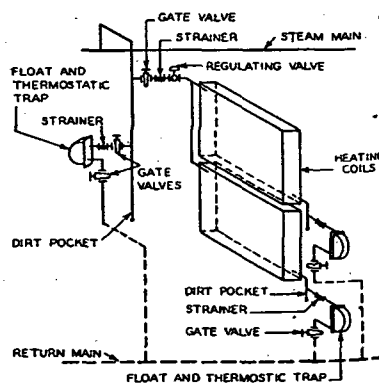


FIG. 50. TYPICAL CONNECTIONS TO FINNED TUBE BLAST HEATING COILS ARRANGED FOR PARALLEL FLOW OF AIR

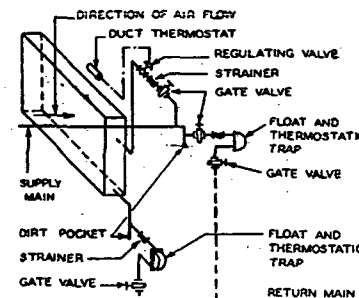


FIG. 51. TYPICAL CONNECTIONS TO FINNED TUBE BLAST HEATING COILS OF THE STEAM DISTRIBUTING OR NON-FREEZE TYPE

Typical two-pipe radiator connections are shown in Figs. 45 and 46. While these show top inlet supply connections which are preferred, it is also possible to connect the supply to the bottom of the radiator. Short radiators may be connected with top supply and bottom return on the same end.

A typical method of connecting convectors is shown in Fig. 47. Sometimes the supply valve is omitted on convector connections, and a damper is supplied in the outlet grille for heat control.

A typical connection for finned pipe convectors is shown in Fig. 48.

Typical connections to blast heaters are shown in Figs. 49, 50, and 51. Fig. 52 shows a typical return and connection for blast heaters connected to high pressure systems.

A typical two-pipe connection to a unit heater is indicated in Fig. 53.

### CONTROL VALVES

Gate valves are recommended in all cases where service demands that the valve be either entirely open or entirely closed, but they should never

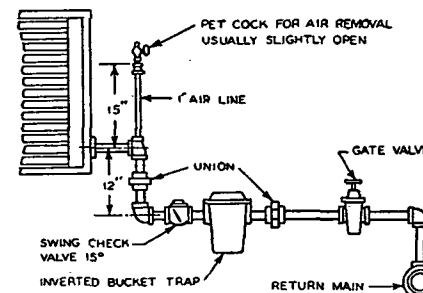


FIG. 52. TYPICAL RETURN CONNECTIONS TO FINNED TUBE BLAST HEATERS WITH HIGH PRESSURE STEAM

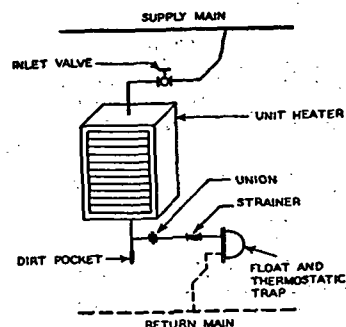


FIG. 53. TYPICAL UNIT HEATER CONNECTIONS FOR TWO-PIPE SYSTEM

be used for throttling. Angle globe valves and straight globe valves should be used for throttling in such cases as by-passes around pressure reducing valves or on by-passes around traps.

#### REFERENCES

<sup>1</sup> A.S.H.V.E. RESEARCH REPORT No. 954—Condensate and Air Return in Steam Heating Systems, by F. C. Houghten and J. L. Blackshaw (A.S.H.V.E. TRANSACTIONS, Vol. 39, 1933, p. 199).

<sup>2</sup> Pipe size tables in this chapter have been compiled in simplified and condensed form for the convenience of the user; at the same time all of the information contained in previous editions of THE GUIDE has been retained.

<sup>3</sup> A.S.H.V.E. Standard Code for Testing and Rating Return Line Low Vacuum Heating Pumps (A.S.H.V.E. TRANSACTIONS, Vol. 40, 1934, p. 33).

#### CHAPTER 22

### HOT WATER HEATING SYSTEMS

Available Head; Friction Loss; Classification; System Design; Examples of Piping Design; One-Pipe Gravity, One-Pipe Forced Circulation, Two-Pipe Gravity, and Two-Pipe Forced Circulation Systems, Expansion Tanks, Installation Details, Zoning of Systems, High Temperature Systems

A HEATING system is called a hot water system if water is used to convey heat by flowing through pipes connecting a boiler or water heater with radiators, convectors or other suitable heat dispensing means. There are two types: the gravity system in which the water flows by virtue of thermo-syphon action, and the forced system in which a pump, usually driven by an electric motor, sometimes by a steam turbine or other means, maintains the necessary flow. Most panel heating systems (see Chapter 24) fall into the category of forced hot water systems, and the design procedures pertaining to pipe sizing and friction contained in this chapter are largely applicable to such systems.

Historically, the gravity system is much the older, and many such systems have been in satisfactory operation for several decades. Operation depends on the difference in density of the water due to difference in temperature in the flow and return pipes. The available head is therefore limited, and the pipes must be ample in size to permit adequate flow of water. In the forced system, the pipes, valves and fittings can be much smaller, with a resultant saving in the cost of installation, since the available head is limited only by consideration of economy in pumping the water. With the forced system, higher boiler temperatures and automatic control of the pump or circulator make possible the use of indirect water heaters with hot water systems when that is desirable. (See Chapter 49.)

#### AVAILABLE CIRCULATION HEAD

The available head in a gravity circulation system may be found from the equation:

$$h_a = \frac{\rho_2 - \rho_1}{144} \times 2.31 \times 12,000 \quad (1)$$

where

$h_a$  = available head per foot of height, milinches (1 milinch = 1/1000 of 1 in of water).

$\rho_1$  = average density of flow water, pounds per cubic foot.

$\rho_2$  = average density of return, pounds per cubic foot.

144 = square inches per square foot.

2.31 = height of water column equivalent to 1 psi, feet.

12,000 = milinches equivalent of 1 ft of water column.

The available head may also be found from Fig. 1. For example, at a flow temperature of 200 F and a 35 deg drop, and with the mains located 4 ft above the center line of the boiler, the available head is 600 milinches. This is found by following the 200 F flow riser line in Fig. 1 to its intersection with the 165 F return riser line, and then reading, horizontally, a head



TABLE 2. HEAT-CARRYING CAPACITY OF STANDARD BLACK PIPES  
WITH TEMPERATURE DROP OF 20 DEG\*Nominal Pipe Sizes  $\frac{3}{8}$  in. to 12 in., and Friction 4 to 800 milinches per foot (A = Capacity, Mbh. B = Velocity, inches per second) (One milinch equals 0.001 in.)

| MILINCH FRICTION LOSS PER FOOT OF PIPE |   | NOMINAL PIPE SIZE, INCHES |               |               |      |                 |                 |      |                 |      |                 |      |      |       |       |       |       |
|----------------------------------------|---|---------------------------|---------------|---------------|------|-----------------|-----------------|------|-----------------|------|-----------------|------|------|-------|-------|-------|-------|
|                                        |   | $\frac{3}{8}$             | $\frac{1}{2}$ | $\frac{3}{4}$ | 1    | 1 $\frac{1}{4}$ | 1 $\frac{1}{2}$ | 2    | 2 $\frac{1}{2}$ | 3    | 3 $\frac{1}{2}$ | 4    | 5    | 6     | 8     | 10    | 12    |
| 4                                      | A | 0.75                      | 1.35          | 2.85          | 5.4  | 11.3            | 17.0            | 33.0 | 63.1            | 95   | 141             | 197  | 363  | 596   | 1250  | 2320  | 3730  |
|                                        | B | 1.5                       | 1.7           | 2.1           | 2.4  | 2.9             | 3.2             | 3.8  | 4.3             | 5.0  | 5.5             | 6.0  | 7.0  | 7.9   | 9.6   | 11    | 12    |
| 6                                      | A | 0.9                       | 1.7           | 3.6           | 6.75 | 14.0            | 21.2            | 41.3 | 66.4            | 119  | 176             | 248  | 456  | 748   | 1570  | 2920  | 4690  |
|                                        | B | 1.8                       | 2.1           | 2.6           | 3.0  | 3.6             | 4.0             | 4.7  | 5.3             | 6.2  | 6.9             | 7.5  | 8.8  | 10    | 12    | 14    | 16    |
| 8                                      | A | 1.05                      | 2.0           | 4.2           | 7.9  | 16.4            | 24.8            | 48.4 | 77.9            | 140  | 207             | 291  | 535  | 879   | 1850  | 3440  | 5530  |
|                                        | B | 2.1                       | 2.5           | 3.0           | 3.5  | 4.2             | 4.7             | 5.6  | 6.3             | 7.3  | 8.0             | 8.8  | 10   | 12    | 14    | 17    | 19    |
| 10                                     | A | 1.2                       | 2.2           | 4.7           | 8.9  | 18.6            | 28.0            | 54.7 | 88.1            | 158  | 234             | 329  | 605  | 997   | 2100  | 3910  | 6270  |
|                                        | B | 2.4                       | 2.8           | 3.4           | 4.0  | 4.8             | 5.3             | 6.3  | 7.1             | 8.2  | 9.1             | 9.9  | 12   | 13    | 16    | 19    | 21    |
| 12                                     | A | 1.35                      | 2.45          | 5.2           | 9.8  | 20.5            | 31.0            | 60.4 | 97.4            | 175  | 259             | 364  | 671  | 1100  | 2320  | 4330  | 6950  |
|                                        | B | 2.7                       | 3.1           | 3.7           | 4.4  | 5.3             | 5.9             | 6.9  | 7.8             | 9.1  | 10              | 11   | 13   | 15    | 18    | 21    | 24    |
| 14                                     | A | 1.45                      | 2.65          | 5.65          | 10.7 | 22.3            | 33.7            | 65.8 | 106             | 190  | 282             | 397  | 731  | 1200  | 2530  | 4730  | 7590  |
|                                        | B | 2.9                       | 3.4           | 4.1           | 4.8  | 5.7             | 6.4             | 7.6  | 8.5             | 9.9  | 11              | 12   | 14   | 16    | 20    | 23    | 26    |
| 16                                     | A | 1.55                      | 2.85          | 6.05          | 11.5 | 24.0            | 36.3            | 70.8 | 114             | 205  | 303             | 428  | 787  | 1300  | 2730  | 5100  | 8190  |
|                                        | B | 3.1                       | 3.6           | 4.4           | 5.1  | 6.2             | 6.9             | 8.1  | 9.7             | 11   | 12              | 13   | 15   | 17    | 21    | 25    | 28    |
| 20                                     | A | 1.75                      | 3.25          | 6.85          | 13.0 | 27.1            | 41.0            | 80.0 | 129             | 232  | 344             | 484  | 892  | 1470  | 3100  | 5790  | 9300  |
|                                        | B | 3.5                       | 4.1           | 4.9           | 5.8  | 7.0             | 7.7             | 9.2  | 10              | 12   | 13              | 15   | 17   | 20    | 24    | 28    | 32    |
| 25                                     | A | 2.0                       | 3.65          | 7.75          | 14.7 | 30.6            | 46.3            | 90.5 | 148             | 263  | 389             | 548  | 1010 | 1670  | 3510  | 6570  | 10560 |
|                                        | B | 4.0                       | 4.6           | 5.6           | 6.5  | 7.9             | 8.8             | 10   | 12              | 14   | 15              | 17   | 19   | 22    | 27    | 32    | 36    |
| 30                                     | A | 2.2                       | 4.0           | 8.55          | 16.2 | 33.8            | 51.2            | 100  | 162             | 290  | 430             | 607  | 1120 | 1850  | 3900  | 7280  | 11710 |
|                                        | B | 4.4                       | 5.1           | 6.1           | 7.2  | 8.7             | 9.7             | 11   | 13              | 15   | 17              | 18   | 22   | 25    | 30    | 35    | 40    |
| 35                                     | A | 2.35                      | 4.4           | 9.3           | 17.6 | 36.8            | 55.7            | 109  | 176             | 316  | 469             | 661  | 1220 | 2010  | 4250  | 7940  | 12780 |
|                                        | B | 4.7                       | 5.5           | 6.7           | 7.9  | 9.5             | 11              | 13   | 14              | 16   | 18              | 20   | 23   | 27    | 33    | 39    | 44    |
| 40                                     | A | 2.55                      | 4.7           | 10.0          | 18.9 | 39.8            | 59.9            | 117  | 189             | 341  | 505             | 712  | 1320 | 2170  | 4580  | 8570  | 13780 |
|                                        | B | 5.1                       | 5.9           | 7.2           | 8.4  | 10              | 11              | 13   | 15              | 18   | 20              | 22   | 25   | 29    | 35    | 42    | 47    |
| 50                                     | A | 2.85                      | 5.3           | 11.3          | 21.4 | 44.7            | 67.7            | 133  | 214             | 386  | 572             | 807  | 1490 | 2460  | 5190  | 9720  | 15650 |
|                                        | B | 5.7                       | 6.7           | 8.1           | 9.5  | 12              | 13              | 15   | 17              | 20   | 22              | 24   | 29   | 33    | 40    | 47    | 54    |
| 60                                     | A | 3.15                      | 5.85          | 12.4          | 23.6 | 49.4            | 74.9            | 147  | 238             | 427  | 633             | 893  | 1650 | 2730  | 5760  | 10780 | 17380 |
|                                        | B | 6.3                       | 7.4           | 8.9           | 11   | 13              | 14              | 17   | 19              | 22   | 25              | 27   | 32   | 36    | 44    | 52    | 60    |
| 70                                     | A | 3.45                      | 6.35          | 13.5          | 25.7 | 53.8            | 81.4            | 160  | 258             | 465  | 690             | 973  | 1800 | 2970  | 6380  | 11760 | 18950 |
|                                        | B | 6.9                       | 8.0           | 9.7           | 11   | 14              | 15              | 18   | 21              | 24   | 27              | 29   | 35   | 40    | 48    | 57    | 65    |
| 80                                     | A | 3.7                       | 6.8           | 14.5          | 27.6 | 57.9            | 87.6            | 172  | 278             | 500  | 743             | 1050 | 1940 | 3200  | 6770  | 12690 | 20440 |
|                                        | B | 7.4                       | 8.6           | 10            | 12   | 15              | 17              | 20   | 22              | 26   | 29              | 32   | 37   | 43    | 52    | 62    | 70    |
| 100                                    | A | 4.15                      | 7.7           | 16.4          | 31.1 | 65.4            | 99.0            | 194  | 314             | 566  | 840             | 1190 | 2200 | 3630  | 7680  | 14400 | 23200 |
|                                        | B | 8.3                       | 9.7           | 12            | 14   | 17              | 19              | 22   | 25              | 30   | 33              | 36   | 42   | 48    | 59    | 70    | 80    |
| 150                                    | A | 5.2                       | 9.6           | 20.4          | 38.8 | 81.6            | 124             | 243  | 393             | 709  | 1050            | 1490 | 2760 | 4560  | 9650  | 18220 | 29220 |
|                                        | B | 10                        | 12            | 15            | 17   | 21              | 23              | 28   | 32              | 37   | 41              | 45   | 53   | 61    | 74    | 88    | 101   |
| 200                                    | A | 6.05                      | 11.2          | 23.9          | 45.4 | 95.5            | 145             | 285  | 461             | 832  | 1240            | 1750 | 3240 | 5360  | 11350 | 21320 | 34400 |
|                                        | B | 12                        | 14            | 17            | 20   | 25              | 27              | 33   | 37              | 43   | 48              | 53   | 62   | 71    | 87    | 104   | 118   |
| 300                                    | A | 7.5                       | 13.9          | 29.7          | 56.6 | 119             | 181             | 356  | 577             | 1040 | 1550            | 2190 | 4060 | 6730  | 14270 | 26830 | 43300 |
|                                        | B | 15                        | 18            | 21            | 25   | 31              | 34              | 41   | 46              | 54   | 60              | 66   | 78   | 90    | 110   | 131   | 149   |
| 400                                    | A | 8.75                      | 16.2          | 34.7          | 66.2 | 140             | 212             | 417  | 676             | 1220 | 1820            | 2570 | 4780 | 7910  | 16790 | 31580 | 51000 |
|                                        | B | 18                        | 21            | 26            | 30   | 36              | 40              | 48   | 54              | 64   | 71              | 78   | 92   | 105   | 129   | 154   | 175   |
| 500                                    | A | 9.85                      | 18.3          | 39.2          | 74.8 | 158             | 239             | 471  | 765             | 1380 | 2060            | 2910 | 5410 | 8970  | 19040 | 35840 | 57880 |
|                                        | B | 20                        | 23            | 29            | 33   | 41              | 45              | 54   | 62              | 72   | 80              | 88   | 104  | 119   | 147   | 174   | 199   |
| 600                                    | A | 10.9                      | 20.2          | 43.2          | 82.5 | 174             | 264             | 521  | 848             | 1530 | 2280            | 3220 | 5990 | 9930  | 21100 | 39740 | 64210 |
|                                        | B | 22                        | 26            | 32            | 37   | 45              | 50              | 60   | 68              | 80   | 89              | 97   | 115  | 132   | 162   | 193   | 221   |
| 800                                    | A | 12.7                      | 23.6          | 50.5          | 96.5 | 204             | 310             | 610  | 992             | 1790 | 2670            | 3780 | 7030 | 11670 | 24820 | 46750 | 75620 |
|                                        | B | 25                        | 30            | 37            | 43   | 52              | 59              | 70   | 80              | 94   | 104             | 114  | 135  | 155   | 191   | 228   | 260   |

\* For other temperature drops the pipe capacities may be changed correspondingly. For example, with a temperature drop of 30 deg. the capacities shown in this table are to be multiplied by 1.5.

alent number of elbows of the same pipe size which would have the same friction loss. An elbow is assumed to have the same friction loss as a straight pipe having a length equal to 25 diameters (nominal) of the elbow.

The resistance of various types of fittings expressed in equivalent elbow resistance is shown in Table 1.

The friction loss in pipes and tubing may be determined from Fig. 2 and Table 2 for black iron pipes, and from Fig. 3 and Table 3 for type L copper tubing. The scale at bottom of Figs. 2 and 3 is the heat carrying capacity in thousands of Btu per hour based on a 20 deg temperature difference between flow and return risers. In order to use the scale for other than 20 deg difference, refer to footnote under Figs. 2 and 3.

If the flow in a given pipe is calculated in pounds per hour, it may be

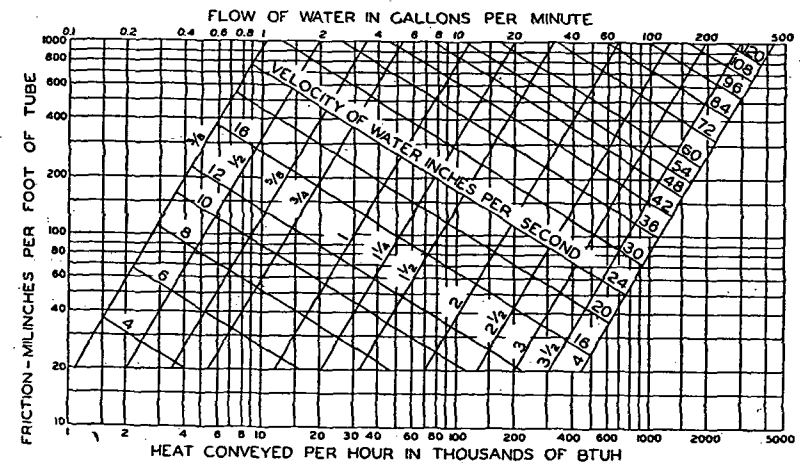


FIG. 3. FRICTION IN TYPE L COPPER TUBING

Lower scale of chart is based on 20 deg temperature difference between flow and return risers. To find friction when temperature drop is other than 20 deg, multiply the actual heat conveyed by  $\frac{20}{\text{actual temp. drop}}$  and read the corresponding friction.

converted to corresponding gallons per minute by dividing the flow in pounds by 500, after which the friction may be found by entering Figs. 2 and 3 at the top scale reading which corresponds to the flow in gallons per minute as determined.

Orifices drilled in plates inserted in pipe unions are convenient means for introducing friction, where required to balance various circuits. The friction losses caused by various sizes of orifices are given in Table 4.

### CLASSIFICATION OF SYSTEMS

Gravity or forced systems of piping may be classified according to piping arrangement and type of circulation as shown in Table 5. Flow and return main piping (gravity systems) for one-pipe, two-pipe direct return, and two-pipe reversed return systems are shown in Figs. 4, 5, and 6, re-

TABLE 3. HEAT-CARRYING CAPACITY OF TYPE L COPPER TUBING WITH TEMPERATURE DROP OF 20 DEG.  
Nominal Tube Sizes  $\frac{1}{8}$  in. to 4 in., and Friction 60 to 720 milinches per foot. (A = Capacity, Mbh. B = Velocity, inches per second) (One milinch equals 0.001 in.)

| NOMINAL TUBE SIZE, IN. |   | MILINCH FRICTION LOSS PER FOOT OF TUBE |      |      |      |      |      |      |      |      |      |      |      |
|------------------------|---|----------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|                        |   | 720                                    | 600  | 480  | 360  | 300  | 240  | 180  | 150  | 120  | 90   | 75   | 60   |
| $\frac{1}{8}$          | A | 8.9                                    | 7.8  | 7.0  | 5.9  | 5.4  | 4.7  | 3.9  | 3.6  | 3.1  | 2.7  | 2.3  | 2.1  |
|                        | B | 23.6                                   | 20.8 | 18.6 | 15.7 | 14.4 | 12.5 | 10.4 | 9.6  | 8.2  | 7.2  | 6.1  | 5.6  |
| $\frac{1}{4}$          | A | 16.7                                   | 15.0 | 13.0 | 11.2 | 10.0 | 8.7  | 7.5  | 6.6  | 5.6  | 5.0  | 4.5  | 3.9  |
|                        | B | 27.6                                   | 24.8 | 21.5 | 18.5 | 16.5 | 14.4 | 12.4 | 10.9 | 9.3  | 8.3  | 7.4  | 6.4  |
| $\frac{3}{8}$          | A | 29.0                                   | 26.0 | 22.5 | 19.0 | 17.5 | 15.0 | 13.0 | 11.5 | 10.0 | 8.5  | 7.6  | 6.7  |
|                        | B | 32.2                                   | 28.8 | 25.0 | 21.1 | 19.4 | 16.6 | 14.4 | 12.8 | 11.1 | 9.4  | 8.4  | 7.4  |
| $\frac{1}{2}$          | A | 43.5                                   | 39.0 | 34.5 | 29.0 | 26.5 | 23.0 | 19.6 | 17.5 | 15.0 | 13.0 | 12.0 | 10.5 |
|                        | B | 34.6                                   | 31.1 | 27.5 | 23.1 | 21.1 | 18.3 | 15.6 | 13.9 | 12.0 | 10.4 | 9.6  | 8.4  |
| 1                      | A | 93                                     | 84   | 74   | 63   | 57   | 50   | 42.5 | 38   | 34   | 28.5 | 26   | 23   |
|                        | B | 43                                     | 39   | 34   | 29   | 27   | 23   | 20   | 18   | 16   | 13   | 12   | 11   |
| 1 1/4                  | A | 160                                    | 145  | 128  | 107  | 97   | 85   | 73   | 65   | 57   | 48.5 | 44   | 39   |
|                        | B | 49                                     | 45   | 39   | 33   | 30   | 26   | 22   | 20   | 18   | 15   | 14   | 12   |
| 1 1/2                  | A | 280                                    | 240  | 206  | 175  | 160  | 140  | 118  | 108  | 93   | 79   | 71   | 62   |
|                        | B | 56                                     | 52   | 45   | 38   | 35   | 30   | 26   | 23   | 20   | 17   | 15   | 13   |
| 2                      | A | 560                                    | 510  | 450  | 380  | 340  | 300  | 250  | 225  | 195  | 170  | 150  | 133  |
|                        | B | 70                                     | 64   | 56   | 47   | 42   | 37   | 31   | 28   | 24   | 21   | 19   | 17   |
| 2 1/2                  | A | 1100                                   | 930  | 820  | 700  | 630  | 550  | 470  | 420  | 370  | 310  | 280  | 250  |
|                        | B | 89                                     | 75   | 66   | 57   | 51   | 44   | 38   | 34   | 30   | 25   | 23   | 20   |
| 3                      | A | 1650                                   | 1500 | 1300 | 1100 | 990  | 860  | 730  | 650  | 565  | 480  | 430  | 375  |
|                        | B | 94                                     | 85   | 74   | 62   | 56   | 49   | 41   | 37   | 32   | 27   | 24   | 21   |
| 3 1/2                  | A | 2500                                   | 2250 | 2000 | 1750 | 1500 | 1320 | 1100 | 1000 | 860  | 730  | 660  | 580  |
|                        | B | 105                                    | 94   | 84   | 73   | 63   | 55   | 46   | 42   | 36   | 31   | 28   | 24   |
| 4                      | A | 3600                                   | 3200 | 2800 | 2400 | 2150 | 1900 | 1600 | 1440 | 1250 | 1150 | 950  | 840  |
|                        | B | 116                                    | 103  | 90   | 77   | 69   | 61   | 51   | 46   | 40   | 37   | 31   | 27   |

\* For other temperature drops the pipe capacities may be changed correspondingly. For example, with temperature drop of 30 deg the capacities shown in this table are to be multiplied by 1.5.

spectively. These figures would also illustrate forced circulation if a pump or circulator were shown in the return line at the boiler.

One-pipe gravity systems require very precise design owing to the small circulating head available. Also, circulation in them is slow, and temperature drop is large toward the end of the main, and consequently these systems are usually considered impractical.

One-pipe forced systems compared with gravity systems provide more rapid circulation, with consequent smaller temperature drop in mains and more uniform water temperature in all radiators, and are therefore preferred. Special flow and return fittings are available for improving the circulation to risers.

Two-pipe systems have separate flow and return mains. If the return main is direct as shown in Fig. 5 the radiator at the end of the system has

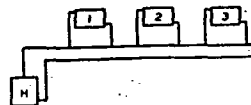


FIG. 4. ONE-PIPE SYSTEM

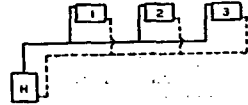


FIG. 5. A TWO-PIPE DIRECT RETURN SYSTEM



FIG. 6. A TWO-PIPE REVERSED RETURN SYSTEM

TABLE 4. FRICTION (IN MILINCHES) OF CENTRAL CIRCULAR DIAPHRAGM ORIFICES IN UNIONS  
(One milinch equals 0.001 in.)

| DIAMETER OF ORIFICES (INCHES) | VELOCITY OF WATER IN PIPE IN INCHES PER SECOND |      |      |        |        |        |        |        |        |        |  |  |
|-------------------------------|------------------------------------------------|------|------|--------|--------|--------|--------|--------|--------|--------|--|--|
|                               | 2                                              | 3    | 4    | 6      | 8      | 10     | 12     | 15     | 24     | 36     |  |  |
| <b>3/4-in. Pipe</b>           |                                                |      |      |        |        |        |        |        |        |        |  |  |
| 0.25                          | 1300                                           | 2900 | 5000 | 11,300 | 20,800 | 32,000 | 45,000 |        |        |        |  |  |
| 0.30                          | 650                                            | 1450 | 2500 | 5700   | 10,400 | 16,000 | 23,000 | 57,000 |        |        |  |  |
| 0.35                          | 330                                            | 740  | 1300 | 2900   | 5200   | 8000   | 12,000 | 26,000 | 47,000 |        |  |  |
| 0.40                          | 170                                            | 380  | 660  | 1500   | 2600   | 4000   | 6800   | 13,000 | 24,000 | 53,000 |  |  |
| 0.45                          |                                                | 185  | 330  | 740    | 1300   | 2000   | 2900   | 6500   | 12,000 | 27,000 |  |  |
| 0.50                          |                                                |      | 155  | 350    | 620    | 970    | 1400   | 3200   | 5700   | 13,000 |  |  |
| 0.55                          |                                                |      | 75   | 170    | 300    | 480    | 700    | 1600   | 2800   | 6400   |  |  |
| <b>1-in. Pipe</b>             |                                                |      |      |        |        |        |        |        |        |        |  |  |
| 0.35                          | 900                                            | 2000 | 3500 | 7800   | 14,000 | 22,000 | 32,000 |        |        |        |  |  |
| 0.40                          | 460                                            | 1000 | 1800 | 4000   | 7200   | 12,000 | 17,000 | 37,000 | 65,000 |        |  |  |
| 0.45                          | 270                                            | 570  | 1000 | 2300   | 4100   | 6400   | 9300   | 21,000 | 37,000 |        |  |  |
| 0.50                          | 160                                            | 330  | 580  | 1400   | 2300   | 3700   | 5400   | 12,000 | 22,000 | 50,000 |  |  |
| 0.55                          |                                                | 190  | 330  | 750    | 1300   | 2200   | 3000   | 7000   | 13,000 | 28,000 |  |  |
| 0.60                          |                                                |      | 200  | 440    | 800    | 1300   | 1800   | 4200   | 7400   | 17,000 |  |  |
| 0.65                          |                                                |      | 120  | 260    | 460    | 720    | 1100   | 2400   | 4300   | 10,000 |  |  |
| <b>1 1/4-in. Pipe</b>         |                                                |      |      |        |        |        |        |        |        |        |  |  |
| 0.45                          | 1000                                           | 2250 | 4000 | 8900   | 16,000 | 25,000 | 36,000 |        |        |        |  |  |
| 0.50                          | 660                                            | 1450 | 2600 | 5800   | 10,400 | 16,400 | 23,000 | 53,000 |        |        |  |  |
| 0.55                          | 430                                            | 950  | 1700 | 3800   | 6800   | 10,500 | 15,000 | 34,000 | 60,000 |        |  |  |
| 0.60                          | 280                                            | 630  | 1100 | 2500   | 4400   | 6900   | 10,000 | 22,000 | 40,000 |        |  |  |
| 0.65                          | 190                                            | 420  | 750  | 1700   | 3000   | 4700   | 6700   | 15,000 | 27,000 | 60,000 |  |  |
| 0.70                          |                                                | 285  | 510  | 1150   | 2000   | 3100   | 4500   | 10,000 | 18,000 | 40,000 |  |  |
| 0.75                          |                                                | 190  | 330  | 750    | 1300   | 2100   | 3000   | 6700   | 12,000 | 28,000 |  |  |
| <b>1 1/2-in. Pipe</b>         |                                                |      |      |        |        |        |        |        |        |        |  |  |
| 0.55                          | 850                                            | 1900 | 3300 | 7400   | 13,000 | 21,000 | 30,000 |        |        |        |  |  |
| 0.60                          | 600                                            | 1300 | 2300 | 5400   | 8600   | 16,800 | 21,000 | 50,000 |        |        |  |  |
| 0.65                          | 400                                            | 850  | 1500 | 3600   | 7200   | 10,400 | 14,000 | 30,000 | 53,000 |        |  |  |
| 0.70                          | 260                                            | 600  | 1100 | 2600   | 4400   | 7000   | 10,000 | 21,000 | 39,000 |        |  |  |
| 0.75                          | 180                                            | 400  | 760  | 1800   | 3000   | 5000   | 7000   | 14,000 | 28,000 |        |  |  |
| 0.80                          |                                                | 300  | 540  | 1200   | 2200   | 3200   | 5000   | 10,200 | 19,000 | 45,000 |  |  |
| 0.85                          |                                                | 200  | 380  | 860    | 1600   | 2300   | 3000   | 7800   | 13,000 | 30,000 |  |  |
| <b>2-in. Pipe</b>             |                                                |      |      |        |        |        |        |        |        |        |  |  |
| 0.70                          | 890                                            | 1850 | 3500 | 7400   | 14,000 | 22,300 | 33,000 |        |        |        |  |  |
| 0.80                          | 470                                            | 975  | 1800 | 3900   | 7400   | 11,700 | 17,000 | 37,000 |        |        |  |  |
| 0.90                          | 255                                            | 560  | 1000 | 2200   | 4200   | 6500   | 9500   | 20,500 | 38,000 |        |  |  |
| 1.00                          | 160                                            | 340  | 610  | 1320   | 2520   | 4000   | 5800   | 12,500 | 23,000 | 49,000 |  |  |
| 1.10                          |                                                | 214  | 375  | 850    | 1600   | 2500   | 3700   | 7900   | 14,000 | 30,000 |  |  |
| 1.20                          |                                                |      | 195  | 460    | 950    | 1360   | 1910   | 4200   | 8100   | 16,800 |  |  |
| 1.30                          |                                                |      |      | 275    | 525    | 980    | 1375   | 3100   | 4400   | 8850   |  |  |

Note.—The losses of head for the orifices in the 1 1/4-in. and 2-in. pipe were calculated from those in the smaller pipes, the calculations being based on the assumption that, for any given velocity, the loss of head is a function of the ratio of the diameter of the pipe to that of the orifice. This had been found to be practically true in the tests to determine the losses of head in orifices in 3/4-in., 1-in., and 1 1/4-in. pipe, conducted by the Texas Engineering Experiment Station, and also in the tests to determine the losses of head in orifices in 4-in., 6-in., and 12-in. pipe, conducted by the Engineering Experiment Station of the University of Illinois. (Bulletin 109, Table 6, p. 38, Davis and Jordan).

the longest supply and longest return piping. The lengths of circuits to the various radiators may be equalized by using a *reversed return* main (see Fig. 6). In some cases *reversed return* mains require no more piping than *direct return* systems.

With *gravity* circulation and *direct* return piping it is necessary to design the longest circuit for the available circulating head, and to obtain the same resistance in all other circuits by proper selection of pipe sizes, by addition of fittings, or by use of orifices. When a *reversed return* system is used, it is usually found that very little adjustment is required to attain uniform distribution to all radiators.

*Forced circulation* in two-pipe systems, because of increased available circulating head, permits design for higher velocities with a consequent reduction in pipe sizes. The increased velocity also shortens the heating-up period and facilitates control of circulation. Reversed return mains are also advantageous in forced circulation systems, in equalizing piping resistance to all heating units.

TABLE 5. CLASSIFICATION OF HOT WATER HEATING SYSTEMS

| PIPING ARRANGEMENT          | TYPE OF CIRCULATION | EXPANSION TANK |        |
|-----------------------------|---------------------|----------------|--------|
|                             |                     | Open           | Closed |
| One-Pipe                    | Gravity             | Open           | Closed |
| Two-Pipe<br>Direct Return   | Gravity             | Open           | Closed |
| Two-Pipe<br>Reversed Return | Gravity             | Open           | Closed |

### PIPING SYSTEM DESIGN

In designing hot water heating systems certain assumptions are usually made for the purpose of simplification as follows:

1. Water temperature drop is assumed to be 30 to 35 deg for gravity systems and 20 deg for forced circulation systems. These values usually result in economical design but, particularly in large forced circulation systems, it is necessary to take into account the cost of pumping the water required at various velocities in relation to the annual charges in the capital cost of the system.
2. Water velocities in forced systems in excess of 4 fps in piping of 1½ in. I. D. or less are likely to cause disturbing noises in residences. In factories or in installations having larger pipe sizes, velocities as high as 8 or 8.5 fps are not uncommon.
3. Design outlet water temperatures in gravity systems are generally selected between 140 and 200 F (with the average approximately 180 F); while forced circulation design temperatures vary from 170 to 220 F, although higher temperatures can be used if the pressure in the system corresponds.
4. For forced circulation systems, the allowable friction loss, which is based upon the available circulating head, is determined partially by the characteristics of the pumps available.
5. Forced hot water system friction should usually be held between 600 and 250 milinches per foot. Above 600 milinches high velocities would be encountered, and below 250 milinches circulation would become too slow, so that much of the rapid response expected from forced circulation would be lost.

### Hot Water Heating Systems

The water to be circulated is

$$W = H / (C \Delta t) \quad (2)$$

where

$W$  = weight of water, pounds per hour [gallons per minute =  $W / (8 \times 60)$ ].

$H$  = heat required, Btu per hour.

$C$  = specific heat of water (= 1).

$\Delta t$  = drop in temperature between supply and return, Fahrenheit degrees.

The following graded series of examples of the design of hot water piping systems will illustrate the fundamental principles and methods. The differences between reversed return and direct return systems are shown, and the methods of balancing the several radiators or circuits are illustrated. A simple gravity system is shown in Fig. 7, and an elementary forced circulation system is diagrammed in Fig. 8.

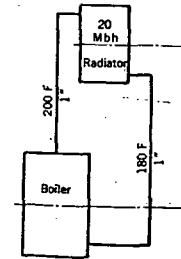


FIG. 7. GRAVITY SYSTEM

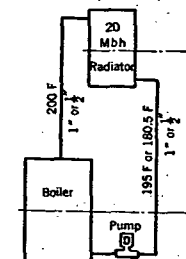


FIG. 8. FORCED CIRCULATION SYSTEM

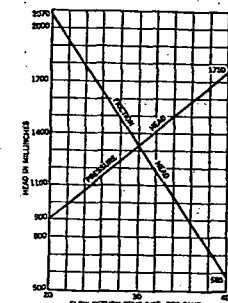


FIG. 9. DETERMINATION OF REQUIRED TEMPERATURE DIFFERENCE

### Elementary Gravity System

**Example 1:** A simple gravity-circulation system is illustrated in Fig. 7 with one radiator that is giving off heat at the rate of 20,000 Btu per hr or 20 Mbh. The boiler imparts heat to the water at the same rate, and the water circulates at a uniform velocity. This uniform velocity is such that the friction of the circuit is equal to the head developed by the difference in density between the supply and return water and the height of the system. The circuit consists of 1 boiler, 1 radiator, 2 ells, 1 radiator valve and a total of 24 ft of pipe.

**Solution:** With the average water temperatures of 200 and 180 F in the supply and return risers, respectively, the head will be 90 milinches per foot of water column. This head may be found from Fig. 1. Since the center of the radiator is 10 ft above the center of the boiler, the total head of the circuit is 10 x 90, or 900 milinches, or 0.9 in. of 190 F water. The friction of the circuit must then also be 900 milinches. The friction of 1 ft of 1 in. pipe is found from Fig. 2 to be about 46 milinches at 20 Mbh, and the corresponding velocity 9 in. per second. Note that all values in Fig. 2 are based on a temperature difference of 20 deg.

Similarly, if a 1½ in. pipe were to be used, the friction head would be about 12 milinches per foot, and the corresponding velocity about 5 in. per second, from Fig. 2.

To find the friction in the elbows, boiler, radiator, and valve, Table 1 is used, and the entire circuit is found to be equal to 10 elbow-equivalents plus 24 ft of pipe. Each elbow-equivalent is equal to a pipe length of 25 times the nominal diameter. Then the equivalent lengths of straight pipe are 45 ft of 1 in. pipe or 50 ft of 1½ in. pipe. In many cases, it is sufficiently accurate to add 50 percent to the total pipe length to correct for resistance of fittings.

Hence, if 1 in. pipe is used, the friction of the circuit will be 45 x 46, or 2070 mil-

inches, and if 1½ in. pipe is used, the friction will be 50 × 12, or 600 milinches. A 1 in. pipe would, therefore, be too small and a 1½ in. pipe too large to permit the desired circulation with a flow-return temperature difference of 20 deg.

If the circuit is of 1 in. pipe, the circulation will take place with a temperature difference greater than 20 deg, and if the circuit is of 1½ in. pipe, the circulation will take place with a temperature difference smaller than 20 deg. To find, for example, the temperature difference at which a circuit of 1 in. pipe would transmit the required 20 Mbh, assume the difference to be 40 deg.

From Fig. 1, the head available for producing circulation would be 175 milinches per foot, or 1750 for the system, for a temperature drop from 200 to 160 F. The friction of the system may be found from Fig. 2; the chart of this figure is based on a temperature difference of 20 deg; if the temperature difference were 40 deg, the heat conveyed would be twice that shown in the chart. Hence, find 10 Mbh on the lower scale, proceed vertically upward to the intersection with the 1 in. line, and from there to the left scale read 13 milinches per foot. Note that the velocity would then be only about 5 in. per second. The total friction would then be 45 × 13 or 585 milinches. Since the head would be 1750, circulation would take place with a temperature difference less than 40 deg. The required temperature difference may be determined by constructing the diagram of Fig. 9, from which it appears that the temperature difference with which the 1 in. pipe circuit would function is about 30 deg. Hence, if the

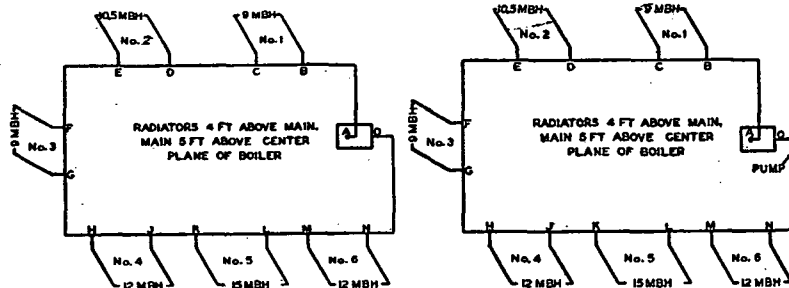


FIG. 10. ONE-PIPE GRAVITY CIRCULATION SYSTEM (EXAMPLE 3)

flow riser temperature is 200, the return riser temperature will be 170, and the average water temperature in the radiator about 185 F.

### Elementary Forced Circulation System

**Example 2:** Design a system for the piping arrangement shown in Fig. 8, according to one of the outlined procedures. The procedure may be as follows: Assume the head developed by the circulating pump and the pipe size and, find the flow-return temperature difference; or, assume the head developed by the pump and the flow-return temperature difference, and find the pipe size; or, assume the pipe size and the flow-return temperature difference, and find the head which the circulating pump must develop.

**Solution:** Assume that the circulating pump will develop a head of 2 ft or 24,000 milinches and that a 1 in. pipe is to be used. The equivalent length of the circuit will then be 45 ft, as in Fig. 7, and the available head will be 24,000/45, or 533 milinches per foot. In Fig. 2, find 533 on the left scale, move horizontally to the intersection with the 1 in. pipe line, and read about 77 Mbh delivered by the pipe (with a velocity of about 35 in. per second) for a temperature difference of 20 deg. Since the circuit is to deliver only 20 Mbh, the temperature difference will be 20 divided by 77 and multiplied by 20, or 5.2 deg. Hence, if the flow riser temperature is 200, the return riser temperature will be about 195, and the average water temperature in the radiator about 197.5 F.

If a ¾ in. pipe were used instead of a 1 in., the equivalent length of circuit would be 35 ft instead of 45; the unit head, 686 milinches instead of 533; the velocity, 27 in. per

second instead of 35; the temperature difference, 19.5 instead of 5.2; and the average water temperature in the radiator, about 190.5 instead of 197.5 F.

If the 1 in. pipe is used for the circuit, the gravity head will be 22 milinches per foot, or 220 for the circuit (Fig. 1, 200 to 195). Since this is only 1 percent of the pump head (24,000 milinches), it may be neglected in the calculation, as was done previously. However, there are cases in which the gravity head is so large compared with the pump head that it should be included in the calculation.

The methods just described for the design of the two elementary systems are fundamental, and apply to the design of all hot water heating systems. In every system, however large and complicated, the pipe system must be such that the head forcing the water from the boiler to any one radiator is equal to the friction in that radiator's circuit when the radiator is receiving its proper quantity of hot water, and the system is functioning at a steady rate.

Other examples illustrating design of various systems follow.

### One-Pipe Gravity Circulation System

**Example 3:** Select pipe sizes for the one-pipe gravity system having a total load of 67,500 Btu, shown in Fig. 10. Assume: flow temperature 190 F, return temperature 160 F, mains 5 ft above datum plane of boiler, center plane of radiators 4 ft above the mains, length of main 100 ft.

**Solution:** From Fig. 1 the available circulating head for 190 F flow and 160 F return temperature is 126 milinches per foot of height. The available circulating head for design of the main is therefore 5 × 126 = 630 milinches. The measured length of main, plus 50 percent added for resistance of fittings, equals 150 ft equivalent length.

The main can then be designed for a friction loss of 630 ÷ 150 = 4 milinches per foot. From Table 2 at 4 milinch friction loss, a 2 in. pipe will supply 33 Mbh and a 2½ in. pipe will supply 53.1 Mbh at 20 deg drop. This is equivalent at 30 deg drop to 49.5 Mbh for 2 in., and 79.6 Mbh for 2½ in. pipe. A 2½ in. main will therefore be selected, and the pressure drop will be somewhat less than 4 milinches per foot.

The piping from main to radiators is sized in a similar manner. Assume that water reaches point B, Fig. 10, at 190 F and has a 30 deg drop in the radiator circuit. From Fig. 1 the available head is 126 milinches per foot of height or a total of 4 × 126 = 504 milinches for the circuit (with the radiator 4 ft above the main).

The measured length of piping is 11 ft and the fittings add 14 elbow equivalents (which would be equivalent to 22 ft if the pipe size is assumed to be ¾ in.); the equivalent length is therefore 33 ft. The circuit can therefore be designed for a friction loss of 504 ÷ 33 = 15 milinches per foot.

From Table 2 by interpolation a ¾ in. pipe would supply 5.85 Mbh at 20 deg drop or 8.78 Mbh at 30 deg drop. Since the load is 9 Mbh, the ¾ in. size will be satisfactory.

The remaining radiator circuits may be sized in a similar manner. Allowance should be made in one-pipe gravity systems for the drop in temperature which occurs in the supply main as the cooler water returns from the radiators. The drop will be in the same proportion to the total drop of 30 deg as the load supplied to any point in the main bears to the total system load, e.g., the temperature at D will be 190 -  $\left(\frac{9000}{67,500} \times 30\right)$  = 186 F. At point F the temperature will be 190 -  $\left(\frac{9000 + 10,500}{67,400} \times 30\right)$  = 181 F.

### One-Pipe Forced Circulation System

**Example 4:** Select pipe sizes for the one-pipe forced circulation system having a load of 67,500 Btu shown in Fig. 11. Assume a water temperature drop of 20 deg. The water temperature does not affect the size of piping, but does affect the radiator sizes required.

**Solution:** The water to be circulated at 20 deg drop will be 67,500 ÷ 20 = 3375 lb per hour or  $\frac{3375}{8 \times 60}$  = 7 gpm.

By reference to manufacturers' pump capacity charts (typical example, Fig. 12),



it will be found that a 1 in. pump will deliver 7 gpm against a head of  $4\frac{1}{2}$  ft (54,000 milinches).

Since the main from A to O has an equivalent length of 150 ft (100 ft actual length plus 50 percent added for friction loss in fittings), the main may be sized for  $54,000/150 = 360$  milinches per foot.

From Table 2 by interpolation at 360 milinches friction loss and at 20 deg drop, a 1 in. pipe would supply 62,600 Btu per hour, and a  $1\frac{1}{2}$  in. pipe would supply 131,600. Since the 1 in. pipe is too small, a  $1\frac{1}{2}$  in. pipe will be used.

Since the  $1\frac{1}{2}$  in. pipe offers less than 360 milinches resistance per foot, the velocity of water will increase until the output of the pump and the friction loss are in equilibrium at some point on the pump performance curve, for instance, at 10 gpm and a head of 4 ft or  $48,000 \div 150 = 320$  milinches per foot of pipe. The friction loss in the main between flow and return connections to radiators will be assumed to be 320 milinches per foot.

In determining sizes for the piping from the main to any radiator, the resistance in the radiator circuit such as B-C (which has a load of 9 Mbh) is made equal to the

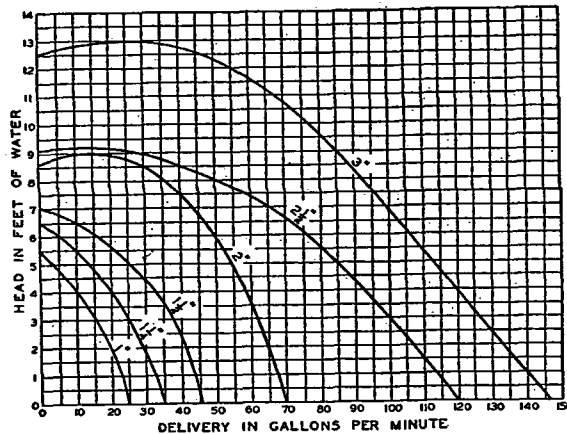


FIG. 12. PERFORMANCE CHART FOR CIRCULATING PUMP

resistance in the main from B to C which, if there are 3 ft of main between connections, is  $3 \times 320 = 960$  milinches. If the total equivalent length of the radiator circuit determined by use of Table 1 is 32 ft, the radiator circuit B-C will be sized for a friction loss of  $960 \div 32 = 30$  milinches per foot, for which in Table 2 a  $\frac{3}{4}$  in. pipe is found to supply 8550 Btu per hr, and will be considered ample.

Other radiator circuits such as D-E, F-G, etc., can be sized in a similar manner.

### Two-Pipe Gravity System (with Reversed Return)

**Example 5:** Select pipe sizes for the two-pipe gravity system shown in Fig. 13. The center plane of the highest radiator is 8 ft above the center plane of the boiler. Assume a 180 F flow temperature and a 150 F return temperature.

**Solution:** The piping should be sized so that the frictional resistance at the desired rate of flow is equal to the available circulating head.

From Fig. 1 at 180 F flow and 150 F return temperature, the available head is 118 milinches per foot of height or  $8 \times 118 = 944$  milinches total for the highest radiator. The longest circuit from boiler to radiator and back to boiler must therefore have a resistance of 944 milinches. The longest circuit (see Fig. 13) is A-D + D-H + H-N containing 38 ft of pipe and, if 50 percent is added for equivalent length of fittings the equivalent length is 57 ft.

### Hot Water Heating Systems

The circuit should then be designed for a friction loss of  $944 \div 57 = 16$  milinches per foot (approximately). The pipe size may be found from Table 2 at 16 milinches per foot, but since the temperature drop is 30 deg, find pipe size corresponding to 20/30 of actual load for each section as follows:

| SECTION | LOAD MBH | SIZE OF PIPE FOR 16 MILINCHES PER FOOT | SECTION | LOAD MBH | SIZE OF PIPE FOR 16 MILINCHES PER FOOT |
|---------|----------|----------------------------------------|---------|----------|----------------------------------------|
| A-B     | 58       | $1\frac{1}{2}$                         | G-H     | 11       | 1                                      |
| B-C     | 31       | $1\frac{1}{4}$                         | H-K     | 19       | $1\frac{1}{4}$                         |
| C-D     | 20       | $1\frac{1}{4}$                         | K-L     | 25       | $1\frac{1}{4}$                         |
| D-E     | 16       | 1                                      | L-M     | 31       | $1\frac{1}{4}$                         |
| E-F     | 6        | $\frac{3}{4}$                          | M-N     | 58       | $1\frac{1}{2}$                         |

Piping to the radiators may be sized from Table 2 for the same resistance, 16 milinches per foot, but since the temperature drop is 30 deg, find pipe size corresponding to 20/30 of actual load for each section as follows:

|                |    |               |               |               |                |               |
|----------------|----|---------------|---------------|---------------|----------------|---------------|
| Radiator       | #1 | #2            | #3            | #4            | #5             | #6            |
| Load, Mbh      | 11 | 8             | 6             | 6             | 24             | 3             |
| Pipe size, In. | 1  | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{2}$ | $\frac{1}{2}$ |

A hot water heating system will adjust its rate of flow until the friction loss balances the available head. It is therefore self-correcting in regard to small errors made in selection of pipe sizes.

### Two-Pipe Forced Circulation System

**Example 6:** Select pipe sizes for the two-pipe forced circulation reversed return system having a total load of 159 Mbh shown in Fig. 14. Assume a difference of 20 deg in supply and return water temperature. The total equivalent length of the longest circuit is 180 ft. The gravity circulating head due to difference in temperature may be disregarded in design.

**Solution:** The water to be circulated is  $159,000 \div 20 = 7950$  lb per hr or  $\frac{7950}{60 \times 8} = 16.5$  gpm. From a pump performance chart such as Fig. 12 it is found that 16.5 gpm will be delivered by a 1 in. pump against a 3 ft head (36,000 milinches) or a  $1\frac{1}{2}$  in. pump against a 4.5 ft head (54,000 milinches).

The longest circuit, including the supply and return main and the longest radiator circuit, is 120 ft and, if 50 percent is added for friction loss in fittings, the equivalent length is 180 ft. If the 1 in. pump is used, the piping will be sized for  $36,000/180 = 200$  milinches per foot, resulting in selection from Table 2 of a 2 in. main for the Section A-B which supplies 159 Mbh. The large difference in pump and main size, as well as the low velocity resulting from the 200 milinch per foot friction loss, indicates that the  $1\frac{1}{2}$  in. pump should be considered. The design friction loss, if the  $1\frac{1}{2}$  in. pump is used, can be  $54,000/180 = 300$  milinches per foot and, at this friction loss, Table 2 will indicate the pipe sizes for the various sections in Fig. 14 as follows:

| SUPPLY  |     |                | RETURN  |     |                |
|---------|-----|----------------|---------|-----|----------------|
| Section | Mbh | Pipe Size, In. | Section | Mbh | Pipe Size, In. |
| A-B     | 159 | $1\frac{1}{2}$ | J-K     | 16  | $\frac{3}{4}$  |
| B-C     | 91  | $1\frac{1}{4}$ | K-L     | 28  | $\frac{3}{4}$  |
| C-D     | 76  | $1\frac{1}{4}$ | L-M     | 42  | 1              |
| D-E     | 63  | $1\frac{1}{4}$ | M-N     | 54  | 1              |
| E-F     | 49  | 1              | N-O     | 76  | $1\frac{1}{4}$ |
| F-G     | 37  | 1              | O-P     | 91  | $1\frac{1}{4}$ |
| G-H     | 16  | $\frac{3}{4}$  | P-Q     | 159 | $1\frac{1}{2}$ |

The radiator circuits may also be sized for the same friction loss, 300 milinches per foot, using Table 2 as follows:

|                |               |               |               |               |               |               |
|----------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Radiator       | #1            | #2            | #3            | #4            | #5 and #6     | #7            |
| Load, Mbh      | 16            | 12            | 14            | 12            | 16            | 16            |
| Pipe size, In. | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ |

<sup>a</sup> Where circuit divides, use  $\frac{1}{2}$  in. branch to #5 and  $\frac{1}{2}$  in. to #6 radiator.

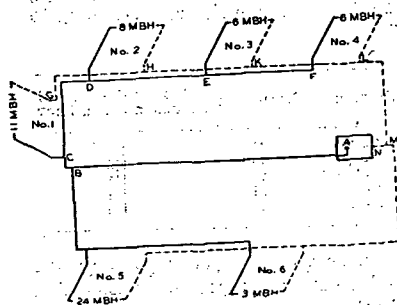


FIG. 13. TWO-PIPE REVERSED RETURN GRAVITY SYSTEM (EXAMPLE 5)

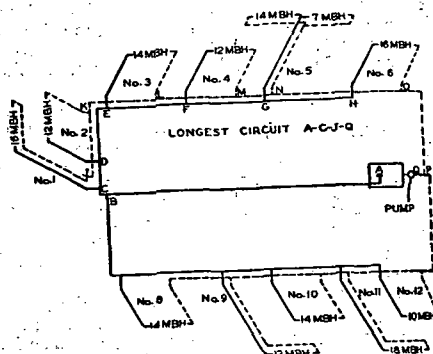


FIG. 14. FORCED CIRCULATION TWO-PIPE REVERSED RETURN SYSTEM

### EXPANSION TANKS

Water heated from 40 F to 200 F expands about 0.04 of the original volume. The expansion tank permits the change in volume of the water in the heating system to take place without producing undesirable stresses due to pressure in any part of the system. Expansion tanks may be open, as illustrated in Fig. 15, or closed as shown in Fig. 16. An open expansion tank has free vent to the atmosphere and consequently, the pressure on the surface of the water is always that of one atmosphere. The minimum contents of an open tank should be 0.06 of the volume of the water in the system including that in the boiler, heat transmitters, pipes, etc. This capacity is 50 percent in excess of the actual increase in volume of water

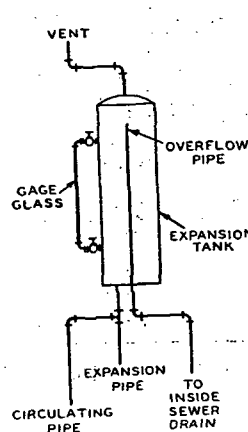


FIG. 15. AN OPEN EXPANSION TANK

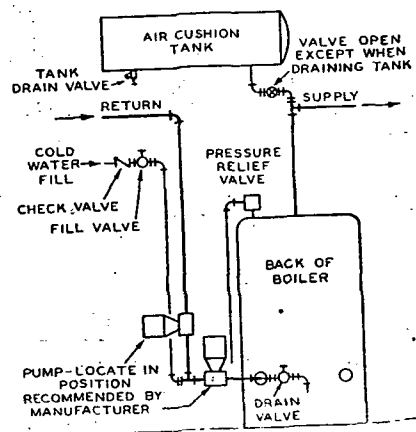


FIG. 16. A CLOSED EXPANSION TANK

due to increase in temperature from 40 F to 200 F. The tank should be located at least 3 ft above the highest radiator. Provision must be made to prevent freezing of the water in the tank as well as in the pipe leading to the tank.

In accordance with Paragraph H-92 of the ASME Low Pressure Heating Boiler Code 1946: "All hot water heating systems shall be so installed that there will be no opportunity for the fluid relief column to freeze or to be accidentally shut off. If the system is equipped with an open expansion tank, an internal over-flow from the upper portion of the expansion tank must be provided in addition to an open vent, the internal over-flow to be carried within the building to a suitable plumbing fixture or to the basement." (See Fig. 15.)

When the vent from an open expansion tank is extended through the roof, it should be not less than 4 in. in diameter from a point below the roof, through and beyond the roof line. This will prevent vapor, which sometimes rises from an expansion tank, from closing the vent during outside freezing temperatures.

In a gravity circulation system, the pipe to the open expansion tank should be connected to the supply riser from the boiler, so that the air liberated from the water in the boiler will enter the expansion tank.

In a forced circulation system, the pipe to an open expansion tank should be connected on the suction side of the circulating pump.

A closed expansion tank is sealed against free venting to the atmosphere. The tank may be above the highest radiator or heat transmitter, or may be below the lowest one. The minimum contents of a closed expansion tank must be such that the expansion of the water due to increase in temperature will be cushioned against a reservoir of compressed air above the water level in the expansion tank. The tank must provide space not only for the change in water volume, but also for variations in air volume within the tank due to changes in air pressure. If the closed expansion tank is below the heat transmitters, the tank should be larger than if it is above them, and the higher the building, under such circumstances, the larger should be the air capacity in excess of that required for increase in water volume due to temperature rise.

The size of an expansion tank for installation in a closed system may be determined by the following formula:

$$V = \frac{E}{\frac{P_1}{P_1 + 0.434H} - \frac{P_2}{P_2}} \quad (3)$$

where

$V$  = required tank capacity, gallons.

$E$  = expansion of water from cold system to flow riser temperature, gallons.

$P_1$  = atmospheric pressure, psia.

$P_2$  = maximum tank pressure specified for heated system, psia.

$H$  = height of top of filled system above tank, feet. (NOTE: Top of system open to atmosphere when system is filled.)

**Example 7:** Select a closed expansion tank for basement installation on a system containing 5000 gal and operating at 200 F flow temperature. The static head, due to the height of the system, is 70 ft. The maximum pressure should not exceed 100 psig.

**Solution:** Assume that the system is filled at 40 F. Then

$$E = 0.04 \times 5000 = 200 \text{ gal.}$$

$$P_1 = 14.7 \text{ psia}$$

$$P_2 = 100 + 14.7 = 114.7 \text{ psia.}$$

Substituting these values in Equation 3,

$$V = \frac{200}{\frac{14.7}{14.7 + 0.434(70)} - \frac{14.7}{114.7}} = \frac{200}{0.327 - 0.128} = 1000 \text{ gal.}$$

The size of a basement-located closed expansion tank should be at least equal to the following:

One story buildings:  $x = 0.10 V$     Three story buildings:  $x = 0.17 V$

Two story buildings:  $x = 0.13 V$     Four story buildings:  $x = 0.23 V$

where

$x$  = expansion tank size in gallons.

$V$  = water volume in heating system in gallons.

This condition favors, especially in tall buildings, the placing of the closed expansion tank above the highest heat transmitter.

TABLE 6. REQUIRED ASME SIZE OF CLOSED EXPANSION TANK

| Sq Ft of Equivalent Direct Radiation Installed | GALLON TANK | Sq Ft of Equivalent Direct Radiation Installed | GALLON TANK |
|------------------------------------------------|-------------|------------------------------------------------|-------------|
| Up to 350                                      | 18          | Up to 1400                                     | 40          |
| Up to 450                                      | 21          | Up to 1600                                     | 2-30        |
| Up to 650                                      | 24          | Up to 1800                                     | 2-30        |
| Up to 900                                      | 30          | Up to 2000                                     | 2-35        |
| Up to 1100                                     | 35          | Up to 2400                                     | 2-40        |

For systems with more than 2400 sq ft of installed equivalent direct water radiation, the required capacity of the cushion tank shall be increased on the basis of one gallon tank capacity per 33 sq ft of additional equivalent direct radiation.

It is common practice to use multiple tank installations on large systems in lieu of one tank, the required capacity of which would be beyond commercially available sizes.

Any closed expansion tank located above the heat transmitters of a hot water heating system should be connected by a direct pipe with the flow main leaving the boiler, in order to enable the air to pass easily to the expansion tank. In a closed hot water heating system the water under pressure tends to absorb air at a rate increasing with pressure increase and decreasing with temperature increase.

Means must be provided to adjust and to observe the proportion of air within any closed expansion tank. This involves the provision of an air inlet valve, a water gage, and a relief valve. A source of supply of compressed air for renewing the air cushion is highly desirable, especially in large, high pressure, hot water heating systems where it is inconvenient, if not impracticable, to drain down the water in the system so as to permit introduction of atmospheric pressure air.

In smaller installations, gage fittings on the tank are usually omitted in order to prevent air loss from the tank. Occasional inspection of the tank or the necessity of adding water to the system will then indicate whether air should be added to the tank.

The ASME Low Pressure Heating Boiler Code 1946, in paragraph H-92, specifies that provision must be made for draining a closed expansion

tank without emptying the system. The Code also specifies the minimum sizes of closed expansion tanks based upon the equivalent direct radiation installed. (See Table 6.)

For every hot water heating system, the designer should calculate the volume of water contained in the radiators, piping system, boiler, etc., in order to select the proper size of expansion tank. The water content of the piping can be obtained from Table 7. For a rough selection of size, however, it is sometimes assumed that 50 percent of the volume of water is contained in the radiators, and that the water content per square foot of radiator heating surface is 0.2 gal for column radiators, and 0.13 gal for tube type radiators.

Another rough method for determining the size of an expansion tank to be located above the highest radiator, is to divide the square feet of radiation by the factor 40 to obtain the required capacity in gallons of the tank.

### INSTALLATION DETAILS

Items that should be considered in the design of piping for a hot water system are:

All piping must be so pitched that all air in the system can be vented either through an open expansion tank, radiators or automatic relief valves. When piping must be

TABLE 7. VOLUME OF WATER IN STANDARD PIPE

| PIPE SIZE, IN. | LINEAL FT OF PIPE CONTAINING 1 GAL | PIPE SIZE, IN. | LINEAL FT OF PIPE CONTAINING 1 GAL |
|----------------|------------------------------------|----------------|------------------------------------|
| $\frac{1}{8}$  | 63.1                               | 2              | 5.75                               |
| $\frac{1}{4}$  | 36.1                               | 2½             | 4.02                               |
| $\frac{3}{8}$  | 22.2                               | 3              | 2.60                               |
| $\frac{1}{2}$  | 12.8                               | 4              | 1.52                               |
| $\frac{3}{4}$  | 9.47                               | 5              | 0.96                               |
|                |                                    | 6              | 0.67                               |

run around an obstacle such as a beam, it is advisable to drop the piping below the beam. If looped over the beam, it becomes necessary to provide for venting of air from the high point of the pipe.

When changing the size of horizontal runs of pipe, eccentric fittings should be used to keep the tops of the pipes in line to permit free passage of air along the pipe.

All piping must be arranged so that the entire system can be drained. Sections of piping individually valved shall have corresponding drain valves.

In large buildings, the piping may be zoned according to exposure of building, usage of building, or method of control.

All piping must be installed so that it is free to expand and contract with changes of temperature without producing undue stresses in the pipes or connections. For this purpose it is generally sufficient to allow for a variation in length of 1 in. for 100 ft of pipe.

The pipe system should be designed so that each circuit has its correct friction for balanced water distribution. This may be done by change of pipe size or change in piping detail.

The connections from the boiler to the mains should be short and direct, to reduce the friction, and should allow for expansion.

The mains and branches should pitch up and away from the heater, generally not less than 1 in. in 10 ft.

The connections from mains to branches and to risers should be such that circulation through the risers will start in the right direction. Hence, in a one-pipe system the flow connection must be nearer the heater than the return connection. In a correctly-designed two-pipe system, the pressure in the flow main is higher than that in the return main, and a slight variation in the distances of the flow and return connections from the heater is not material; but it is generally best to have the two connections about equally distant from the heater.

Generally, connections to risers or radiators are taken out of the top of mains at either 45 or 90 deg from the horizontal plane.

Supply connections are usually made at the bottom of radiators so that circulation will not be stopped by accumulation of air, as would be the case with a top supply

connection. Short radiators are sometimes connected for top supply and bottom return on the same end. When so connected, attention must be given to venting of air from the top of the radiator somewhat oftener than when bottom connections are used.

Unless used as heating surface, all piping, both flow and return, should be insulated.

All large systems should be provided with extra stop and drain valves, suitably located so that parts of the system may be isolated for repairs without making it necessary to drain the water from the entire system.

**Relief Valve.** The ASME Low Pressure Heating Boiler Code requires that all hot water heating boilers shall be equipped with a tested and rated relief valve having adequate capacity to match the gross output of the

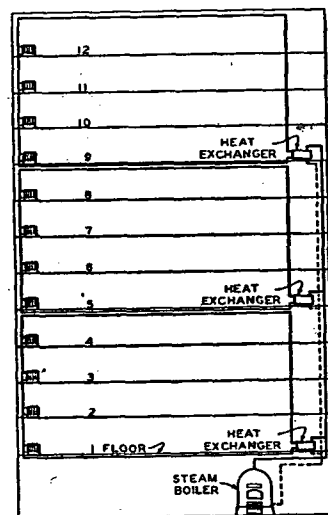


FIG. 17. VERTICAL ZONING OF HOT WATER HEATING SYSTEM IN A 12-STORY BUILDING (Provision should be made for expansion in each closed circuit.)

boiler. In order to comply with the requirement, relief valves must be connected to the top of the boiler and a discharge pipe must be connected to the relief valve and so arranged that there will be no danger of scalding attendants. The proper location of the relief valve is shown in Fig. 16.

### ZONING

In large hot water systems, improved control and economy can be achieved by separating the systems into sections or zones (vertical or horizontal) which can be operated independently of each other. Variations in heat requirement of the different zones, as influenced by the exposure of the building, solar heat, weather conditions, heat from processes, type of occupancy, building chimney effect, etc., can readily be compensated for when heat can be supplied only where needed.

In tall buildings, vertical zoning such as shown in Fig. 17 not only provides the advantages of control and economy, but also reduces the water

pressure in the system to that caused only by the number of floors served by each section. As shown in Fig. 17 a steam boiler can conveniently be used to supply steam to the heat exchanger supplying heated water to each zone.

## HIGH TEMPERATURE WATER SYSTEM

### General Considerations

The high temperature water system is a form of conveying heat using water as the medium, at temperatures well above 212 F and usually, in current practice, between 300 and 400 F. Water being a most satisfactory heat carrier, will transport heat over long distances with comparatively small line losses and without expensive equipment to maintain or replace.

With high temperature water the boiler, instead of generating steam, heats the water to a specified temperature and corresponding pressure. The

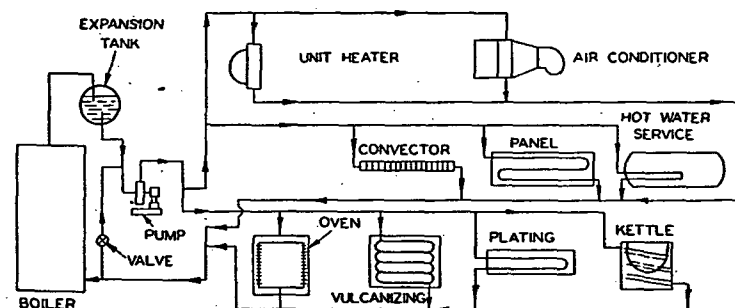


FIG. 18. SCHEMATIC ARRANGEMENT OF TYPICAL HIGH TEMPERATURE WATER SYSTEM

water thus heated is discharged under pressure from the boiler into the system through a circulating pump designed for the high temperatures involved. The water is thus circulated in a closed circuit from the central station to the extended areas requiring heat and back again to the boiler. In this way the heat, whether for space heating or process work, is distributed efficiently and economically since any heat not usefully employed in the system is returned to the boiler for reheating and redistribution. Fig. 18 illustrates an industrial application of a high temperature water system.

### Fundamental Principles

In high temperature water systems water is heated under pressure and its temperature is raised to that corresponding to the pressure imposed, which is above the evaporation point of water at atmospheric pressure. As the temperature of the water rises, the pressure in the system must also be raised to ensure that the pressure is always above the equivalent evaporation pressure.

In modern systems, the pressure can be maintained by using steam or a compressed inert gas. With steam, the steam space within the boiler or the steam space in an external drum or tank, which is also used as an expansion

vessel, is utilized to produce the required pressure. By using an inert gas, the desired system pressure can be maintained while the water temperature can be regulated to the desired system temperature.

The properties of water which must be considered in the design are:

1. Boiling point ( $t$ ) vs. pressure. (See Fig. 19)
2. Density or specific volume ( $v_s$ ) vs. temperature.

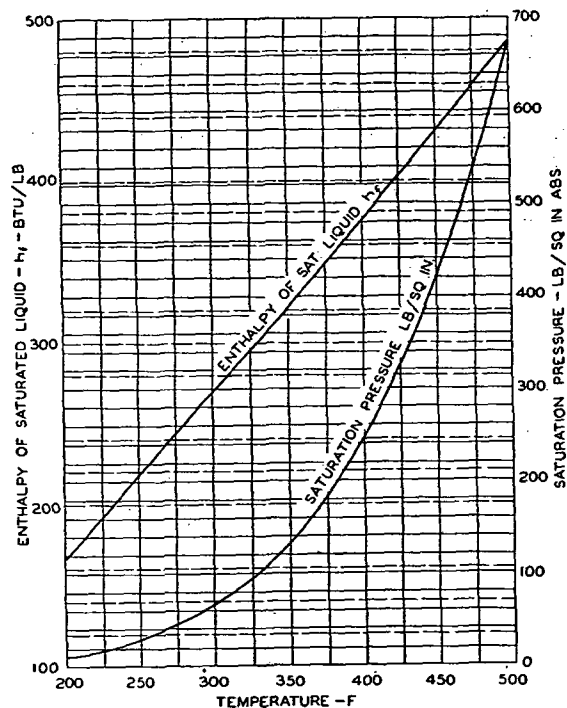


FIG. 19. RELATION OF SATURATION PRESSURE AND ENTHALPY TO WATER TEMPERATURE

3. Enthalpy or sensible heat ( $h_t$ ) vs. temperature.
4. Viscosity ( $\mu$ ) vs. temperature.

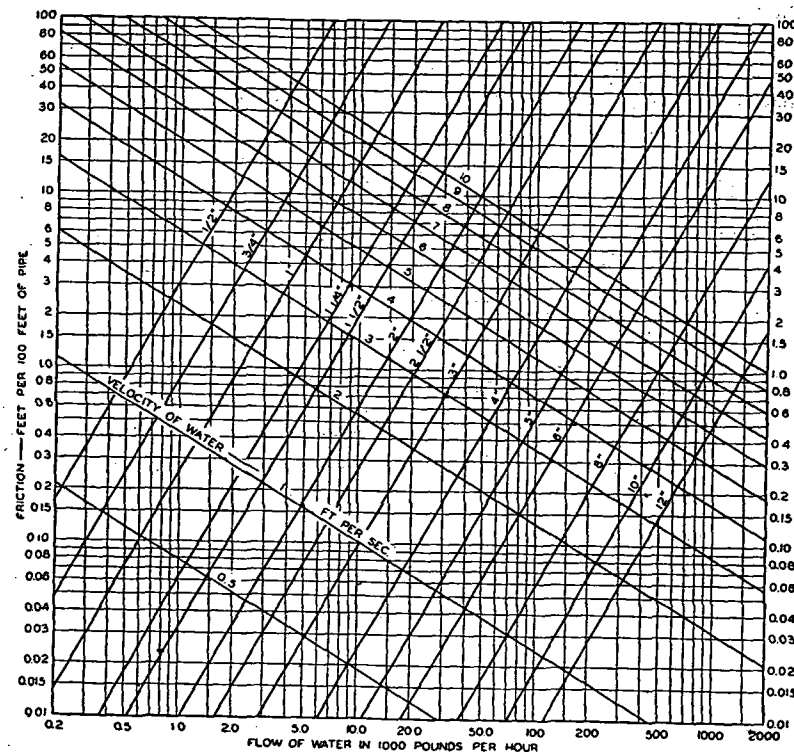
Boiling point, specific volume and enthalpy are all discussed in Chapter 3, and the data for the normal temperature pressure ranges are given in Table 3 of Chapter 3. As viscosity is reduced materially with increase in temperature, the consequent reduction in pipe friction should be considered a prime asset of high temperature water systems. (See Fig. 20.)

Since the specific heat of water varies only slightly with temperature, it can be ignored in normal design. But as the specific volume varies with temperature, it has been found more convenient in design to use *pounds per*

hour in lieu of gallons per minute, and the accompanying charts are plotted on this basis.

### Design and Economics

High temperature water systems differ from conventional systems in that flow main temperatures range from 250 F to 400 F. For flow temperatures of 250 to 350 F, temperature drops of 80 deg to 150 deg are in common.



The relation between flow in thousands of pounds per hour and friction loss in feet per 100 ft of pipe as shown in Fig. 20 is based on the Fanning formula (Equation 8, Chapter 4) with values of the density and viscosity of water chosen for 300 F. When corrections are desirable Fig. 21 may be used to correct the friction loss as found in Fig. 20.

The friction loss in fittings expressed in equivalent feet of pipe is given in Table 8.

### Circuits

High temperature water is used directly in unit heaters, air heating coils, steel heating panels, and process equipment. Evaporators or steam generators are used for generating steam where required for steam heating sys-

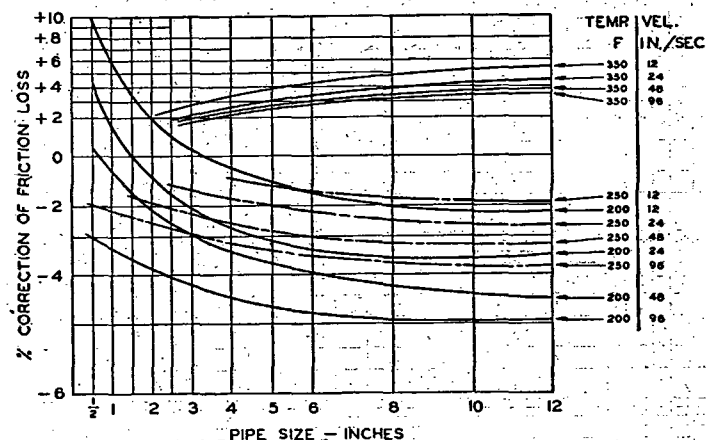


FIG. 21. CORRECTION OF 300 F FRICTION LOSS FOR OTHER WATER TEMPERATURES

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tems and equipment. Converters or heat exchangers are also used for building heating and domestic hot water service systems.

Smaller district heating systems pressurized at 12 to 15 psig with distribution at 250 F are in common use. In such installations the water is drawn into the individual building systems and recirculated by means of a conventional circulator. Temperature is controlled in each system by a control valve at the high temperature line. The control is usually of the indoor-outdoor type, but many variations are used. Sufficient pressure head is usually available to permit circulation of the high temperature water through domestic water heaters for individual supply in each building.

### Pumps for High Temperature Systems

Circulating pumps form one of the most important components of the system, and are installed in the flow main to increase the static pressure in the main and thereby maintain a satisfactory temperature-pressure rela-

TABLE 8. HEAD LOSS IN FITTINGS\*  
(For turbulent flow)

| FITTINGS                 | PIPE SIZE<br>INCHES | FEET OF SAME SIZE PIPE HAVING EQUAL LOSS* |     |     |     |     |     |     |     |      |     |      |     |     |
|--------------------------|---------------------|-------------------------------------------|-----|-----|-----|-----|-----|-----|-----|------|-----|------|-----|-----|
|                          |                     | 10                                        | 8   | 6   | 5   | 4   | 3   | 2½  | 2   | 1½   | 1¼  | 1    | ¾   | ½   |
| Globe Valve              | 340                 | 270                                       | 200 | 170 | 135 | 105 | 83  | 70  | 55  | 45   | 36  | 28   | 21  |     |
| Gate Valve               | 7                   | 5.75                                      | 4.5 | 3.5 | 3   | 2.2 | 1.7 | 1.5 | 1.2 | 1    | 0.8 | 0.6  | 0.5 |     |
| 90° Welding Elbow        | 11                  | 8.5                                       | 6.5 | 5.5 | 4.5 | 3.5 | 2.6 | 2.2 | 1.8 | 1.5  | 1.2 | 0.9  | 0.7 |     |
| 45° Welding Elbow        | 7                   | 6                                         | 4.5 | 3.6 | 3   | 2.4 | 1.7 | 1.5 | 1.2 | 1    | 0.8 | 0.6  | 0.5 |     |
| 22½° Welding Elbow       | 5                   | 4                                         | 3   | 2.5 | 2   | 1.6 | 1.3 | 1.1 | 0.9 | 0.7  | 0.6 | 0.5  | 0.3 |     |
| Lateral <sup>b</sup>     | 26                  | 20                                        | 16  | 13  | 11  | 8   | 6.5 | 5.5 | 4   | 3.5  | 2.8 | 2.2  | 1.6 |     |
| Lateral <sup>c</sup>     | 17                  | 14                                        | 10  | 8.5 | 7   | 5   | 4   | 3.5 | 2.8 | 2.5  | 1.8 | 1.5  | 1.1 |     |
| Welding Tee <sup>e</sup> | 13                  | 10                                        | 8   | 7   | 5.5 | 4   | 3.2 | 2.6 | 2   | 1.7  | 1.4 | 1.2  | 0.8 |     |
| Concentric Reducers      |                     |                                           |     |     |     |     |     |     |     |      |     |      |     |     |
| to                       |                     | 10                                        | 8   | 6   | 5   | 4   | 3   | 2½  | 2   | 1½   | 1¼  | 1    | ¾   | ½   |
| From                     |                     |                                           |     |     |     |     |     |     |     |      |     |      |     |     |
| 10                       |                     |                                           | 1   | 2.5 | 3   | 2.8 |     |     |     |      |     |      |     |     |
| 8                        |                     |                                           | 3.5 |     | 1.2 | 2   | 2.2 | 2.2 |     |      |     |      |     |     |
| 6                        |                     |                                           | 10  | 3.5 |     | 0.5 | 1.3 | 1.8 | 1.7 |      |     |      |     |     |
| 5                        |                     |                                           | 12  | 7.5 | 1.5 |     | 0.5 | 1.2 | 1.4 | 1.5  |     |      |     |     |
| 4                        |                     |                                           | 12  | 9.5 | 4.5 | 1.5 |     | 0.6 | 1.2 | 1.4  | 1.5 |      |     |     |
| 3                        |                     |                                           | 10  | 7   | 5   | 1.8 |     | 0   | 0.8 | 1    | 1   |      |     |     |
| 2½                       |                     |                                           |     | 7.5 | 6   | 3.8 | 0.7 |     | 0   | 0.7  | 0.8 | 0.75 |     |     |
| 2                        |                     |                                           |     |     | 6   | 5   | 2.5 | 0.8 |     | 0    | 0.6 | 0.6  | 0.6 |     |
| 1½                       |                     |                                           |     |     |     | 5   | 3.8 | 2.8 | 9   |      | 0   | 0.5  | 0.5 | 0.5 |
| 1¼                       |                     |                                           |     |     |     |     | 4   | 3   | 2   | 0.3  |     | 0    | 0   | 0.3 |
| 1                        |                     |                                           |     |     |     |     |     | 3   | 2.5 | 1.25 | 0.5 |      | 0   | 0.3 |
| ¾                        |                     |                                           |     |     |     |     |     |     | 2.5 | 2    | 1.3 | 0.5  |     | 0   |
| ½                        |                     |                                           |     |     |     |     |     |     |     | 2    | 1.8 | 1.5  | 0.8 |     |

\* Compiled from data published by Tube Turns, Inc., a Division of the National Cylinder Gas Co.

<sup>b</sup> Used by permission.

<sup>c</sup> Water deflected through branch.

<sup>d</sup> Water flowing straight through fitting.

<sup>e</sup> For eccentric reducers, the values read for concentric reducers must be increased by 33%.

<sup>f</sup> Equivalent length of pipe having a Fanning friction coefficient of 0.006.

tionship and keep the pressure in the system at all times above the evaporation temperature of the water.

It is common practice to use single-inlet single-stage centrifugal pumps operating at 1750 rpm and having water-cooled bearings and glands (although mechanical seals are coming into use). With pumps of this type the total differential head should not exceed 150 ft.

Pumps for high temperature must be specially designed and constructed to withstand the higher pressure and temperature, at which they will operate, and the higher stresses involved. For space heating loads where

the flow varies greatly, it is common practice to use two or more pumps, although care should be taken in motor sizing to avoid overloading when one or more pumps may not be in operation. By use of multiple pumps light loads during off peak periods can be handled economically.

When selecting the size of the pump, consideration should be given to the temperature conditions under which the pump will operate. To illustrate this, at 212 F the density of water is 59.88 lb per cu ft, whereas at 380 F it has dropped to 54.36. Therefore, as the weight of a gallon of water is considerably less, the pump will have to handle a much larger volume of water. On large installations the pump sizes can be kept down to practical limits by the use of multiple pumps connected in parallel to a common header.

To prevent flashing at the pump suction line, a bypass connection with valve is made between the supply and return lines to allow a small quantity of the cooler return water to mix with the supply water from the expansion drum. Thus the temperature of the water entering the pump suction line is a few degrees lower than the evaporation pressure, yet subjected to the full pressure in the drum. The valve is set manually to pass the minimum quantity of water as required above.

#### Pipe, Fittings, and Insulation

Steel pipe and fittings are generally used. An effort should be made to avoid the use of non-ferrous materials, since the action of the water at elevated temperatures on these materials is difficult to predict.

Steel pipe should be used throughout, and piping external to the boiler house should be welded. Within the boiler house flanges are recommended to facilitate inspection and provide ready access. Branches should take off with easy sweeps and full radius bends be used for all changes of direction. Provision for expansion is as important as for steam at the same temperatures. Piping should be insulated to the same thickness and standards as for steam at the same temperature.

Valves for high temperature water should be made with cast steel bodies and stainless steel trim since these have proved far more satisfactory than bronze valves. Wedge-type gate valves are recommended for isolating and for use within the boiler house. For general use throughout the system, globe valves are preferred.

Valves combining flow control and regulation are preferable for high temperature water where heat balancing is necessary, since a small quantity of this water contains a large quantity of heat. As high temperature water is more penetrating than low temperature water, leakage due partly to capillary action should not be ignored because even a small amount of leakage evaporates immediately. This slight leakage becomes noticeable only on the outside of the gland and spindle of the valve where thin deposits of salts are left after evaporation.

#### Control

The control of temperature is usually obtained by conventional means although it is common practice to place control valves on the outlet line of the heat absorbing equipment where the temperatures are lower. In larger distribution systems means of controlling differential pressures between the flow and return mains are advisable.

With space and process heating, temperatures can be controlled within

close limits by the use of two- and three-way mixing valves modulating or by-passing some of the high temperature water. Such controls are essential at heat exchangers or converters.

#### Boilers or Hot Water Generators

Almost any high pressure boiler can be used for high temperature water systems, but certain types as, for example, the water tube boiler, are more advantageous than others. Boiler selection is important and such problems as frictional head loss, available water space, flue outlet, type of firing,

TABLE 9. PROPERTIES OF WATER (212 F TO 400 F)

| TEMPERATURE<br>F | PRESSURE* psia | DENSITY<br>Lb/CuFt | SPECIFIC HEAT<br>Btu/(lb)(°F) | TOTAL HEAT ABOVE 32 F |          |
|------------------|----------------|--------------------|-------------------------------|-----------------------|----------|
|                  |                |                    |                               | Btu/Lb*               | Btu/CuFt |
| 212              | 14.70          | 59.88              | 1.0055                        | 180.00                | 10.760   |
| 220              | 17.19          | 59.66              | 1.0068                        | 188.06                | 11.222   |
| 230              | 20.78          | 59.37              | 1.0087                        | 198.15                | 11.764   |
| 240              | 24.97          | 59.17              | 1.0104                        | 208.26                | 12.327   |
| 250              | 29.82          | 58.84              | 1.0126                        | 218.39                | 12.856   |
| 260              | 35.43          | 58.62              | 1.0148                        | 228.55                | 13.403   |
| 270              | 41.85          | 58.25              | 1.0174                        | 238.74                | 13.912   |
| 280              | 49.20          | 58.04              | 1.0200                        | 248.95                | 14.555   |
| 290              | 57.55          | 57.65              | 1.0230                        | 259.20                | 14.942   |
| 300              | 67.01          | 57.41              | 1.0260                        | 269.48                | 15.476   |
| 310              | 77.68          | 57.00              | 1.0296                        | 279.80                | 15.955   |
| 320              | 89.65          | 56.65              | 1.0332                        | 290.17                | 16.444   |
| 330              | 103.03         | 56.31              | 1.0368                        | 300.59                | 16.931   |
| 340              | 117.99         | 55.95              | 1.0404                        | 311.05                | 17.407   |
| 350              | 134.62         | 55.65              | 1.0440                        | 321.55                | 17.899   |
| 360              | 153.01         | 55.19              | 1.0486                        | 332.10                | 18.333   |
| 370              | 173.33         | 54.78              | 1.0532                        | 342.71                | 18.778   |
| 380              | 195.70         | 54.36              | 1.0578                        | 353.39                | 19.213   |
| 390              | 220.19         | 53.96              | 1.0624                        | 364.14                | 19.644   |
| 400              | 247.25         | 53.62              | 1.0670                        | 374.96                | 20.106   |

\* Reprinted by permission from *Thermodynamic Properties of Steam*, by J. H. Keenan and F. G. Keyes published by John Wiley and Sons, Inc., 1938 edition.

etc., need careful consideration. The larger the system, involving heat distribution circuits of three, four, five miles or more, the greater will be the frictional head on the pumps, so every care should be taken to reduce the head loss in the boiler to a minimum and thus reduce the pump horsepower. Frictional loss through a boiler operating with entrained steam and air in the tubes and headers, can be a serious factor.

Balancing is another problem which can be made simple when the system is well designed. During the spring and autumn months and in mild weather at any time, the heat load will be low and only one boiler will be required. To put a boiler on the line or take one off is simplified if all boiler supply lines are connected into a common expansion drum. Boilers are then controlled from the pressure developed in the drum and the high temperature water supply taken through a dip pipe below the water level.

Since the heat storage in the system is very high (Table 9 illustrates this in Btu per cubic foot) advantage of this high temperature water charac-



teristic can be taken when considering the number and output of the boilers. The output of the central boiler plant can be greatly reduced and the initial cost of the system lowered accordingly if the thermal storage of the system is taken into account.

### Storage

High temperature water systems offer the opportunity of storing heat to even out the peak loads and low loads within the 24-hour cycles. Storage is usually accomplished by means of by-passing water from the flow to the return mains and thereby storing heat in the return main for future use, or by accumulators. Systems which experience normal peaks can obtain as much as 15 percent added capacity through this heat storage. Where peaks are more severe, this storage or thermal flywheel will allow even greater savings.

### Distribution

The conventional conduit or tunnel distribution systems are employed with similar techniques used for installation except that grading of the piping is not important. The mains may be run at different elevations at will, although the high points should be vented by the use of air collectors and the low points should be drained.

### REFERENCES

- <sup>1</sup> Friction Heads in One-Inch Standard Cast-Iron Tees, by F. E. Giesecke and W. H. Badgett (A.S.H.V.E. TRANSACTIONS, Vol. 37, 1931, p. 395).
- <sup>2</sup> Supplementary Friction Heads in One-Inch Cast-Iron Tees, by F. E. Giesecke and W. H. Badgett (A.S.H.V.E. TRANSACTIONS, Vol. 38, 1932, p. 111).
- <sup>3</sup> *Heating and Air Conditioning of Buildings*, by Oscar Faber and J. R. Kell (Architectural Press, London).

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## CHAPTER 23

# RADIATORS, CONVECTORS, BASEBOARD AND FINNED-TUBE UNITS

Definitions, Heat Emission, Radiators, Convectors, Baseboard Radiation, Finned-Tube Radiation, Ratings, Heating Effect, Effect of Operating Conditions, Effect of Paint, Enclosed Radiators, Heating the Radiator and Convector

**R**ADIATORS, convectors, baseboard, and finned-tube are the common types of heat-distributing units used in steam and hot water heating systems. They are used to supply heat to a room by radiation and convection. The function of these devices is to maintain occupancy comfort through the control of the mean radiant and air temperatures in the area. Since heat losses through the various parts of the structure constantly tend to lower these temperatures below the comfort point, the room-heating unit should be so placed and regulated that its output will replace the losses when and where they occur. If 80 percent of the room heat loss occurs through a cold wall or window area, then 80 percent of the input should be introduced in or directed toward that area.

The term *radiator* is generally confined to sectional cast-iron radiation. They emit a large part of their heat by radiation. Cast-iron radiator types may be column, large-tube, small-tube or wall.

The term *convector* refers to a heat-distributing unit which operates with gravity recirculated room air, is surrounded on all sides by an enclosure having an air-inlet opening at its bottom end and an air-outlet opening at its top, and is installed inside the heated room or is recessed in the wall.

The terms *baseboard* and *baseboard radiation* refer to steam- or water-type heat-distributing units designed for installation along the bottom of the walls of rooms, replacing the conventional baseboard. They operate with gravity-recirculated room air, and have a substantial portion of their frontal face surface directly exposed to the room.

The term *finned-tube* refers to steam-, or water-type heat-distributing units composed of a finned-tube element fabricated from metallic tubing which has a plurality of metallic fins bonded to the tube. These heaters are designed for installation without enclosure, or with open-type grilles, covers, or enclosures having top, front, or inclined outlets.

### HEAT EMISSION

Steam-, and water-type heat-distributing units emit heat by radiation and convection. These heat-transfer processes and the factors that affect them are discussed in detail in Chapter 5. In general, those units having a large portion of their heated surface exposed directly to the room emit a larger proportion of heat by radiation than do units which have the heating surface completely or partly concealed from view.

The output of a heat-distributing unit can be measured only by the heat

TABLE 1. COLUMN-TYPE CAST-IRON RADIATOR

| HEIGHT<br>Inches | GENERALLY ACCEPTED RATING PER SECTION <sup>a</sup> |        |             |        |              |        |
|------------------|----------------------------------------------------|--------|-------------|--------|--------------|--------|
|                  | One Column                                         |        | Two Column  |        | Three Column |        |
|                  | Sq Ft                                              | Btu/hr | Sq Ft       | Btu/hr | Sq Ft        | Btu/hr |
| 15               |                                                    |        | 1½          | 360    |              |        |
| 18               |                                                    |        | 2           | 480    | 2½           | 540    |
| 20               | 1½                                                 | 360    | 2½          | 540    | 3            | 720    |
| 22               |                                                    |        | 2½          | 560    |              |        |
| 23               | 1¾                                                 | 400    |             |        |              |        |
| 26               | 2                                                  | 480    | 2¾          | 640    | 3¾           | 900    |
| 32               | 2½                                                 | 600    | 3½          | 800    | 4½           | 1080   |
| 38               | 3                                                  | 720    | 4           | 960    | 5            | 1200   |
| 45               |                                                    |        | 5           | 1200   | 6            | 1440   |
|                  |                                                    |        |             |        |              |        |
|                  | Four Column                                        |        | Five Column |        | Six Column   |        |
|                  | Sq Ft                                              | Btu/hr | Sq Ft       | Btu/hr | Sq Ft        | Btu/hr |
| 13               |                                                    |        |             |        | 3            | 720    |
| 16               |                                                    |        |             |        | 3¾           | 900    |
| 18               | 3                                                  | 720    | 4¾          | 1120   | 4½           | 1080   |
| 20               |                                                    |        |             |        | 5            | 1200   |
| 22               | 4                                                  | 960    |             |        |              |        |
| 26               | 5                                                  | 1200   | 7           | 1680   |              |        |
| 32               | 6½                                                 | 1560   |             |        |              |        |
| 38               | 8                                                  | 1920   | 10          | 2400   |              |        |
| 45               | 10                                                 | 2400   |             |        |              |        |

<sup>a</sup> These ratings are based on steam at 215 F and air at 70 F. They apply only to installed radiators exposed in a normal manner; not to radiators installed behind enclosures, grilles, or under shelves. For Btu per hour ratings at other temperatures, divide table values by factors found in Table 6.

TABLE 2. LARGE-TUBE CAST-IRON RADIATORS

Sectional, cast-iron, tubular-type radiators of the large-tube pattern, that is, having tubes approximately 1½ in. in diameter, 2½ in. on centers.

| NUMBER OF<br>TUBES PER<br>SECTION | CATALOG RATING<br>PER SECTION <sup>a</sup> |        | HEIGHT | WIDTH   | SECTION<br>CENTER<br>SPACING <sup>b</sup> | LEG HEIGHT <sup>c</sup><br>TO TAPPING |
|-----------------------------------|--------------------------------------------|--------|--------|---------|-------------------------------------------|---------------------------------------|
|                                   | Sq Ft                                      | Btu/hr |        |         |                                           |                                       |
| 3                                 | 1¾                                         | 420    | 20     |         | 2½                                        | 4½                                    |
|                                   | 2                                          | 480    | 23     |         | 2½                                        | 4½                                    |
|                                   | 2½                                         | 560    | 26     | 4½      | 2½                                        | 4½                                    |
|                                   | 3                                          | 720    | 32     |         | 2½                                        | 4½                                    |
|                                   | 3½                                         | 840    | 38     |         | 2½                                        | 4½                                    |
| 4                                 | 2¼                                         | 540    | 20     |         | 2½                                        | 4½                                    |
|                                   | 2½                                         | 600    | 23     |         | 2½                                        | 4½                                    |
|                                   | 2¾                                         | 660    | 26     | 6¼-6½   | 2½                                        | 4½                                    |
|                                   | 3¼                                         | 840    | 32     |         | 2½                                        | 4½                                    |
|                                   | 4¼                                         | 1020   | 38     |         | 2½                                        | 4½                                    |
| 5                                 | 2¾                                         | 640    | 20     |         | 2½ <sup>d</sup>                           | 4½                                    |
|                                   | 3                                          | 720    | 23     |         | 2½ <sup>d</sup>                           | 4½                                    |
|                                   | 3½                                         | 840    | 26     | 8-8½    | 2½ <sup>d</sup>                           | 4½                                    |
|                                   | 4½                                         | 1040   | 32     |         | 2½ <sup>d</sup>                           | 4½                                    |
|                                   | 5                                          | 1200   | 38     |         | 2½ <sup>d</sup>                           | 4½                                    |
| 6                                 | 3                                          | 720    | 20     |         | 2½                                        | 4½                                    |
|                                   | 3½                                         | 840    | 23     |         | 2½                                        | 4½                                    |
|                                   | 4                                          | 960    | 26     | 9-10½   | 2½                                        | 4½                                    |
|                                   | 5                                          | 1200   | 32     |         | 2½                                        | 4½                                    |
|                                   | 6                                          | 1440   | 38     |         | 2½                                        | 4½                                    |
| 7                                 | 2½                                         | 600    | 14     |         | 2½                                        | 3                                     |
|                                   | 3                                          | 720    | 17     | 11½-12½ | 2½                                        | 3                                     |
|                                   | 3½                                         | 880    | 20     |         | 2½                                        | 3 or 4½                               |

<sup>a</sup> These ratings are based on steam at 215 F and air at 70 F. They apply only to installed radiators exposed in a normal manner; not to radiators installed behind enclosures, grilles, or under shelves. For Btu per hour ratings at other temperatures, divide table values by factors found in Table 6.

<sup>b</sup> Maximum assembly 60 sections. Length equals number of sections times 2½ in.

<sup>c</sup> Where greater than standard leg heights are required, this dimension shall be 6 in., except for 7-tube sections, in heights from 13 to 20 in., inclusive, for which this dimension shall be 4½ in. Radiators may be furnished without legs.

<sup>d</sup> For 5-tube hospital-type radiation, this dimension is 3 in.

it emits and is generally expressed in units of: Btu per hr; *Mbh* (1000 Btu per hr); or in equivalent direct radiation (e.g., 240 Btu per hr for steam).

## RADIATORS

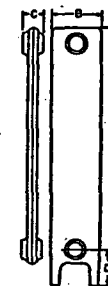
Column and large-tube radiators are no longer manufactured, but since many of these units are still in use, Tables 1 and 2 are included to provide principal dimensions and average ratings of them.

The small-tube type radiators, with a spacing of 1½ in. per section, are about the only available cast-iron radiating surface for homes and office buildings. Small-tube radiators occupy less space than the older column and large-tube radiators, and are particularly suited for installation in recesses.

After a study of the demand for various sizes of radiators, the *Institute of*

TABLE 3. SMALL-TUBE CAST-IRON RADIATORS

| NUMBER<br>OF<br>TUBES<br>PER<br>SECTION | CATALOG<br>RATING<br>PER<br>SECTION <sup>a</sup> |        | SECTION DIMENSIONS       |            |         |                                 |
|-----------------------------------------|--------------------------------------------------|--------|--------------------------|------------|---------|---------------------------------|
|                                         |                                                  |        | A<br>Height <sup>c</sup> | B<br>Width |         | D<br>Leg<br>Height <sup>c</sup> |
|                                         |                                                  |        |                          | Minimum    | Maximum |                                 |
|                                         | Sq Ft                                            | Btu/hr | In.                      | In.        | In.     | In.                             |
| 3 <sup>d</sup>                          | 1.6                                              | 384    | 25                       | 3¼         | 3½      | 1¾                              |
| 4 <sup>d</sup>                          | 1.6                                              | 384    | 19                       | 4¼         | 4¾      | 1¾                              |
|                                         | 1.8                                              | 432    | 22                       | 4¼         | 4¾      | 1¾                              |
|                                         | 2.0                                              | 480    | 25                       | 4¼         | 4¾      | 1¾                              |
| 5 <sup>d</sup>                          | 2.1                                              | 504    | 22                       | 5½         | 6½      | 1¾                              |
|                                         | 2.4                                              | 576    | 25                       | 5½         | 6½      | 1¾                              |
| 6 <sup>d</sup>                          | 2.3                                              | 552    | 19                       | 6¼         | 8       | 1¾                              |
|                                         | 3.0                                              | 720    | 25                       | 6¼         | 8       | 1¾                              |
|                                         | 3.7                                              | 888    | 32                       | 6¼         | 8       | 1¾                              |



<sup>a</sup> These ratings are based on steam at 215 F and air at 70 F. They apply only to installed radiators exposed in a normal manner; not to radiators installed behind enclosures, grilles, or under shelves. For Btu per hour ratings at other temperatures, divide table values by factors found in Table 6.

<sup>b</sup> Length equals number of sections times 1½ in.

<sup>c</sup> Overall height and leg height, as produced by some manufacturers, are one inch greater than shown in Columns A and D. Radiators may be furnished without legs. Where greater than standard leg heights are required this dimension shall be 4½ in.

<sup>d</sup> Or equal.

Boiler and Radiator Manufacturers, in cooperation with the Division of Simplified Practice, National Bureau of Standards, established Simplified Practice Recommendation R174-47 for small-tube cast-iron radiators. Table 3 shows the size and dimensions now being manufactured.

Wall radiators are hung from wall brackets and are well adapted to use in factory buildings. Tests have shown that the heat emitted from a wall-type radiator may be reduced from 5 to 10 percent if the radiator is placed near the ceiling with the bars horizontal and in an air temperature exceeding 70 F. When radiators are placed near the ceiling, there is usually such a large difference in the temperature between the floor level and the ceiling that it becomes difficult to heat the living zone of the rooms satisfactorily. Dimensions and heat emission rates for wall radiators are given in Table 4.

## CONVECTORS

A typical recessed convector is shown in Fig. 1. The room air enters the convector enclosure near the floor line, below the heating element, is heated in passing through the element, and is delivered to the room through

the outlet grille located near the top of the enclosure. Factory-assembled units consisting of a heating element, casing, and outlet grille with damper are widely used. Grilles may be used over air inlets.

In cases where enclosures are to be used but are not furnished by the heater manufacturer, it is important that the proportions of the cabinet and the grilles be so designed that they will not impair the performance of the assembled convector. It is desirable that the enclosure or housing for the convector fit as snugly as possible so that the air to be heated cannot by-pass the heating element in passing through the enclosure.

Cast-iron heating units may be concealed in a cabinet or enclosure for appearance. In such cases a greater percentage of heat is conveyed to the room by convection thereby resulting in a form of gravity convector.

The output of a convector, for any given length and depth, is a function of the height of the discharge grille above the heating element. The published ratings are generally given in terms of Btu per hour or square feet of *Equivalent Direct Radiation*, EDR. For steam convectors, as for radiators, 240 Btu per hr may be taken as an equivalent square foot of radiation. When more than one heating unit is used, one mounted above the other in

TABLE 4. CAST-IRON WALL RADIATORS

| APPROXIMATE DIMENSIONS—INCHES |                 |           | HEAT OUTPUT <sup>a</sup> |        |
|-------------------------------|-----------------|-----------|--------------------------|--------|
| Height                        | Length or Width | Thickness | Sq Ft                    | Btu/hr |
| 13 1/4                        | 16 1/2          | 3         | 6 1/2                    | 1560   |
| 13 1/4                        | 22              | 3         | 8                        | 1920   |
| 22                            | 13 1/4          | 3         | 8                        | 1920   |
| 13 1/4                        | 29              | 3         | 11                       | 2640   |
| 29                            | 13 1/4          | 3         | 11                       | 2640   |

<sup>a</sup> These ratings are based on steam at 215 F and air at 70 F. They apply only to installed radiators exposed in a normal manner, not to radiators installed behind enclosures, grilles, or under shelves. For Btu per hour ratings at other temperatures divide table values by factors found in Table 6.

the same cabinet, the output of the upper unit or units will be materially less than that of the bottom unit.

### BASEBOARD RADIATION

Baseboard radiation is divided into three types: (1) radiant, (2) radiant-convector and (3) finned-tube.<sup>1</sup> *Radiant-type* baseboard is made of cast iron or steel. This type of unit emits a large proportion of heat to the room by radiation. These units are sometimes suspended from the ceiling in rooms such as kitchens having little or no available wall space for floor mounted units. For this location, as compared with floor mounting, the amount of convected heat obtained from the unit is reduced, and consequently 25 to 50 percent additional surface must be installed.

*Radiant-convector type* baseboard also is made of cast iron or steel. These units are provided with air openings at the top and bottom to permit circulation of room air over the wall side of the unit where extended surface is provided to obtain maximum heat output. A large part of the heat obtained from these units is transferred by convection. This type of baseboard which has a greater output per linear foot than the radiant type, has advantages where wall space is at a premium or the heat loss of the room is high.

*Finned-tube type* of baseboard has a finned-tube heating element which is concealed by a long low sheet-metal cover. A major portion of the heat is transferred to the room by convection. The output of this type of base-

board varies over a wide range depending on the enclosure depth and height, the diameter of the tube, and the number and size of fins. When selecting this type of baseboard the designer should avoid using a unit with too high an output per linear foot because performance is best when units are installed along as much of the exposed wall as possible.

The basic advantage of the baseboard radiator or of the long low narrow radiator is that its normal placement is along the cold walls and under areas where the greatest heat loss occurs in a room. Other advantages claimed for the baseboard radiator are: it is inconspicuous; it is clean in operation; it offers a minimum of interference with furniture placement, and, it distributes the heat near the floor. This last characteristic reduces the floor to ceiling temperature gradient to about 2 to 4 F deg, and tends to produce uniform temperatures throughout the room. It also makes baseboard radiators especially adaptable to basementless homes, where cold floors are prevalent.<sup>2</sup>

Heat loss calculations for baseboard heating systems are the same as

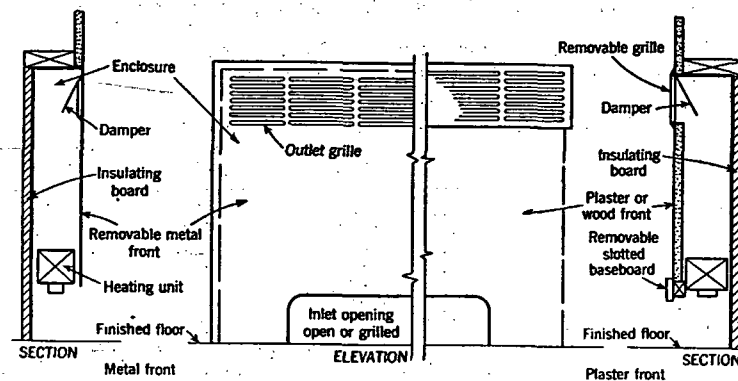


FIG. 1. TYPICAL RECESSED CONVECTOR

those used for other types of radiation. The procedure for designing baseboard heating systems is given in *I = B = R* Installation Guide No. 5.<sup>1</sup> Ratings for baseboard radiation are expressed in Btu per linear foot.

### FINNED-TUBE RADIATION

The finned-tube type of radiation is always installed in the same manner as pipe or pipe coils. It is rapidly superseding pipe coils as much more output can be obtained per linear foot of pipe. When installed in two or three tiers in a hot-water system, long sweep return bends may be used to connect the tiers. Header type connections are not satisfactory for long hot-water coils due to the tendency of water to short circuit along the path of least resistance.

*Pipe coils* are assemblies of standard pipe or tubing (1 in. to 2 in.) which are used as radiators. In older practice these coils were commonly used in factory buildings, but are not often found in this service today. When coils are used, the miter-type assembly is preferable, as it readily permits expansion in the pipe.

The heat emission of pipe coils placed vertically on a wall, with the pipes horizontal, is given in Table 5, which has been developed from available data and does not represent definite results of tests. For such coils the

heat emission varies as the height of the coil. The heat emission of each pipe in *ceiling* coils, placed horizontally, is about 126 Btu, 156 Btu, and 175 Btu per linear foot of pipe, respectively, for 1-in., 1½-in., and 1¾-in. coils.

When vertical pipes leading through small rooms are left uninsulated for the purpose of supplying heat, the overall coefficient of heat transfer may be safely estimated at 2.5 Btu per (hr) (sq ft) (F deg temperature difference between the heating medium and the average air).

### RATINGS

A standard method of testing radiators was adopted by the A.S.H.A.E. in 1927.<sup>3</sup> This Code provides for a standard test room, the temperature of which is to be maintained at 70 F, measured in the center of the room at an elevation of 5 ft above the floor. The steam temperature in the radiator is to be 215 F, which corresponds to 15.6 lb per sq in. absolute. The weight of condensate per hour, under these standard conditions, multiplied by the difference in the enthalpy of the steam entering the radiator and that of the condensate leaving the radiator, gives the radiator output

TABLE 5. HEAT EMISSION OF PIPE COILS PLACED VERTICALLY ON A WALL (PIPES HORIZONTAL) CONTAINING STEAM AT 215 F AND SURROUNDED WITH AIR AT 70 F

*Btu per linear foot of coil per hour (not linear feet of pipe)*

| SIZE OF PIPE    | 1 IN. | 1½ IN. | 1¾ IN. |
|-----------------|-------|--------|--------|
| Single row..... | 132   | 162    | 185    |
| Two.....        | 252   | 312    | 348    |
| Four.....       | 440   | 545    | 616    |
| Six.....        | 567   | 702    | 793    |
| Eight.....      | 651   | 796    | 907    |
| Ten.....        | 732   | 907    | 1020   |
| Twelve.....     | 812   | 1005   | 1135   |

in Btu per hour. This output divided by 240 gives the steam rating of the radiator in equivalent square feet, EDR.

The method of testing and rating both ferrous and non-ferrous convectors, which is now generally accepted, is given in Commercial Standard CS140-47, Testing and Rating Convectors,<sup>4</sup> which has been developed co-operatively by the Convector Manufacturers Association, the Institute of Boiler and Radiator Manufacturers, other members of the trade, and the National Bureau of Standards.

The rating of a top outlet convector is established at a value not in excess of the *condensation capacity* (which is the heat extracted from the steam or water in the convector, under standard test conditions). The rating of a front-outlet or inclined-outlet convector includes the *condensation capacity* plus an allowance for heating effect<sup>5, 6</sup> in the occupied zone, based on convector enclosure height from bottom of the enclosure to top of the outlet. The heating-effect allowance for a front-outlet convector varies from 0 percent for a 36-in. outlet height to 15 percent for an outlet height of 18 in. or less.

For an inclined-outlet convector the heating effect allowance is obtained by multiplying the allowance for a front-outlet convector by a factor (angle of outlet to horizontal ÷ 90).

A Testing and Rating Code for Baseboard Type of Radiation was first adopted by the Institute of Boiler and Radiator Manufacturers in 1950. A

revised second edition<sup>7</sup> of the code was published in 1952. The second edition contains test procedures for determining both steam and water capacities. The ratings are expressed in Btu per hour per linear foot, and may also be expressed in square feet of steam radiation per linear foot. Both steam and water ratings include an effective heat allowance of 15 percent of the heat capacity determined by test.

Manufacturers who wish to publish baseboard radiation ratings as  $I=B=R$  ratings may submit test data to the  $I=B=R$  Baseboard Rating Committee and receive approval of test procedure and ratings. The following catalog information must be given for  $I=B=R$  Steam Ratings: (1) name or other type of designation, (2)  $I=B=R$  emblem, (3) rating in Btu per linear ft, (4) percentage added to capacity in determining rating, (5) a statement that ratings are based on active length, (6) the difference between active and total length, and (7) if a finned tube element is used, a statement of the fin size, thickness and spacing.

The following additional information must be given for  $I=B=R$  water ratings: (1) the water temperatures and flow rates for which ratings have been approved, and (2) pressure loss through the unit.

TABLE 6. FACTORS TO CONVERT  $I=B=R$  FINNED-TUBE STEAM RATINGS TO HOT WATER RATINGS AT TEMPERATURES INDICATED

| AVERAGE RADIATOR TEMPERATURE | FACTOR | AVERAGE RADIATOR TEMPERATURE | FACTOR | AVERAGE RADIATOR TEMPERATURE | FACTOR |
|------------------------------|--------|------------------------------|--------|------------------------------|--------|
| 150                          | 0.45   | 175                          | 0.65   | 200                          | 0.88   |
| 155                          | 0.49   | 180                          | 0.69   | 205                          | 0.91   |
| 160                          | 0.53   | 185                          | 0.73   | 210                          | 0.95   |
| 165                          | 0.57   | 190                          | 0.78   | 215                          | 1.00   |
| 170                          | 0.61   | 195                          | 0.82   | 220                          | 1.05   |

A Testing and Rating Code for Finned-Tube Type of Radiation<sup>8</sup> was adopted by The Institute of Boiler and Radiator Manufacturers in 1951, and the code was amended in 1954. This code contains a test procedure for determining steam ratings. The code contains a table of effective heat allowances which may be added to the condensate output (corrected to standard conditions) in establishing the rating. These allowances vary from zero for an installed height of 36 in. or more to a maximum of 15 percent for an installed height of 18 in. or less. Water ratings are determined by applying the factors in Table 6 to approved  $I=B=R$  steam ratings.

Manufacturers who wish to publish finned-tube radiation ratings as  $I=B=R$  ratings must submit test data to the  $I=B=R$  Finned-Tube Rating Committee and receive approval of test procedure and rating. In their catalogs they must show information similar to that required when publishing ratings for baseboard radiation.

### Heating Effect

The acceptance of heating effect allowance by the industry is the result of observation such as the following:<sup>6</sup>

1. The heating effect of a radiator cannot be judged solely by the amount of steam condensed within the radiator.
2. Smaller floor-to-ceiling temperature differentials can be maintained with long, low, thin, direct radiators, than can be maintained with high, direct radiators.
3. The larger portion of the floor-to-ceiling temperature differential in a room of average ceiling height heated with direct radiators occurs between the floor and the breathing level.
4. The comfort level (approximately 2 ft-6 in. above floor) is below the breathing

line level (approximately 5 ft-0 in. above floor), and temperatures taken at the breathing line may not be indicative of the actual heating effect of a radiator in the room. The comfort-indicating temperature should be taken below the breathing line level.

5. High column radiators placed at the sides of window openings do not produce as comfortable heating effects as long, low, direct radiators placed beneath windows.

The application of a heating-effect allowance implies that some radiators and convectors use less steam than others for producing equal comfort heating results in the room.

All authorities do not agree that the use of such an allowance is justified. No standard method for evaluating the heating effect of radiators and convectors and correlating it with comfort has yet been accepted.

TABLE 7. CORRECTION FACTORS FOR DIRECT CAST-IRON RADIATORS AND CONVECTORS\*

| STEAM PRESS. (APPROX.) |                         | HEATING<br>MEDIUM<br>TEMP F<br>STEAM OR<br>WATER | FACTORS FOR DIRECT<br>CAST-IRON RADIATORS |      |      |      |      |      |      | FACTORS FOR CONVECTORS  |      |      |      |      |      |      |
|------------------------|-------------------------|--------------------------------------------------|-------------------------------------------|------|------|------|------|------|------|-------------------------|------|------|------|------|------|------|
| Gage Vacuum<br>In. Hg. | Abs<br>Lb per<br>Sq In. |                                                  | ROOM TEMPERATURE F                        |      |      |      |      |      |      | INLET AIR TEMPERATURE F |      |      |      |      |      |      |
|                        |                         |                                                  | 80                                        | 75   | 70   | 65   | 60   | 55   | 50   | 80                      | 75   | 70   | 65   | 60   | 55   | 50   |
| 22.4                   | 3.7                     | 150                                              | 2.58                                      | 2.36 | 2.17 | 2.00 | 1.86 | 1.73 | 1.62 | 3.14                    | 2.83 | 2.57 | 2.35 | 2.15 | 1.98 | 1.84 |
| 20.3                   | 4.7                     | 160                                              | 2.17                                      | 2.00 | 1.86 | 1.73 | 1.62 | 1.52 | 1.44 | 2.57                    | 2.35 | 2.15 | 1.98 | 1.84 | 1.71 | 1.59 |
| 17.7                   | 6.0                     | 170                                              | 1.86                                      | 1.73 | 1.62 | 1.52 | 1.44 | 1.35 | 1.28 | 2.16                    | 1.98 | 1.84 | 1.71 | 1.59 | 1.49 | 1.40 |
| 14.6                   | 7.5                     | 180                                              | 1.62                                      | 1.52 | 1.44 | 1.35 | 1.28 | 1.21 | 1.15 | 1.84                    | 1.71 | 1.59 | 1.49 | 1.40 | 1.32 | 1.24 |
| 10.9                   | 9.3                     | 190                                              | 1.44                                      | 1.35 | 1.28 | 1.21 | 1.15 | 1.10 | 1.05 | 1.59                    | 1.49 | 1.40 | 1.32 | 1.24 | 1.17 | 1.11 |
| 6.5                    | 11.5                    | 200                                              | 1.28                                      | 1.21 | 1.15 | 1.10 | 1.05 | 1.00 | 0.96 | 1.40                    | 1.32 | 1.24 | 1.17 | 1.11 | 1.05 | 1.00 |
| Lb per Sq In.          |                         |                                                  |                                           |      |      |      |      |      |      |                         |      |      |      |      |      |      |
| 1                      | 15.6                    | 215                                              | 1.10                                      | 1.05 | 1.00 | 0.96 | 0.92 | 0.88 | 0.85 | 1.17                    | 1.11 | 1.05 | 1.00 | 0.95 | 0.91 | 0.87 |
| 2                      | 21                      | 230                                              | 0.96                                      | 0.92 | 0.88 | 0.85 | 0.81 | 0.78 | 0.76 | 1.00                    | 0.95 | 0.91 | 0.87 | 0.83 | 0.79 | 0.76 |
| 5                      | 21                      | 250                                              | 0.81                                      | 0.78 | 0.76 | 0.73 | 0.70 | 0.68 | 0.66 | 0.83                    | 0.79 | 0.76 | 0.73 | 0.70 | 0.68 | 0.65 |
| 27                     | 42                      | 270                                              | 0.70                                      | 0.68 | 0.66 | 0.64 | 0.62 | 0.60 | 0.58 | 0.70                    | 0.68 | 0.65 | 0.63 | 0.60 | 0.58 | 0.56 |
| 52                     | 67                      | 300                                              | 0.58                                      | 0.57 | 0.55 | 0.53 | 0.52 | 0.51 | 0.49 | 0.56                    | 0.54 | 0.53 | 0.51 | 0.49 | 0.48 | 0.47 |

\* To determine the size of a radiator or a convector for a given space, multiply the heat loss of the space in Btu per hour by the proper factor from the above table and select radiator or convector having an equivalent Btu per hour rating.

An alternate method is to divide the heat loss in Btu per hour by 240 and multiply the result by the proper factor from the above table and select radiator or convector having an equivalent square foot rating.

To determine the heating capacity of a radiator or a convector under conditions other than the basic ones with the heating medium at a temperature of 215 F, and the room temperature at 70 F in the case of a radiator, and the inlet air temperature at 85 F in the case of a convector, divide the heating capacity at the basic rating conditions by the proper factor from the above table.

### EFFECT OF OPERATING CONDITIONS

The heat output of a radiator, convector, baseboard or finned-tube unit is an exponential function of the temperature difference between the air in the room and the heating medium in the room-heating unit, or, expressed as an equation

$$H = c(t_s - t_r)^n \quad (1)$$

where

$H$  = heat output in Btu per hour.

$c$  = a constant determined by test for each type.

$t_s$  = average temperature of heating medium, Fahrenheit. For hot water the arithmetical average of the entering and leaving water temperatures is used.

$t_r$  = room air temperature Fahrenheit. Air temperature 60 in. above the floor is generally used for radiators while the temperature 3 in. above the floor or at the inlet of the heating unit is used for all other types of heating units.

$n$  = an exponent which equals 1.3 for radiators, 1.4 for baseboard radiation, and

1.5 for convectors. For finned-tube radiation  $n$  varies with both air and heating-medium temperatures.

Correction factors for converting outputs at standard rating conditions to outputs at other operating conditions are given in Tables 7 and 8.

### Effect of Paint

For a radiator, the finish coat of paint affects the heat output. Oil paints of any color will give about the same results as unpainted black or rusty surfaces, but an aluminum or a bronze paint will reduce the heat emitted by radiation. The net effect may be a reduction of 10 percent or more in the total heat output of the radiator.<sup>9, 10, 11</sup>

TABLE 8. CORRECTION FACTORS FOR FINNED-TUBE AND BASEBOARD RADIATION\*

| STEAM PRESSURE APPROX  |                      | HEATING MEDIUM TEMP. F<br>STEAM OR WATER | FACTORS FOR FINNED-TUBE  |      |      |      |      |      |      |      | FACTORS FOR BASEBOARD    |      |      |      |      |      |  |  |
|------------------------|----------------------|------------------------------------------|--------------------------|------|------|------|------|------|------|------|--------------------------|------|------|------|------|------|--|--|
| Gage Vacuum<br>In. Hg. | Abs Lb per<br>Sq in. |                                          | Inlet Air Temperature, F |      |      |      |      |      |      |      | Inlet Air Temperature, F |      |      |      |      |      |  |  |
|                        |                      |                                          | 80                       | 75   | 70   | 65   | 60   | 55   | 50   | 80   | 75                       | 70   | 65   | 60   | 55   | 50   |  |  |
| 22.4                   | 3.7                  | 150                                      | 2.80                     | 2.50 | 2.20 | 1.95 | 1.81 | 1.67 | 1.54 | 2.86 | 2.61                     | 2.38 | 2.20 | 2.03 | 1.89 | 1.76 |  |  |
| 20.3                   | 4.7                  | 160                                      | 2.34                     | 2.14 | 1.94 | 1.75 | 1.62 | 1.50 | 1.37 | 2.38 | 2.20                     | 2.03 | 1.89 | 1.76 | 1.64 | 1.56 |  |  |
| 17.7                   | 6.0                  | 170                                      | 2.01                     | 1.86 | 1.70 | 1.56 | 1.46 | 1.36 | 1.26 | 2.03 | 1.89                     | 1.76 | 1.64 | 1.54 | 1.44 | 1.38 |  |  |
| 14.6                   | 7.5                  | 180                                      | 1.76                     | 1.65 | 1.53 | 1.42 | 1.32 | 1.24 | 1.15 | 1.76 | 1.64                     | 1.55 | 1.44 | 1.38 | 1.29 | 1.23 |  |  |
| 10.9                   | 9.3                  | 190                                      | 1.53                     | 1.45 | 1.36 | 1.28 | 1.20 | 1.12 | 1.03 | 1.54 | 1.44                     | 1.37 | 1.29 | 1.22 | 1.16 | 1.09 |  |  |
| 6.5                    | 11.5                 | 200                                      | 1.38                     | 1.31 | 1.24 | 1.16 | 1.09 | 1.02 | 0.95 | 1.38 | 1.29                     | 1.23 | 1.16 | 1.09 | 1.05 | 1.00 |  |  |
| Lb per sq in.          |                      |                                          |                          |      |      |      |      |      |      |      |                          |      |      |      |      |      |  |  |
| 1                      | 15.6                 | 215                                      | 1.17                     | 1.12 | 1.06 | 1.00 | 0.95 | 0.90 | 0.85 | 1.16 | 1.10                     | 1.05 | 1.00 | 0.95 | 0.92 | 0.88 |  |  |
| 6                      | 21                   | 230                                      | 1.00                     | 0.97 | 0.93 | 0.90 | 0.86 | 0.82 | 0.78 | 1.00 | 0.96                     | 0.92 | 0.88 | 0.84 | 0.81 | 0.77 |  |  |
| 15                     | 30                   | 250                                      | 0.88                     | 0.85 | 0.82 | 0.78 | 0.75 | 0.71 | 0.67 | 0.86 | 0.82                     | 0.79 | 0.76 | 0.73 | 0.70 | 0.68 |  |  |
| 27                     | 42                   | 270                                      | 0.75                     | 0.73 | 0.70 | 0.68 | 0.65 | 0.62 | 0.59 | 0.73 | 0.70                     | 0.68 | 0.66 | 0.63 | 0.61 | 0.59 |  |  |
| 52                     | 67                   | 300                                      | 0.62                     | 0.60 | 0.58 | 0.56 | 0.54 | 0.52 | 0.50 | 0.58 | 0.57                     | 0.55 | 0.53 | 0.52 | 0.51 | 0.49 |  |  |

\* To determine the heating capacity under conditions other than the basic ones with the heating medium at a temperature of 215 F, and the inlet air temperature at 65 F, divide the heating capacity at the basic rating conditions by the proper factor from the above table.

### ENCLOSED RADIATORS

The general effect of an enclosure placed about a direct radiator is to restrict the air flow, diminish the radiation and, when properly designed, improve the heat distribution within the heated space.<sup>6, 12</sup>

Some commercial enclosures and shields for use on direct radiators are equipped with water pans for the purpose of adding moisture to the air in the room. Tests<sup>13</sup> show that an average evaporative rate of about 0.235 lb per (hr) (sq ft of water surface) may be obtained from such pans, when a radiator is steam heated and the relative humidity in the room is between 25 and 40 percent. This source of supply of moisture alone is not adequate to maintain a relative humidity above 25 percent on a zero day.

### HEATING THE RADIATOR AND CONVECTOR

The maximum condensation occurs in a heating unit when the steam is first turned on. Tests<sup>14</sup> on an old-style column-type cast-iron radiator indicated that in the first 10 min the condensation rate reached a peak of 0.95 lb per sq ft of radiation per hour and 10 to 15 min later dropped to a rate of 0.24 lb. In one-pipe gravity systems the rate of steam supply to the heating unit, while heating up, is frequently retarded by controlled

elimination of air through air valves or traps. In two-pipe systems automatic control valves may also retard the supply of steam. Vacuum types of air venting valves may be used to reduce the length of the venting periods.

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## CHAPTER 24

### PANEL HEATING

Definitions; Application Methods: Embedded Piping for Ceilings, Walls, or Floors; Warm Air and Electrically Heated Ceilings, Walls; or Floors; Output from Panel Surfaces: Radiation, Convection and Combined Heat Transfer; Floor Panel Design: Design Conditions, Calculation of Room Heat Loss, Determination of UMRT, Determination of Panel Output, Graphical Determination of Panel Input and Water Temperature; Ceiling and Wall Panel Design; Hot Water Piping, Installation and Control; Snow Melting: Design and Installation

IN this chapter the term, Panel Heating, is used to describe a method of space heating which employs large heated areas of interior room surfaces operating at relatively low surface temperatures (80 to 125 F). The heating elements usually consist of warm water piping, warm air ducts, or low temperature electrical resistance elements embedded in, or located behind, ceiling, wall, or floor surfaces.

Panel heating may be considered as another method of convenient and effective space heating. The heat loss requirements may be calculated in the conventional manner except that the heat loss through the area occupied by the heated panel need not be included. An assumed reverse heat loss from the panel, however, should be included in determining heating main size and the boiler load. The heat release from the panel is expressed in terms of hourly heat output per square foot of surface. The room air temperatures to be maintained are approximately the same as those maintained by heating systems employing cast-iron radiators, convectors, or warm air ducts.

This chapter does not include a separate discussion of such topics as the influence of radiation on human comfort, the mechanisms by which human beings release heat, and other similar topics that apply to all methods of heating interior spaces for human comfort. The reader is referred to Chapter 6 for a detailed discussion of these subjects.

### APPLICATION METHODS

The great majority of panel installations of the past 50 years (which is the period of the modern utilization of this method of heating) have used warm water as the heating medium which is circulated in embedded piping. More recently, the use of warm air ducts, and embedded electrical heating elements, has come into favor, especially where specific local factors have influenced such use. Steam has been used only occasionally because of the problems which result from its higher temperature.

When the heating medium is warm water, both ferrous (steel or wrought iron) or non-ferrous (generally copper or aluminum) pipe or tube are used widely in ceiling, wall, or floor panel construction. Tube sizes used are  $\frac{3}{8}$ ,  $\frac{1}{2}$ ,  $\frac{5}{8}$  and  $\frac{7}{8}$  in. O.D., while piping is generally  $\frac{1}{2}$ ,  $\frac{3}{4}$  or 1 in. IPS. Where coils are embedded in concrete or plaster, no threaded joints should be used for either pipe coils or mains. The construction should be of all-welded type. Changes in direction should be made by bending the pipe itself, rather than by use of fittings. Solder-joint fittings are used for

non-ferrous heating coils and piping. It is recommended that a medium temperature solder of 95 percent tin—5 percent antimony, or capillary brazing alloys, be used. All piping is, generally, subjected to a hydrostatic test of at least three times the working pressure, but not less than 150 psig.

The more common forms of application of panel heating fall into the following general categories: (1) embedded piping for ceilings; (2) embedded piping for walls; (3) embedded piping for floors; (4) air heated ceilings, walls or floors; (5) electrically heated ceilings, walls or floors.

### Embedded Piping for Ceilings

When piping is embedded in ceilings, the construction used is generally one of the following:

- a. Pipe or tube is embedded in the lower portion of a concrete slab, generally very close to its lower surface. If plaster is to be applied to the concrete, the piping

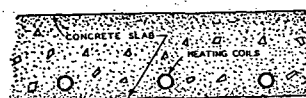


FIG. 1. COILS IN STRUCTURAL CONCRETE SLAB

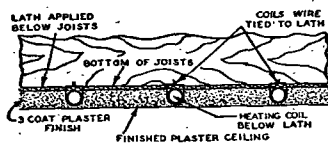


FIG. 3. COILS IN PLASTER BELOW LATH

may be placed directly on the wood forms. If the slab is to be used without plaster finish, then the piping should be installed not less than  $\frac{3}{4}$  in. above the undersurface of the slab. Fig. 1 shows this method of construction. The minimum coverage must be in compliance with the local building code requirements.

- b. Pipe or tubing is embedded in a metal lath and plaster ceiling. If the lath is suspended to form a hung ceiling, both the lath and the heating coils are securely wired to the supporting members in such a way that the lath is below, but in good contact with the coils, as shown in Fig. 2. Plaster is then applied to the metal lath, care being taken to embed the coil, as shown in Fig. 2.

- c. Copper tubes of the smaller diameters are attached to the underside of wire lath or gypsum lath. Plaster is then applied to the lath to embed the tube, as shown in Fig. 3.

- d. Other forms of ceiling construction utilize prefabricated panels of metal, composition board, wood paneling, etc., having warm water piping, tube or channels built into the panel sections.

Coils are usually of the sinuous type, although some header or grid type coils have been used in ceilings. Coils may be of either ferrous or non-fer-

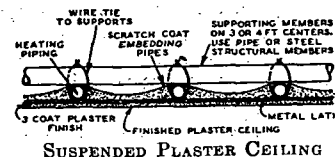


FIG. 2. COILS IN PLASTER ABOVE LATH

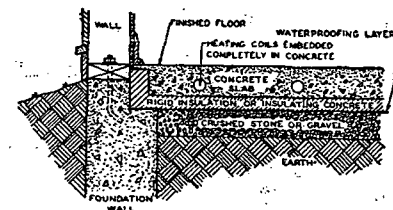
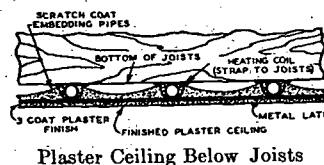


FIG. 4. COILS IN FLOOR SLAB ON GRADE

rous pipe or tube, with coil pipes spaced from  $4\frac{1}{2}$  to 9 in. on centers, depending on the required output, pipe or tube size, and other factors.

Where plastering is applied to pipe coils, a standard three-coat gypsum plastering specification<sup>1</sup> is followed, with a minimum of  $\frac{3}{8}$  in. of cover below the tubes when the tubes are installed below the lath. Generally, the surface temperature of plaster panels should not exceed 120 F, and this is usually met by limiting the water temperature in the pipes or tubes in contact with the plaster to a maximum temperature of 140 F. Insulation should be placed above the coils to reduce the reverse loss which is the difference between the heat supplied to the coil and the net useful output to the heated room.

In order to protect the plaster installation and to assure proper air drying of the plaster, it is recommended that no heat be applied to the panels for two weeks after all plastering work has been completed. When the system is started for the first time, the water supplied to the panels should be at a temperature not more than 20 deg above the prevailing room temperature at that time (but not in excess of 90 F). Water should be circulated at this temperature for about two days. Then the water temperature should be increased at a rate of approximately 5 deg increase per day to 140 F.

During the air-drying and preliminary warming-up periods, adequate ventilation should be provided to carry off moisture from the panels. No paint or paper should be applied to the panels until these periods have been completed. No paint or paper should be applied while the panels are being operated. After paint and paper have been applied, a further shorter warm-up period, similar to that for the first time starting, is also recommended.

### Embedded Piping for Walls

Although not so universally used as ceiling panels, wall panels may be constructed by any of the methods outlined for ceilings.

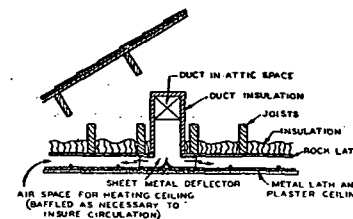


FIG. 5. WARM AIR PLASTER CEILING CONSTRUCTION



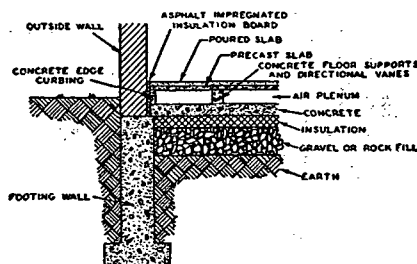


FIG. 6. WARM AIR FLOOR PANEL CONSTRUCTION

### Embedded Piping for Floors

The construction for piping embedded in floors will depend upon whether (a) the floor is laid on grade, or (b) the floor is above grade.

a. Both ferrous and non-ferrous pipe and tube are used in floor slabs which rest on grade. The coils are constructed as either sinuous-continuous pipe coils, or arranged as header coils with the pipes spaced from 6 to 18 in. on centers. The coils are generally installed with 1½ to 4 in. of cover above the coils. It is recommended that insulation be used to reduce the perimeter and reverse losses. Fig. 4 shows the application of pipe coils in slabs resting on grade. Coils should be embedded completely and should not rest on an interface. Any supports used for positioning the heating coils should be non-absorbent and inorganic. It is suggested that reinforcing steel, angle iron, pieces of pipe, or stone concrete mounds be used. No wood, brick, concrete block or similar materials should be used for support of coils. Generally, a waterproofing layer is desirable to protect insulation and piping.

b. Where the coils are embedded in structural load supporting slabs above grade, construction codes may affect their position. Otherwise, the coil piping is installed in the same manner as described for slabs resting on grade.

c. A warm-up and start-up period for concrete panels should be similar to that outlined for plaster panels.

### Air Heated Ceilings, Walls, and Floors

Several methods have been devised to warm the interior room surfaces by circulating heated air through passages behind these surfaces. In some cases, the heated air is recirculated in a closed system. In others, all or a part of the air is passed through the room on its way back to the furnace to provide supplementary heating and ventilation.<sup>2</sup> Figs. 5 and 6 indicate two common types of construction. Care must be exercised to assure com-

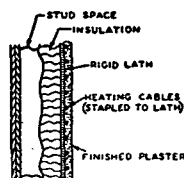


FIG. 7. ELECTRIC HEATING CABLES IN PLASTER

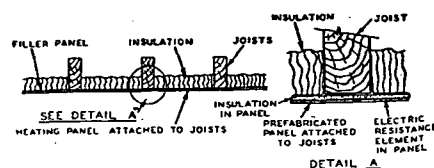


FIG. 8. PREFABRICATED ELECTRIC PANEL

### Panel Heating

pliance with any building codes that might apply. (See also section on Warm Air Ceiling Panel Systems in Chapter 20.)

### Electrically Heated Ceilings, Walls, or Floors

Several different forms of electric resistance units are available for heating the interior room surfaces. These include: (1) resistance cables that may be embedded in a manner similar to hot water piping in concrete or plaster; (2) prefabricated electric heating panels to be attached to room surfaces; and (3) electrically heated fabrics or other materials for application to, or incorporation into, finished room surfaces. Figs. 7 and 8 indicate two methods of installation. The constructions of electric panels for ceilings, walls, and floors are described in greater detail in Chapter 42, Electric Heating.

### OUTPUT FROM PANEL SURFACES

The heat transfer from a panel is accomplished by radiation and convection, which are considered in following paragraphs.

#### Radiation Transfer.

The radiation transfer can be evaluated by means of the relationship set up by Stefan and Boltzmann:

$$\dot{q}_r = 0.173 F_a F_e \left[ \left( \frac{T_s}{100} \right)^4 - \left( \frac{T_w}{100} \right)^4 \right] \quad (1)$$

where

$\dot{q}_r$  = heat transfer by radiation, Btu per (square foot) (hour).

$T_s$  = absolute temperature of panel heated surface, Fahrenheit.

$T_w$  = absolute mean radiant temperature of all unheated surfaces, Fahrenheit.

$F_a$  = the configuration factor (dimensionless).

$F_e$  = the emissivity factor (dimensionless).

For large parallel planes or large enclosed surfaces as ordinarily encountered in panel heating practice:

$$F_a = 1 / \left( \frac{1}{e_1} + \frac{1}{e_2} - 1 \right) \quad (2)$$

where

$e_1$  and  $e_2$  = emissivities of the respective surfaces.

In heating practice  $e_1$  and  $e_2$  are usually equal to 0.9 and  $F_a$  to 0.82. Also, the configuration factor  $F_a$  is equal to 1 for large parallel planes, long concentric cylinders, or smaller bodies in large enclosures. Therefore, for ordinary rooms with parallel walls, regular floors and ceilings, with an emissivity factor of 0.82, Equation 1 can be simplified to:

$$\dot{q}_r = 0.142 \left[ \left( \frac{T_s}{100} \right)^4 - \left( \frac{T_w}{100} \right)^4 \right] \quad (3)$$

Irregularities in room surfaces and materials may introduce some error

in the application of this radiation relationship. However, most authorities are in agreement that the heat emission by radiation, as calculated in this manner, can be considered accurate within 10 percent. Radiation values are shown in Fig. 9 for various surface temperatures. These values are applicable for either floor, wall, or ceiling panel radiation outputs.

### Convection Transfer

Convection values of heat transfer are not easily established. Convection in a panel heated space is usually considered to be of the *natural* type, that is, air motion is generated by the warming (by conduction) of the boundary layer of air which starts moving as soon as its temperature exceeds that of the surrounding air. In practice, however, there are

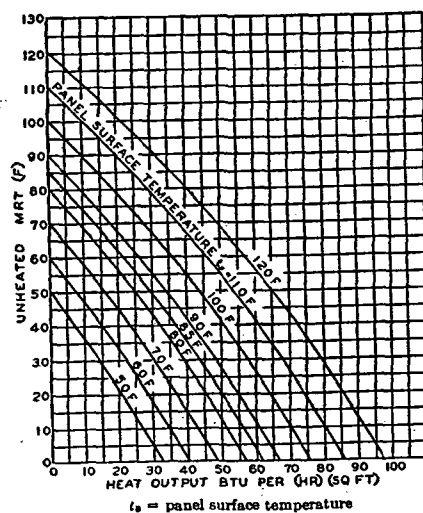


FIG. 9. HEAT OUTPUT BY RADIATION

many factors interfering with *natural* convection. Infiltration, localized drafts, ventilation, and movement of persons are all likely to disturb this process so that it becomes difficult to determine the exact convection effect. Until results from current research become available, an interim evaluation of convection heat exchange can be determined for ordinary panel heating applications from available theoretical relationships.

As investigated<sup>3, 4, 5</sup> by Nusselt and Henky, Griffiths and Davis, Wilkes and Peterson, McAdams and others, natural convection is found to be affected by only two factors: (a) temperature difference between the heat emitting surface and the surrounding air and (b) the position of the surface.

The basic general equation for natural convection from a flat surface is of the following form:

$$q_c = f_c(t_s - t_a)^n \quad (4)$$

where

$q_c$  = heat transfer by convection, Btu per (square foot) (hour).

### Panel Heating

$f_c$  = a coefficient (surface conductance) representing the heat transfer from a unit area per unit difference in temperature, Btu per (square foot) (hour) (Fahrenheit degree temperature difference between surface and air).

$n$  = an exponent depending on surface position and temperature difference between the surface and the surrounding air.

$t_s$  = temperature of the surface, F.

$t_a$  = temperature of the air, F.

The value of  $n$  is usually taken as 1.25 regardless of the magnitude of the temperature difference and the position of the surface. However, Wilkes and Peterson state that a value of 1.12 for  $n$  is more appropriate for *low temperature differences*, with heat flow upward from horizontal surfaces, and that a value of 1.00 is best in the case of heat flow downward from horizontal surfaces. The various investigators mentioned also indi-

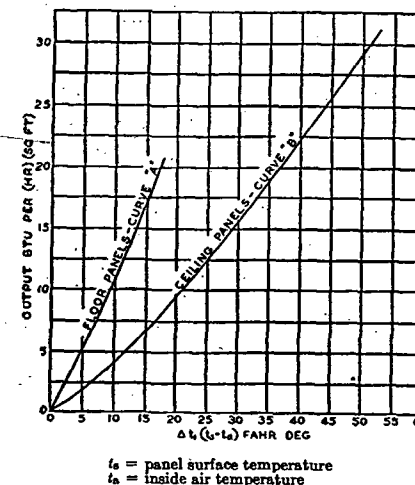


FIG. 10. HEAT OUTPUT BY CONVECTION FROM FLOOR AND CEILING PANELS

cate that values of  $f_c$  vary from 0.2 to 0.38 for downward heat flow from ceilings, and from 0.38 to 0.81 for upward heat flow from floors. The variation in the value of  $f_c$ , as reported by the various investigators, is dependent upon the temperature difference and the value of the exponent  $n$ .

More recent experimental work indicates a provisional correlation between measured convection outputs in actual floor panel heated rooms and the laboratory values obtained by the previous investigators. This correlation indicates that the values obtained from Wilkes and Peterson's equation

$$q_c = 0.81(t_s - t_a)^{1.12} \quad (5)$$

for heat flow upward from horizontal surfaces and small temperature differences, give results that check within reasonable precision the convection output from floor panels, with temperature differences as recommended. Curve A in Fig. 10 is based on the equation of Wilkes and

Peterson, and gives values which may be used for convection outputs from floor panels.

More experimental data are required on convection outputs of ceiling panels. The warming of the air by a ceiling panel does not in itself create convection currents. Instead, it is the action of cooling along the outside wall or walls which causes the air movement. In lieu of actual test data which would take this factor into account, it is recommended that the values obtained from Curve B in Fig. 10, based on the Nusselt and Henky equation

$$q_c = 0.22 (t_a - t_p)^{1.25} \quad (6)$$

be used for determining convection outputs from ceiling panels for various surface temperatures.

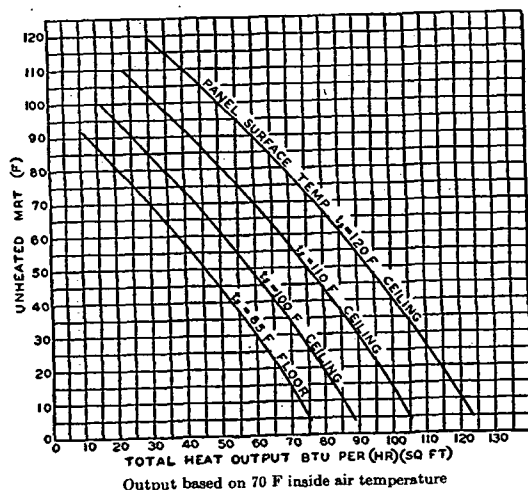


FIG. 11. TOTAL PANEL OUTPUT RADIATION PLUS CONVECTION

#### Combined Heat Transfer

The sum of the radiant heat transfer from Fig. 9 and the convective transfer from curve A or B of Fig. 10, gives the combined useful heat transfer to the room for any combination of panel surface temperature, room air temperature, unheated mean radiant temperature (UMRT), and panel location.

**Example 1:** Find the combined total useful heat transfer from a square foot of floor panel having a surface temperature of 85 F, when the average room air temperature is 70 F and the mean radiant temperature UMRT of the unheated room surfaces is 60 F.

**Solution:**

Radiation  
(Fig. 9 for UMRT of 60 F and  $t_s$  of 85 F)

Btu/(hr)(sq ft)  
21.4

Convection  
(Fig. 10, Curve A for a temperature difference of 15 deg F)

16.9

Total useful heat transfer

38.3

**Example 2:** Find the combined total useful heat transfer from a square foot of ceiling panel having a surface temperature of 100 F, when the average room air temperature is 70 F and the mean radiant temperature UMRT of the unheated room surfaces is 60 F.

#### Panel Heating

perature is 70 F and the mean radiant temperature UMRT of the unheated room surfaces is 60 F.

**Solution:**

Radiation  
(Fig. 9 for UMRT of 60 F and  $t_s$  of 100 F)

Btu/(hr)(sq ft)  
35.3

Convection  
(Fig. 10, Curve B for a  $\Delta t$  of 30 F)

15.5

Total useful heat transfer

50.8

Since the greater number of panel installations are designed for an average room air temperature of 70 F, it is possible to present in chart form

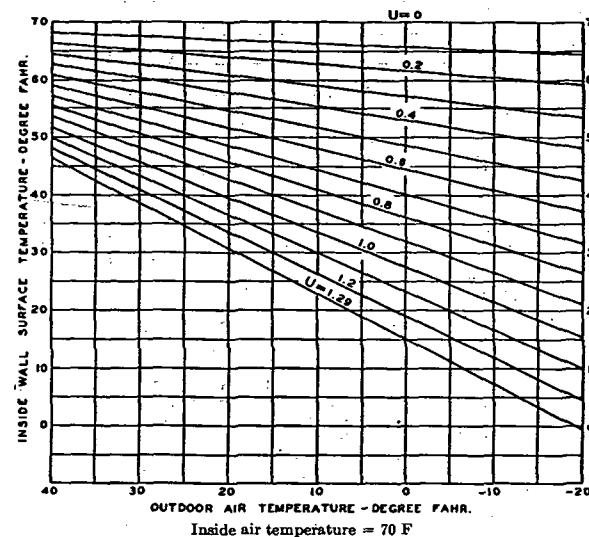


FIG. 12. RELATION OF OVERALL COEFFICIENT OF HEAT TRANSFER TO INSIDE SURFACE TEMPERATURE

(see Fig. 11) the relationship between panel output (radiation plus convection) and the unheated mean radiant temperature for various surface temperatures and panel positions based on 70 F inside air temperature. From Fig. 11 the panel output for *Examples 1* and *2* can be read directly, 38.3 and 50.8 Btu, respectively. Similarly, combined transfer rates for floor or ceiling panels operating under other conditions may be determined from Fig. 11, or from Figs. 9 and 10.

Before Figs. 9 and 11 can be used, the unheated mean radiant temperature UMRT of the room surface must be known. For the purpose of this work, the UMRT may be defined as the average temperature of the unheated surfaces of the space, weighted according to the areas of the surfaces.

The surface temperature of the inside walls may be assumed to be the same as the inside air temperature. The surface temperatures of outside walls or exposed ceilings, for any combination of outside design temperature and transmission coefficient, may be obtained from Fig. 12. If the

inside design temperature is other than 70 F, the values determined from Fig. 12 must be corrected by values obtained from Fig. 13. The following example illustrates the use of Figs. 12 and 13.

**Example 3:** The outside walls of a room have a coefficient of heat transfer  $U = 0.15$ . Inside and outside design air conditions are 68 F and -20 F, respectively. Determine the inside surface temperature of the wall.

**Solution:** From Fig. 12 the inside surface temperature for 70 F and -20 F, and a  $U$  value of 0.15 is found to be 61.5 F. Then from Fig. 13, for a  $\Delta t = -2$  deg and a  $U$  value of 0.15, the correction is -1.8 deg. As the correction is negative, the inside surface temperature will then be  $61.5 - 1.8 = 59.7$  F. The total panel output can then be determined from Figs. 9, 10, and 11.

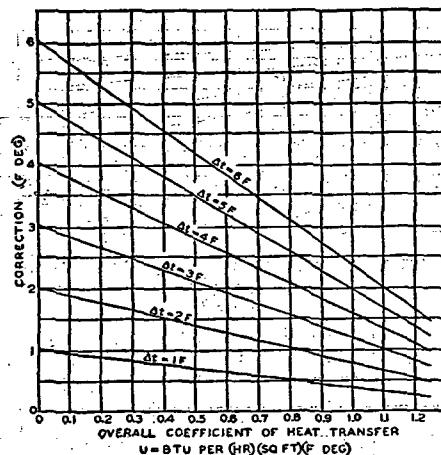


FIG. 13. INSIDE WALL SURFACE TEMPERATURE CORRECTION FOR INSIDE AIR TEMPERATURES OTHER THAN 70 F

$$\Delta t = t_a - 70$$

If  $\Delta t$  is positive:  $t_w' = t_w + \text{correction}$

If  $\Delta t$  is negative:  $t_w' = t_w - \text{correction}$

$t_a$  = inside air temperature

$t_w$  = inside wall surface temperature based on  $t_a = 70$  F

$t_w'$  = actual inside wall surface temperature

After the various wall surface temperatures have been determined, as described, the unheated mean radiant temperature UMRT of the space may be calculated as illustrated in Step 3 of the following section on Floor Panel Design Illustration.

#### Panel Edge Loss

Refer to the section, Heat Losses from Floor Slabs, in Chapter 12. These losses will affect slab temperature and water temperature near outside walls, and must be included in either the room loss or the panel input. In the following example, Item 5, Part 4 can be considered to include this loss, but if the edge loss exceeds the amount allowed by Part 4, the larger loss should be used.

#### FLOOR PANEL DESIGN ILLUSTRATION

The several steps in the design of a panel heating system are listed and illustrated in the following example of the design of a floor panel for the room shown in Fig. 14.

#### 1. Selection of Design Conditions

- Outside design temperature, -10 F.
- Inside design room air temperature, 70 F.
- In this problem a floor panel heating system will be used. There is no basement. Insulation will be used between slab and fill.
- Heating medium, hot water.
- Floor surface temperature, 85 F (Maximum).

#### 2. Calculation of Room Heat Loss

The heat transmission coefficients of the room surfaces are given in Fig. 14. They would usually be obtained from Chapter 9. The room heat loss can be calcu-

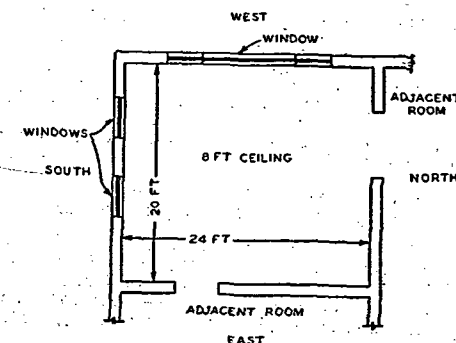


FIG. 14. ROOM PLAN FOR ILLUSTRATION OF METHOD OF DESIGNING A PANEL HEATING SYSTEM

Data: Values of overall heat transfer coefficients as calculated:  
 1. Outside walls  $U = 0.10$   
 2. Ceiling  $U = 0.08$   
 3. Floor  $U = 0.36$   
 4. Windows  $U = 0.55$

lated in the conventional manner, as outlined in Chapter 12. The calculations are shown in Table 1. The heat loss through the surface areas containing the heating medium is not included in the calculation.

The calculated rate of heat loss will determine the amount of heat which must be supplied by the heating panels to the room.

TABLE 1. CALCULATED HEAT LOSS OF ROOM (Fig. 14)

| SURFACES             | AREA<br>Sq Ft | U    | CALCULATION                                              | HEAT LOSS<br>BTU/HR |
|----------------------|---------------|------|----------------------------------------------------------|---------------------|
| Outside walls.....   | 272           | 0.10 | $272 \times 0.10 \times 80$                              | 2,176               |
| Glass.....           | 80            | 0.55 | $80 \times 0.55 \times 80$                               | 3,520               |
| Inside walls.....    | 352           | —    | No heat loss                                             | 0                   |
| Ceiling.....         | 480           | 0.08 | $480 \times 0.08 \times 80$                              | 3,072               |
| Floor.....           | 480           | —    | Heating panel                                            | 0                   |
| Infiltration.....    | —             | —    | $3,840 \text{ cu ft} \times 1.50 \times 80 \times 0.018$ | 8,295               |
| Total heat loss..... |               |      |                                                          | 17,063              |

#### 3. Determination of UMRT

The calculations for determining UMRT are shown in Table 2. The inside surface temperatures shown in the fourth column were determined from Fig. 12.

TABLE 2. CALCULATION OF UMRT

| SURFACE                    |      | AREA<br>Sq Ft | INSIDE SUR-<br>FACE* TEM-<br>PERATURE F | PRODUCT<br>(AREA X<br>TEMPERATURE) |
|----------------------------|------|---------------|-----------------------------------------|------------------------------------|
| Outside walls.....         | 0.10 | 272           | 65                                      | 17,680                             |
| Adjacent inside walls..... | —    | 352           | 70                                      | 24,640                             |
| Ceiling.....               | 0.08 | 480           | 66                                      | 31,680                             |
| Glass.....                 | 0.55 | 80            | 43                                      | 3,440                              |
| Total.....                 |      | 1,184         |                                         | 77,440                             |

$$\text{UMRT} = \frac{\text{Total of products}}{\text{Total area}} = \frac{77,440}{1,184} = 65.4 \text{ F}$$

\* Values of inside wall surface temperature for various  $U$  values and outside design temperatures found in Fig. 12.

#### 4. Determination of Panel Output

Values of total panel output for various panel positions, panel surface temperatures and unheated MRT are given in Fig. 11. From Fig. 11, with a floor panel surface temperature of 85 F and a UMRT of 65.4 F, the total panel output is 34 Btu per (hr) (sq ft of panel surface).

$$\begin{aligned}\text{Panel area} &= 24 \times 20 = 480 \text{ sq ft} \\ \text{Panel output} &= 480 \times 34 = 16,320 \text{ Btu per hr}\end{aligned}$$

This panel output of 16,320 Btu per hr is reasonably close to the calculated room loss of 17,063, and is satisfactory. If this value of total heat output from panel to the room were much less, i.e., 10 or more percent less, than the calculated heat loss from the room, some method of supplementary heating would be needed. Floor panel surface temperatures exceeding 85 F are not recommended.

#### 5. Determination of Panel Input and Water Temperature

Fig. 15 presents a graphical method of determining the required water temperature and total heat input to a panel for various cover depths, tube or pipe sizes and spacings, and rate of heat output to the room.

The panel output for this example has previously been found to be 34 Btu per (hr) (sq ft). Since some of the heat input to the panel is lost to the ground, it is necessary to supply more than 34 Btu per (hr) (sq ft) to the panel by means of the hot water heating medium. The amount of heat which must be supplied to the panel to give the required output may be determined graphically from Fig. 15. Assume that the panel has  $\frac{1}{2}$  in. pipes, spaced on 12 in. centers, and that the depth of cover from top of panel surface to top of pipes is 2.5 in. The four sections of Fig. 15 are marked Part 1 to Part 4 and, as will be evident by following the dashed line on the chart, are used as follows:

**Part 1.** Starting from the depth of cover (2.5 in.), proceed vertically to the line representing pipe spacing on centers (12 in.), and then horizontally to the first ordinate of Part 2.

**Part 2.** Move parallel to the nearest upward sloping line, indicating "2 in. & over" cover, to intersect the ordinate representing  $\frac{1}{2}$  in. pipe, and then proceed horizontally to the first ordinate of Part 3.

**Part 3.** Proceed parallel to and along the nearest downward sloping line to an intersection with the ordinate representing the panel output (34 Btu per sq ft), and then move horizontally to the right hand scale of Part 3 and read a required average water temperature in the coil of 106 F.

**Part 4.** From the water temperature 106 F just found in Part 3, proceed horizontally into Part 4 to intersect the line representing insulation between the slab and fill. Directly below this intersection read 1.09 (on the bottom scale) as the multiplier to be used.

The required panel input is, therefore,  $1.09 \times \text{panel output}$ , or  $1.09 \times 34 = 37.1$  Btu per (sq ft) (hr).

The total required panel input is  $37.1 \times \text{panel area} = 37.1 \times 480 = 17800$  Btuh.

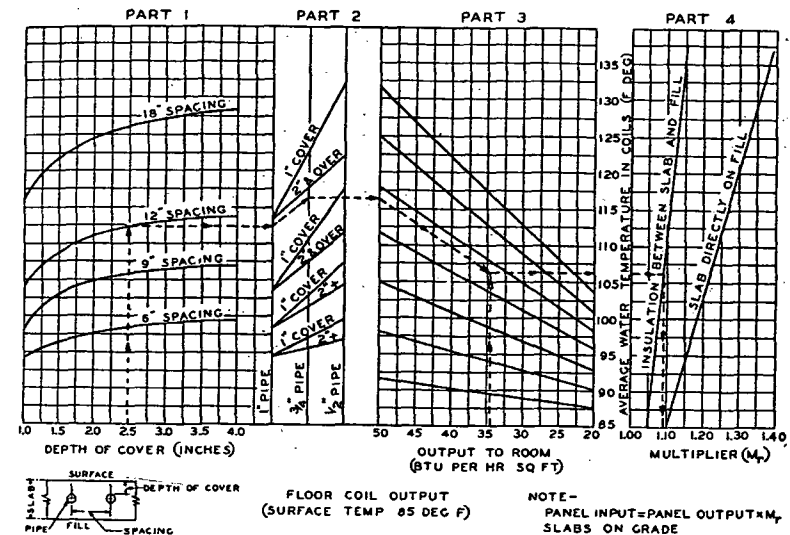


FIG. 15. RELATION OF WATER TEMPERATURES AND COIL OUTPUTS TO COIL SPACING AND DEPTH OF BURY FOR FLOOR COILS IN SLABS ON GRADE

#### CEILING AND WALL PANEL DESIGN

Where coils are embedded in plaster on ceilings or walls, design procedure is simplified considerably by the physical limitations of the space available. For tube fastened to the underside of lath, the largest practical size is  $\frac{3}{8}$  in. O.D., while for ferrous pipes above the lath, it is 1 in. I.P.S. Therefore, the actual tube or pipe size selected is usually determined by the length of coil circuit and its flow resistance in consideration of the available circulating head.

In order to obtain a reasonably even heat distribution over the finished plaster heating surface, pipes or tubes should be spaced on about 6 in. centers, and not over 9 in. centers. Within these limitations it is found in practice that heat output rates do not vary too seriously with variations in pipe and tube size and tube spacing.

In general, for plaster ceiling panels with tubes or pipes spaced on  $4\frac{1}{2}$  to 9 in. centers, the temperature of the circulating water is about 10 to 25 deg above the desired surface temperature.

The hourly heat output per square foot of panel surface may be found by means of Figs. 11, 12, and 13, and the calculations for room heat loss and UMRT, as previously illustrated in the example of floor panel design.

#### HOT WATER PIPING

When water is used as the heating medium, the piping layout and arrangement should be based on the design principles outlined in Chapter 22 for Two-Pipe Forced Circulation Systems. The pressure drops through the coils should be carefully calculated, and it is recommended that all branch circuits and coils be balanced to provide for uniform distribution by means of regulating valves or tees. Generally, a 15 to 20 deg total

temperature drop is used in determining water flow rates, and a total pump head of more than 30 ft is undesirable due to noise caused by high water velocity.

Panel systems involving several rooms and panels comprising a single zone, require that all coils be selected for the same inlet water temperatures. Panel areas and pipe spacing must be selected to make this possible.

### INSTALLATION DETAILS, ACCESSORIES, AND CONTROLS

Installation details, as given in Chapter 22, Hot Water Systems, also apply to piping systems for panel heating. Control problems of panel heating systems are discussed in Chapter 39, Automatic Control.

Efficient venting of air from the coils may be obtained by arranging the circulation so that the air moves in the direction of water flow to a high point in the system where an automatic float-type vent or connection to expansion tank should be provided for its release. Coils should be installed as nearly level as possible or, if they are on sloping surfaces due to structural conditions, they should be arranged to vent air at their high points. Arrangements of pumps, expansion tanks, drainage, and flow and return mains may be generally the same as for conventional hot water heating systems.

### SNOW MELTING

The practicability of melting snow by means of heated coils has been demonstrated in a large number of installations in sidewalks, roadways, ramps, and runways. In addition to eliminating the need for snow removal, other advantages gained are greater safety to pedestrians and vehicles, and reduction of labor in removal of slush from floors.

The design of a snow-melting system involves primarily (1) a determination of the heat requirement which depends on snow fall and atmospheric conditions, (2) the coil and piping design which depends on heat transfer from a panel and on friction loss in piping due to the circulating medium used, and (3) the selection or design of a heat exchanger for heating the circulating medium.

### DESIGN

#### Heating Requirements

The heating requirements for snow melting are affected by four atmospheric factors: (1) rate of snowfall, (2) air temperature, (3) wind velocity, and (4) humidity. The effects of these factors can be evaluated by consideration of the action of snow falling on a warmed surface.

The first flakes fall on a dry, warm surface, and are then warmed to 32 F and melted. The water from the melted snow soon forms a film over the entire area and starts to evaporate. The evaporation of the film is a mass transfer from the surface to the atmosphere. In addition, there is a heat transfer from the film to the ambient air and surfaces.

Both the mass and heat transfers attain a maximum only when the film is entirely free of snow. Theoretically this is impossible because some time will elapse while the snow is warmed to 32 F. For all practical purposes, however, it is permissible to assume the snow to be melted as fast as it falls so that the surface may be considered entirely free of snow. The ratio of free area to total area is known as the *free area ratio*,  $A_r$ . When  $A_r = 1$ , there is no snow on the surface and the mass and heat trans-

TABLE 3. SNOWFALL DATA FOR VARIOUS CITIES\*

| CITY                               | NUMBER OF READINGS WITH<br>MAXIMUM TEMPERATURE IN 6-HOUR<br>PERIOD BELOW FREEZING AT<br>VARIOUS SNOWFALL RATES |                 |                 |                 | TOTAL<br>READINGS<br>TAKEN | ASSUMED<br>DESIGN<br>RATE OF<br>SNOWFALL <sup>b</sup> |
|------------------------------------|----------------------------------------------------------------------------------------------------------------|-----------------|-----------------|-----------------|----------------------------|-------------------------------------------------------|
|                                    | Snowfall Rate in Equivalent Inches<br>of Water per Six Hours.                                                  |                 |                 |                 |                            |                                                       |
|                                    | 0.00<br>to 0.24                                                                                                | 0.25<br>to 0.49 | 0.50<br>to 0.74 | 0.75<br>to 0.99 |                            |                                                       |
| Col. 1                             | Col. 2                                                                                                         | Col. 3          | Col. 4          | Col. 5          | Col. 6                     | Col. 7                                                |
| Albany, N. Y.....                  | 2062                                                                                                           | 29              | 5               | 1               | 3720                       | 0.16                                                  |
| Asheville, N. C.....               | 463                                                                                                            | 5               | 1               | 0               | 3536                       | 0.08                                                  |
| Billings, Mont.....                | 1640                                                                                                           | 4               | 0               | 0               | 3532                       | 0.08                                                  |
| Bismarck, N. D.....                | 2838                                                                                                           | 0               | 0               | 0               | 3720                       | 0.08                                                  |
| Boise, Idaho.....                  | 1300                                                                                                           | 3               | 0               | 0               | 3720                       | 0.08                                                  |
| Boston, Mass.....                  | 1323                                                                                                           | 11              | 4               | 2               | 3720                       | 0.16                                                  |
| Buffalo, N. Y.....                 | 1871                                                                                                           | 23              | 3               | 1               | 3720                       | 0.16                                                  |
| Burlington, Vt.....                | 2390                                                                                                           | 9               | 0               | 0               | 3720                       | 0.08                                                  |
| Caribou, Maine.....                | 1363                                                                                                           | 19              | 1               | 0               | 1672                       | 0.16                                                  |
| Chicago, Ill.....                  | 1498                                                                                                           | 3               | 0               | 1               | 2976                       | 0.08                                                  |
| Cincinnati, Ohio.....              | 1045                                                                                                           | 3               | 0               | 0               | 3720                       | 0.08                                                  |
| Cleveland, Ohio.....               | 1569                                                                                                           | 2               | 0               | 0               | 3720                       | 0.08                                                  |
| Columbus, Ohio.....                | 1351                                                                                                           | 4               | 1               | 0               | 3720                       | 0.08                                                  |
| Denver, Col.....                   | 1207                                                                                                           | 4               | 0               | 0               | 3720                       | 0.08                                                  |
| Detroit, Mich.....                 | 1830                                                                                                           | 5               | 2               | 0               | 3720                       | 0.08                                                  |
| Evansville, Ind.....               | 916                                                                                                            | 5               | 1               | 1               | 3720                       | 0.08                                                  |
| Hartford, Conn.....                | 1514                                                                                                           | 44              | 9               | 3               | 3720                       | 0.25                                                  |
| Kansas City, Mo.....               | 1189                                                                                                           | 12              | 2               | 1               | 3720                       | 0.16                                                  |
| Madison, Wisc.....                 | 2370                                                                                                           | 5               | 2               | 0               | 3720                       | 0.08                                                  |
| Minneapolis, Minn.....             | 2703                                                                                                           | 7               | 0               | 0               | 3720                       | 0.08                                                  |
| Oklahoma City, Okla.....           | 613                                                                                                            | 8               | 4               | 0               | 3720                       | 0.16                                                  |
| Omaha, Neb.....                    | 1795                                                                                                           | 8               | 1               | 0               | 3720                       | 0.16                                                  |
| Philadelphia, Pa.....              | 891                                                                                                            | 10              | 2               | 1               | 3720                       | 0.16                                                  |
| Pittsburgh, Pa.....                | 1365                                                                                                           | 6               | 2               | 0               | 3720                       | 0.08                                                  |
| Portland, Maine.....               | 2054                                                                                                           | 33              | 4               | 1               | 3720                       | 0.16                                                  |
| St. Louis, Mo.....                 | 1088                                                                                                           | 5               | 0               | 1               | 3720                       | 0.08                                                  |
| Salt Lake City, Utah.....          | 1482                                                                                                           | 5               | 0               | 0               | 3720                       | 0.08                                                  |
| Spokane, Wash.....                 | 1545                                                                                                           | 11              | 1               | 0               | 3720                       | 0.16                                                  |
| Washington, D. C.....              | 633                                                                                                            | 7               | 2               | 1               | 3348                       | 0.16                                                  |
| New York, N. Y. <sup>c</sup> ..... |                                                                                                                |                 |                 |                 |                            | 0.16                                                  |

\* Data from U. S. Weather Bureau. Based on readings taken 1:30 a.m., 7:30 a.m., 1:30 p.m., and 7:30 p.m. daily from November 15 to February 15 from 1940 to 1949. (Where the total readings are less than 3720 the period of record is less than 10 years). The difference between Col. 6 and the sum of readings in Cols. 2, 3, 4, and 5 is the number of readings with a maximum temperature (in the 6-hr period) above freezing.

<sup>b</sup> The design rate is found as follows: Proceed to left (on line from any city) from Column 5 until the column containing the tenth reading is found. Assume that the larger value in the heading of the selected column is an average maximum value, and should be multiplied by 2 to obtain the maximum rate for a 6-hour period. This maximum rate divided by 6 is the design rate per hour. This is equivalent to dividing the larger value in the heading of the selected column by 3.

For example: For Albany, N. Y. Columns 5 and 4 total six readings, and consequently the tenth reading is in Column 3, which has the larger value of 0.49 in the column heading. Dividing 0.49 by 3, the design water equivalent of 0.16 inches per hour is found, as listed in Column 7.

<sup>c</sup> New York City record was not used in this tabulation since the records for that station were not comparable with those of the other stations.

fers are at a maximum. When  $A_r = 0$ ; the snow covers the entire area and there is no mass or heat transfer.

Research on the insulating effects of snow indicate that there are just three practical values for the free area ratio,  $A_r$ ; they are 1, 0.5, and 0. A general rule to follow is that emergency areas should be designed with

$A_r = 1$ ; commercial areas (e.g., sidewalks around stores, etc.) may be designed with  $A_r = 0.5$ ; and private driveways, or areas where low installation costs are imperative, may be designed with  $A_r = 0$ . For a more complete discussion of free area ratio and its effect on system performance, see Reference 6.

The equations for the heating requirements of a snow melting system have been derived and thoroughly explained in Reference 7. The general equation for slab output,  $q_o$ , is

$$q_o = q_s + q_m + A_r(q_e + q_h) \quad (7)$$

where

$q_s$  = sensible heat transferred to snow, Btu per (hour) (square foot).

$q_m$  = heat of fusion, Btu per (hour) (square foot).

$A_r$  = ratio of snow-free area to total area, dimensionless.

$q_e$  = heat of vaporization, Btu per (hour) (square foot).

$q_h$  = heat transfer by convection and radiation, Btu per (hour) (square foot).

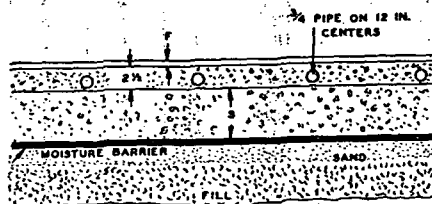


FIG. 16. DETAIL OF SNOW MELTING PANEL

F = Depth of Finish Coat—Assumed as 1/2 in. of concrete. Finish Coat may be asphalt but then cover slab should be reduced from 3 in. Depth of slab should always keep thermal resistance equal to 3 in. of concrete.

S = Depth required by structural design.

The sensible heat,  $q_s$ , to raise the temperature of the snow to 32 F is

$$q_s = 2.6s(32 - t_a) \quad (8)$$

where

$s$  = rate of snowfall, see Table 3, inches of water equivalent per hour.

$t_a$  = air temperature, Fahrenheit.

The heat of fusion,  $q_m$ , to melt the snow is

$$q_m = 746s \quad (9)$$

The heat of vaporization,  $q_e$ , (mass transfer) is

$$q_e = 1074(0.0201v + 0.055)(0.185 - p_{av})A_r \quad (10)$$

where

$p_{av}$  = vapor pressure of moist air, inches of mercury.

The heat transfer,  $q_h$ , (convection and radiation) is

$$q_h = 11.4(0.0201v + 0.055)(t_f - t_a)A_r \quad (11)$$

where

$v$  = wind velocity, miles per hour.

$t_f$  = water film temperature, Fahrenheit.

In addition to determining the four heating requirements, it is necessary to make allowance for back and edge losses. These losses vary from 30 to 50 percent, depending upon the slab construction.

The equation for the required fluid temperature to provide an output  $q_o$  has been derived in Reference 7. For construction similar to Fig. 16, the equation is

$$t_m = 0.5q_o + t_f \quad (12)$$

where

$t_m$  = mean fluid temperature (antifreeze solution), Fahrenheit.

Equation 12 will suffice for 1 in. IPS as well as 3/4 in. — see Fig. 16.

TABLE 4. HEAT OUTPUT AND FLUID TEMPERATURE FOR SNOW MELTING SYSTEMS

| RATE OF SNOWFALL | $A_r$ |       | $t_a = 0 \text{ F}$ |     |     | $t_a = 10 \text{ F}$ |     |     | $t_a = 20 \text{ F}$ |     |     | $t_a = 30 \text{ F}$ |     |     |
|------------------|-------|-------|---------------------|-----|-----|----------------------|-----|-----|----------------------|-----|-----|----------------------|-----|-----|
|                  |       |       | Velocity $v$        |     |     | Velocity $v$         |     |     | Velocity $v$         |     |     | Velocity $v$         |     |     |
|                  |       |       | 5                   | 10  | 15  | 5                    | 10  | 15  | 5                    | 10  | 15  | 5                    | 10  | 15  |
| 0.08             | 1.0   | $q_o$ | 151                 | 205 | 260 | 127                  | 168 | 209 | 102                  | 128 | 154 | 75                   | 84  | 94  |
|                  |       | $t_m$ | 108                 | 135 | 162 | 97                   | 117 | 138 | 85                   | 97  | 110 | 70                   | 75  | 79  |
|                  | 0.0   | $q_o$ | 66                  | 66  | 66  | 64                   | 64  | 64  | 62                   | 62  | 62  | 60                   | 60  | 60  |
|                  |       | $t_m$ | 66                  | 66  | 66  | 65                   | 65  | 65  | 64                   | 64  | 64  | 63                   | 63  | 63  |
| 0.16             | 1.0   | $q_o$ | 218                 | 273 | 327 | 193                  | 233 | 274 | 165                  | 191 | 217 | 135                  | 144 | 154 |
|                  |       | $t_m$ | 142                 | 169 | 198 | 129                  | 149 | 170 | 117                  | 129 | 142 | 100                  | 105 | 109 |
|                  | 0.0   | $q_o$ | 133                 | 133 | 133 | 129                  | 129 | 129 | 125                  | 125 | 125 | 121                  | 121 | 121 |
|                  |       | $t_m$ | 99                  | 99  | 99  | 97                   | 97  | 97  | 95                   | 95  | 95  | 93                   | 93  | 93  |
| 0.25             | 1.0   | $q_o$ | 292                 | 347 | 401 | 265                  | 305 | 346 | 235                  | 261 | 287 | 203                  | 212 | 221 |
|                  |       | $t_m$ | 179                 | 206 | 234 | 165                  | 185 | 206 | 151                  | 163 | 176 | 134                  | 139 | 144 |
|                  | 0.0   | $q_o$ | 208                 | 208 | 208 | 202                  | 202 | 202 | 195                  | 195 | 195 | 188                  | 188 | 188 |
|                  |       | $t_m$ | 137                 | 137 | 137 | 134                  | 134 | 134 | 131                  | 131 | 131 | 127                  | 127 | 127 |

Note: This table is based on a relative humidity of 80 percent for all air temperatures.

$s$  = Rate of snowfall, inches of water equivalent per hour (See Table 3).

$A_r$  = Free area ratio.

$q_o$  = Slab output, Btu per (hour) (square foot).

$t_a$  = Air temperature, Fahrenheit.

$t_m$  = Fluid temperature, Fahrenheit. Based on construction as shown in Fig. 16.

$v$  = Wind velocity, miles per hour.

Values for  $s$  for certain cities are given in Table 3. Using the values for  $s$  given in Table 3, the appropriate values for  $t_a$  and  $v$ , the values for  $q_o$  may be found in Table 4. In preparing Table 4, only values of  $p_{av}$  for relative humidities of 80 percent were used. The variation in  $q_o$  and  $t_m$  for humidities of 75, 80, 85 and 90 percent are given in Reference 6, and may be calculated by solving Equations 13 and 14.

$$\frac{dt_m}{dp_{av}} = -537(0.0201v + 0.055)A_r \quad (13)$$

$$\frac{dq_o}{dp_{av}} = -1074(0.0201v + 0.055)A_r \quad (14)$$

When selecting the heat exchanger, it will be necessary to allow for the thermal properties of the anti-freeze solution. The manufacturer should be given data on the type and concentration of anti-freeze, the tempera-



ture range of operation, the source of heat (steam, hot water, etc.), and the flow rate through the exchanger.

### Hydraulic Requirements

After determining the heating requirements, it is necessary to determine the hydraulic requirements of the system. This can be done by means of the procedures explained in Chapter 4, Fluid Flow, but it is necessary to use the proper physical properties of the antifreeze solution. A complete discussion of the hydraulic problem is given in Reference 8.

The main consideration is the proper allowance for viscosity. Table 5 gives viscosities for two typical fluids used as antifreezes for snow melting systems. Notice the large increase in viscosity for both fluids—about 20 times—as the fluid temperature changes from an operating temperature

TABLE 5. PHYSICAL PROPERTIES OF ANTIFREEZE SOLUTIONS

| SOLUTION                     | FREEZING PROTECTION TEMP., F. | % BY VOLUME | ITEM              | FLUID TEMPERATURE, F. |       |       |       |
|------------------------------|-------------------------------|-------------|-------------------|-----------------------|-------|-------|-------|
|                              |                               |             |                   | 0                     | 80    | 120   | -100  |
| Ethylene Glycol <sup>a</sup> | 0                             | 31.4        | $\nu \times 10^4$ | —                     | 1.92  | 1.14  | 0.77  |
|                              |                               |             | c                 | —                     | 0.839 | 0.854 | 0.874 |
|                              |                               |             | w                 | —                     | 65.1  | 64.4  | 63.6  |
|                              | -20                           | 42.7        | $\nu \times 10^4$ | 16.1                  | 2.55  | 1.46  | 0.95  |
|                              |                               |             | c                 | 0.764                 | 0.813 | 0.832 | 0.856 |
|                              |                               |             | w                 | 66.8                  | 66.0  | 65.3  | 64.4  |
| Light Oil <sup>b</sup>       | -40                           | 51.2        | $\nu \times 10^4$ | 21.3                  | 3.16  | 1.77  | 1.14  |
|                              |                               |             | c                 | 0.717                 | 0.788 | 0.809 | 0.835 |
|                              |                               |             | w                 | 67.6                  | 66.8  | 65.9  | 65.0  |
|                              | -40                           | 100         | $\nu \times 10^4$ | 43.1                  | 5.60  | 3.13  | 2.06  |
|                              |                               |             | c                 | 0.390                 | 0.426 | 0.444 | 0.462 |
|                              |                               |             | w                 | 62.5                  | 60.7  | 59.8  | 59.0  |

<sup>a</sup> Interpolated from Reference 10. <sup>b</sup> From Socony-Vacuum Oil Co.  
 $\nu$  = kinematic viscosity, (feet squared per second) (e.g. for oil at 80 F,  $\nu = 0.000056$  ft<sup>2</sup> per sec.)  
 c = specific heat, Btu per (pound) (Fahrenheit degree).  
 w = specific weight, pounds per cubic foot.

of 160 F to the starting temperature of 0 F. This viscosity change has two effects. First, an increase in viscosity will increase the fluid friction in the piping circuit. Second, an increase in viscosity will decrease the pump capacity—in both volume and head. The effect of viscosity on fluid friction in the piping circuit is illustrated in Fig. 17.

For large installations, the friction losses should be calculated by the Fanning equation

$$h_f = \frac{fLV^3}{2gD}$$

where

- $h_f$  = the loss in head of the fluid under conditions of flow, in feet.
- $l$  = the length of the pipe, in feet.
- $V$  = the velocity, in feet per second.
- $g$  = the acceleration due to gravity = 32.174 ft per (second) (second).
- $D$  = the internal diameter of the pipe in feet.

$f$  = a dimensionless friction coefficient which can be determined from Fig. 4, Chapter 4. The Reynolds number can be computed from data in Table 5.

Solutions for the pipe friction should be plotted for temperatures at the starting condition (probably 0 F) and at the operating condition (use either 120 or 160 F). Then on the same graph plot the operating curve of the pump (see Reference 8 for such a graph). The intersection of the fluid friction curve and pump operating curve will give the operating point for the system. Use the data in Table 6 to allow for the viscosity effect on the pump.

The designer must decide on the tolerable viscosity limit. Generally it is between 300 and 500 SSU, although for commercial or private systems (where  $A_s$  is 0.5 or 0) it may go to 750 SSU.

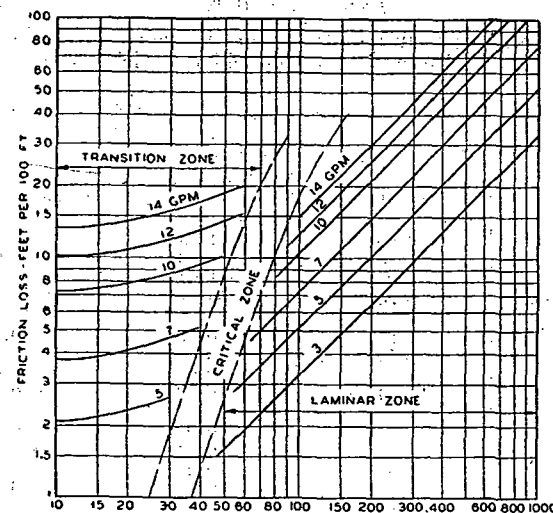


FIG. 17. EFFECT OF VISCOSITY ON FRICTION LOSS  
(For 1-in. Pipe)

Efficiency loss is not important, but head and capacity losses are. Reduced flow means a longer period of time for the system to become operative from a cold start.

The viscosity limit is controlled by means of a low-limit thermostat. For example, if it is desired to hold the viscosity of the solution to less than 200 SSU (43.1 ft sq per sec), then for the oil shown in Table 5, the low limit control would be set at 0 F.

For small installations, a quick method of determining the fluid friction for a one-inch IPS pipe circuit is given in Fig. 17.

The pump capacity, in pounds of fluid per hour is given by

$$C = \frac{A_p q_t}{c_m \Delta t} \quad (15)$$

where

- $C$  = pump capacity, pounds per hour.
- $A_p$  = area of slab, square feet.

$q_t$  = total heat requirement (slab output,  $q_o$ , plus back and edge losses) Btu per (hour) (square foot).  
 $c_m$  = specific heat at temperature  $t_m$ , Btu per (pound) (Fahrenheit degree).  
 $\Delta t$  = temperature drop through circuit, Fahrenheit degrees.

For a temperature drop of  $\Delta t = 20$  F, Equation 15 becomes

$$G = \frac{A_p q_t}{160 w_m c_m} \quad (16)$$

where

$G$  = gallons per minute.

$w_m$  = mean specific weight at temperature  $t_m$ , pounds per cubic foot.

### INSTALLATION

There are certain precautions that must be taken during installation. They concern internal corrosion, flammability, toxicity, cleaning, joints,

TABLE 6. VISCOSITY EFFECT ON CENTRIFUGAL PUMP CHARACTERISTICS

| KINEMATIC VISCOSITY<br>SSU* | CORRECTION FACTORS |               |                 |
|-----------------------------|--------------------|---------------|-----------------|
|                             | Pump Head          | Pump Capacity | Pump Efficiency |
| 0 to 30                     | 1.00               | 1.00          | 1.00            |
| 50                          | 1.00               | 1.00          | 0.94            |
| 100                         | 0.98               | 1.00          | 0.88            |
| 200                         | 0.96               | 0.98          | 0.79            |
| 300                         | 0.95               | 0.97          | 0.73            |
| 400                         | 0.93               | 0.96          | 0.68            |
| 500                         | 0.92               | 0.96          | 0.65            |
| 600                         | 0.91               | 0.95          | 0.62            |
| 700                         | 0.90               | 0.94          | 0.59            |
| 800                         | 0.89               | 0.94          | 0.57            |
| 900                         | 0.88               | 0.93          | 0.55            |
| 1000                        | 0.87               | 0.92          | 0.53            |

\* SSU = Universal Saybolt second.

and hookup. A comprehensive discussion of these precautions may be found in Reference 9.

### Safety

Since ethylene glycol and petroleum distillates are slightly toxic, the system should be installed and maintained independently. There should be no permanent connection between the snow melting system and the drinking water supply.

Ethylene glycol is not considered flammable. In fact, aqueous solutions of less than 60 percent glycol are used for fire sprinkler systems. These solutions do not freeze, and they are effective fire extinguishing agents.

Petroleum distillates suitable for fluids in snow melting systems are classified as non-flammable, but have fire points between 300 and 350 F. When using fluids of this type, care should be taken to collect any oil dripping from the seals on the pump. It is good practice also to provide some barrier between the oil lines and the boiler so that in the event of a leak, a flash back from the boiler will not ignite the oil.

There are other non-flammable fluids, such as those used in some transformers, that can be used as the antifreeze. These fluids are three or four times as expensive as the glycols or oils, but combine the fire protection of the glycols with the corrosion protection of the oils.

### Internal Corrosion

Ethylene glycol solutions tend to become corrosive in service; therefore, rust inhibitors are generally included. Even with an inhibitor, the solution should be tested annually to determine any change in acidity. If the test indicates that the inhibitor has been exhausted, the entire system should be drained and a fresh solution installed.

To increase the life of the inhibitor, the heat exchanger surfaces should be kept below 285 F which corresponds to about 40 psig steam. Temperatures above 300 F accelerate the deterioration of the inhibitors.

### Slab Construction

It has been found satisfactory to use  $\frac{3}{4}$  pipe or tubing on 12-in. centers as a standard coil. If pumping loads require a reduction in friction the pipe size may be increased to 1-in., but the slab depth must be increased accordingly.

The piping should be supported in such a manner that there is a minimum of 2 in. of concrete above and below the pipe. This requires a 5-in. slab for  $\frac{3}{4}$ -in. pipe and  $5\frac{3}{8}$ -in. for 1-in. pipe.

If an insulating material is used, it is generally good practice to provide a moisture barrier between the insulation and the fill. A roofing material (such as a 55 lb. felt) is often used as a moisture barrier. The joints should be mopped, and the fill made smooth enough so that there will be no holes or gaps for moisture transfer. Also, the edges of the barrier should be flashed to the surface of the slab so that the ends are sealed. See Fig. 16.

If the pipe must pass through an expansion joint, a protective coating should be applied to the pipe for a foot or two on both sides of the joint.

If the pipe is kept dry at all times in both summer and winter, no external corrosion problems will occur.

### Thermal Stresses

This problem is discussed in Reference 11. In general, there will be no ill effects from the thermal stresses if these rules of installation and operation are followed:

1. Keep the temperature difference between the fluid and the slab surface to a minimum by:
  - a. Close pipe spacing (see Fig. 16).
  - b. Low temperature drop in fluid,  $\Delta t \leq 20$  F deg.
  - c. Continuous operation (if economically feasible).
2. Keep pipe near surface—about 2 in. cover.
3. Use reinforcing steel designed for thermal stress if high structural loads are expected (such as on highways).

### Testing

After installation and before pouring concrete, all piping should be tested to about 100 psi. This pressure should be maintained until all welds and connections have been checked for leaks. If an oil is used as an antifreeze, the test should be performed with air or some gas (only 50 psi required with an air test) but *not with water*. The danger of using water is that the pipe may not be thoroughly dried when the oil is introduced.

The water will tend to collect, and when the temperature falls below 32 F the collected water may freeze and cause damage.

### Draining

Proper drainage is necessary for both the slab surface and the coil.

The slab must be sloped so that the water from the melted snow can run off. Puddles are objectionable on sidewalks or drives. They cause splashing, and they retard heat flow from the embedded pipes.

The pipes must be placed so that they may be drained. If the anti-freeze becomes corrosive it must be drained. It is not good practice to rely entirely on blowing of air through the system.

### Drifting Snow

It is quite likely that some drifting will occur on every system that is adjacent to a wall or vertical surface. The designer should try to anticipate this condition and add extra piping in these areas. If possible, coils should be added in the vertical surface. Another expedient is to carry the drainage to the area expected to be drifted. The drainage will tend to wash away some of the snow.

### Design Example

**Example 4:** Design a snow melting system for an area of 10,000 sq ft in Pittsburgh Pa. using a free area ratio of 0.5. Assume an air temperature of 10 F and a wind velocity of 10 mph. Use an oil antifreeze solution.

**Solution:** From Table 3 select a snowfall rate of 0.08. From Table 4 find the required heat output of top of slab as  $q_o = 168$  for  $A_r = 1$ , and  $q_o = 64$  for  $A_r = 0$ . Then for  $A_r = 0.5$  use  $q_o = 116$  because  $0.5(168 - 64) + 64 = 116$ . From Equation  $12 t_m = 0.5q_o + t_f = (0.5 \times 116) + 33 = 91$  F.

Assume that back and edge losses are 40 percent. Then the total heat requirement on heat exchanger is

$$A_p q_t = 10,000 \times 1.40 \times 116 = 1,624,000 \text{ Btuh.}$$

From Equation 16

$$G = \frac{A_p q_t}{160 w_m c_m} = \frac{1,624,000}{160 \times 60.5 \times 0.431} = 390 \text{ gpm}$$

(Interpolating from Table 5,  $w_m = 60.5$  and  $c_m = 0.431$  for  $t_m = 91$  F.)

Since a temperature drop of 20 deg was used, the fluid must enter the slab at 101 F and leave at 81 F.

Assume that the coil circuit of longest equivalent length is 300 ft and has a flow of 12 gpm and the pipe is 1-in. IPS. From Table 1, Chapter 27, the I.D. = 1.049 in. = 0.0875 ft and the I. D. section area = 0.864 sq in. = 0.00600 sq ft, hence for 12 gpm, the flow is 0.0268 cu ft per sec and the velocity =  $\frac{0.0268}{0.00600} = 4.47$  fps.

Interpolating from Table 5, the kinematic viscosity is  $4.92 \times 10^{-5}$  ft<sup>2</sup> per sec (An accurate interpolation requires the use of ASTM Standard Viscosity chart B.)

$$\text{Hence the Reynolds number} = \frac{VD}{\nu} = \frac{4.47 \times 0.0875}{4.92 \times 10^{-5}} = 7950$$

From Fig. 4 of Chapter 4, using a roughness factor of  $e = 0.00015$ , whence  $e/D =$

0.00172, the friction factor  $f$  is found to be 0.0355. Substituting in the Fanning equation

$$h_f = f \times \frac{L}{D} \times \frac{V^2}{2g} = 0.0355 \times \frac{300}{0.0875} \times \frac{4.47^2}{64.3} \\ = 37.9 \text{ ft of fluid} = 15.9 \text{ psia.}$$

The pump must deliver 390 gpm against a 15.9 psia head. The heat exchanger must deliver 1,624,000 Btuh with an inlet temperature of 81 F and an outlet temperature of 101 F. (Actually an allowance should be made for temperature drop in the piping between the slab and the heat exchanger.)

The expansion tank should be designed in accordance with the procedure outlined in Chapter 22, Hot Water Heating Systems. The amount of expansion should be based on the change in volume from 0 F to 91 F. From Table 5, determine  $w = 62.5$  lb per cu ft at 0 F, and  $w = 60.5$  lb per cu ft at 91 F. From Table 1, Chapter 27, 10,000 ft of 1-in. IPS contains 44.9 gal. Allowing another 15 gal for heat exchanger, headers, etc., assume the system contains 60 gal. Then the expansion would be  $\frac{60(62.5 - 60.5)}{60.5} = 2.48$  gal.

A quick approximation of required head can be obtained from Fig. 17. At 91 F, the oil has a viscosity of  $4.92 \times 10^{-5}$  ft sq per sec or 35 SSU. Enter Fig. 17 at 35 SSU and rise to the 12 gpm curve, read  $h = 12.5$  ft per 100 ft, then  $h_f = 12.5 \times \frac{300}{100} = 37.5$  ft, which agrees fairly well with the 37.9 ft obtained by the Fanning equation.

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## CHAPTER 25

### UNIT HEATERS AND UNIT VENTILATORS

Definitions; Unit Heaters: Classification, Application, Ratings, Location, Space Temperatures, Control, Piping, Maintenance, Boiler Capacity; Unit Ventilators: Ratings, Capacity Requirements, Application, Selection, Control, Location, Exhaust Flues; Window Ventilators

THE generally accepted meaning of the word *unit* in the terms unit heaters, unit ventilators, and unit humidifiers, is that of a factory-made encased assembly of the functional elements indicated by its name.

The term *unit heater* denotes an assembly of elements, the principal function of which is heating. The essential elements of a unit heater are a fan and motor, a heating element, a housing, and outlet vanes or diffusers. Some types are shown in Figs. 1 to 4.

The term *unit ventilator* denotes an assembly, the principal function of which is to ventilate and cool the space by the introduction of outdoor air. It may serve to heat and circulate the air within the space, or introduce air from outdoors, or may accomplish both in varying proportions. The essential elements of a unit ventilator are fans and motor, heating element, dampers, and outlet grilles or diffusers, all encased in a housing.

### UNIT HEATERS

#### Classification

The various types of unit heaters which are at present available can usually be classified according to one of the three following methods:

1. *By type of heater.* Under this classification there are three types of heating elements to be considered: (a) the *steam or hot water type*, (b) the *electric type*, and (c) the *direct fired type* which may be *gas*, *oil*, or *coal fired*.
2. *By type of fan.* Under this classification there are two types of fans to be considered: (a) the *propeller type* and (b) the *centrifugal type*. Either type may be arranged for horizontal or vertical delivery of air.
3. *By arrangement of elements.* Under this classification there are two types of heaters to be considered: (a) the *draw-through type*, in which the fan draws air through, and (b) the *blow-through type*, in which the fan blows air through the heater.

Unit heaters are available in any combination of the three preceding general classifications. For example, the steam or hot water type may be secured with either the propeller or centrifugal type of fans, and in either the draw-through or blow-through type.

Unit heaters also vary in other minor respects. For example, steam and return inlets and outlets may be located on top and bottom, respectively, or on the same side of the unit. Some units are supported by the piping and some have independent supports. The heating surface of steam or water type units is generally made up of a non-ferrous tube-and-fin assembly; or it may be fabricated of steel, or cast in steel or iron.

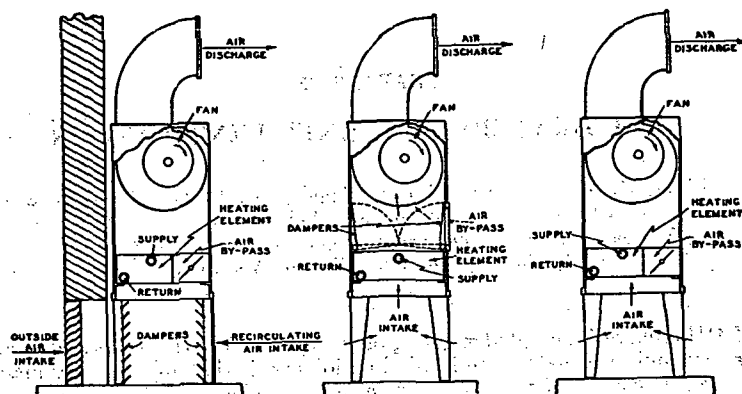


FIG. 1. CENTRIFUGAL FAN TYPE UNIT HEATER—FLOOR MOUNTED

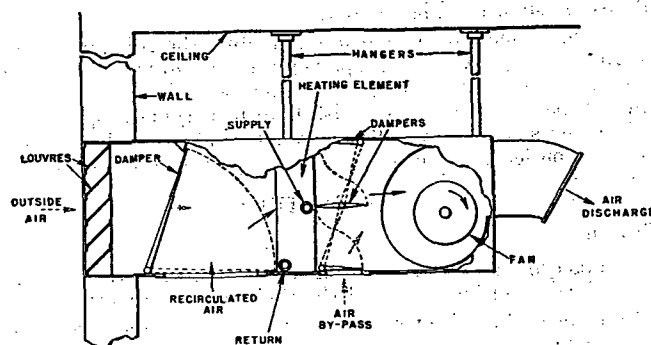


FIG. 2. CENTRIFUGAL FAN TYPE UNIT HEATER—SUSPENDED

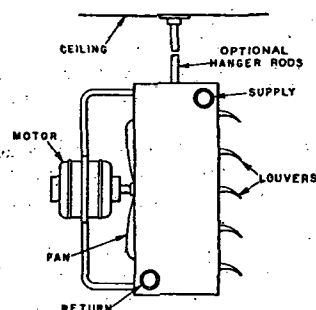


FIG. 3. PROPELLER FAN TYPE UNIT HEATER—HORIZONTAL BLOW

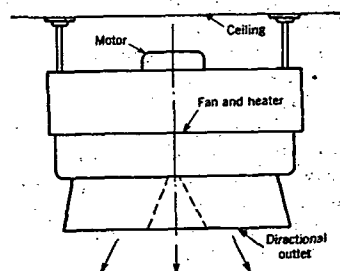


FIG. 4. PROPELLER FAN TYPE UNIT HEATER—VERTICAL BLOW

### Application of Unit Heaters

There are three major factors to consider in the application of unit heaters, namely: (1) heating medium, (2) air distribution, and (3) location of unit.

*Steam or hot water unit heaters* are used principally for heating commercial and industrial structures such as garages, factories, laboratories, and stores. They may also be used for heating finished rooms, if properly applied and concealed, and if some consideration is given to the problem of noise.

Unit heaters may also be adapted to a number of industrial processes, such as drying and curing, in which the use of heated air in rapid circulation with uniform distribution is of particular advantage. They may be used for moisture absorption, such as fog removal in dye houses, or for the prevention of condensation on ceilings or other cold surfaces of buildings in which process moisture is released. When such conditions are severe, it is necessary that the unit heaters draw air from outside in enough volume to provide a rapid air change, and that they operate in conjunction with ventilators or fans for exhausting the moisture-laden air. (See discussion of condensation in Chapter 10.)

*Electric unit heaters* can be used to advantage for supplemental heat in residences, for the heating of ticket booths, watchmen's offices, factory offices, locker rooms, and other isolated rooms scattered over large areas. They are particularly useful in isolated and untended pumping stations or pits where they may be thermostatically controlled to prevent freezing temperatures.

*Gas-fired unit heaters* find application in industrial plants, offices, stores, garages; in fact, in almost every location where steam-type units are used. The installation cost of gas-fired units is usually less than that of a type requiring that a new boiler be installed, unless the number to be installed would justify the cost of a boiler and steam or hot-water unit heater system.

*Oil-fired unit heaters* are used in industrial plants, garages and commercial buildings.

*Coal-fired unit heaters* are used principally in large industrial plants such as foundries.

### Outlet Velocities

Outlet velocities of unit heaters vary from about 400 to 2500 fpm, depending upon the type of unit and the distance (blow) to which the air is to be projected. Noise and drafts must be considered in the choice of air velocities, since both generally increase with increase of air velocity.

In the selection of unit heaters it is important to ascertain that the blow and coverage are sufficient. The blow is dependent to a marked degree on the temperature of air leaving the heater, as well as upon its velocity. (See discussion under heading of Inlet, Outlet, and Space Temperatures with Unit Heaters.) Recommended coverage and mounting heights should be obtained from the manufacturer.

In order to obtain the desired air distribution and heat diffusion, unit heaters are commonly equipped with directional outlets, adjustable louvers, or fixed types of diffusers.

### Ratings of Unit Heaters

It is standard practice to rate unit heaters on the basis of the amount of heat delivered by the air in Btu per hour above an entering air temperature

TABLE 1. CONSTANTS FOR DETERMINING THE CAPACITY OF UNIT HEATERS FOR VARIOUS STEAM PRESSURES AND TEMPERATURES OF ENTERING AIR  
(Based on Steam Pressure of 2 psig and Entering Air Temperature of 60 F)

|                   | STEAM PRESSURE PSIG | TEMPERATURE OF ENTERING AIR |      |      |      |      |      |      |      |      |      |      |      |
|-------------------|---------------------|-----------------------------|------|------|------|------|------|------|------|------|------|------|------|
|                   |                     | -10°                        | 0°   | 10°  | 20°  | 30°  | 40°  | 50°  | 60°  | 70°  | 80°  | 90°  | 100° |
| BLOW-THROUGH TYPE | 0                   | 1.54                        | 1.45 | 1.37 | 1.27 | 1.19 | 1.11 | 1.03 | 0.96 | 0.88 | 0.81 | 0.74 | 0.67 |
|                   | 2                   | 1.59                        | 1.50 | 1.41 | 1.32 | 1.24 | 1.16 | 1.08 | 1.00 | 0.93 | 0.85 | 0.78 | 0.71 |
|                   | 5                   | 1.64                        | 1.55 | 1.46 | 1.37 | 1.29 | 1.21 | 1.13 | 1.05 | 0.97 | 0.90 | 0.83 | 0.76 |
|                   | 10                  | 1.73                        | 1.64 | 1.55 | 1.46 | 1.38 | 1.29 | 1.21 | 1.13 | 1.06 | 0.98 | 0.91 | 0.84 |
|                   | 15                  | 1.80                        | 1.71 | 1.61 | 1.53 | 1.44 | 1.34 | 1.28 | 1.19 | 1.12 | 1.04 | 0.97 | 0.90 |
|                   | 20                  | 1.86                        | 1.77 | 1.68 | 1.58 | 1.50 | 1.42 | 1.33 | 1.25 | 1.17 | 1.10 | 1.02 | 0.95 |
|                   | 30                  | 1.97                        | 1.87 | 1.78 | 1.68 | 1.60 | 1.51 | 1.43 | 1.35 | 1.27 | 1.19 | 1.12 | 1.04 |
|                   | 40                  | 2.06                        | 1.96 | 1.86 | 1.77 | 1.68 | 1.60 | 1.51 | 1.43 | 1.35 | 1.27 | 1.19 | 1.12 |
|                   | 50                  | 2.13                        | 2.04 | 1.94 | 1.85 | 1.76 | 1.67 | 1.58 | 1.50 | 1.42 | 1.34 | 1.26 | 1.19 |
|                   | 60                  | 2.20                        | 2.09 | 2.00 | 1.90 | 1.81 | 1.73 | 1.64 | 1.56 | 1.47 | 1.39 | 1.31 | 1.24 |
|                   | 70                  | 2.26                        | 2.16 | 2.06 | 1.96 | 1.87 | 1.78 | 1.70 | 1.61 | 1.53 | 1.45 | 1.37 | 1.29 |
|                   | 75                  | 2.28                        | 2.18 | 2.09 | 1.99 | 1.90 | 1.81 | 1.72 | 1.64 | 1.55 | 1.47 | 1.40 | 1.32 |
|                   | 80                  | 2.31                        | 2.21 | 2.11 | 2.02 | 1.93 | 1.84 | 1.75 | 1.66 | 1.58 | 1.50 | 1.42 | 1.34 |
|                   | 90                  | 2.36                        | 2.26 | 2.16 | 2.06 | 1.97 | 1.88 | 1.79 | 1.71 | 1.62 | 1.54 | 1.46 | 1.38 |
|                   | 100                 | 2.41                        | 2.31 | 2.20 | 2.11 | 2.02 | 1.93 | 1.84 | 1.75 | 1.66 | 1.58 | 1.50 | 1.42 |
| DRAW-THROUGH TYPE | 0                   | 1.48                        | 1.41 | 1.33 | 1.25 | 1.18 | 1.11 | 1.03 | 0.96 | 0.89 | 0.82 | 0.75 | 0.69 |
|                   | 2                   | 1.52                        | 1.44 | 1.36 | 1.29 | 1.22 | 1.14 | 1.07 | 1.00 | 0.93 | 0.86 | 0.79 | 0.73 |
|                   | 5                   | 1.57                        | 1.49 | 1.41 | 1.33 | 1.26 | 1.19 | 1.11 | 1.05 | 0.98 | 0.91 | 0.84 | 0.77 |
|                   | 10                  | 1.64                        | 1.56 | 1.48 | 1.40 | 1.33 | 1.25 | 1.18 | 1.11 | 1.04 | 0.97 | 0.90 | 0.84 |
|                   | 15                  | 1.69                        | 1.61 | 1.53 | 1.46 | 1.38 | 1.31 | 1.24 | 1.17 | 1.10 | 1.03 | 0.96 | 0.90 |
|                   | 20                  | 1.73                        | 1.65 | 1.57 | 1.50 | 1.42 | 1.35 | 1.28 | 1.21 | 1.14 | 1.07 | 1.00 | 0.94 |
|                   | 30                  | 1.80                        | 1.73 | 1.65 | 1.57 | 1.50 | 1.42 | 1.35 | 1.28 | 1.21 | 1.15 | 1.08 | 1.01 |
|                   | 40                  | 1.86                        | 1.79 | 1.71 | 1.64 | 1.56 | 1.49 | 1.42 | 1.35 | 1.28 | 1.22 | 1.15 | 1.08 |
|                   | 50                  | 1.93                        | 1.85 | 1.77 | 1.70 | 1.63 | 1.55 | 1.48 | 1.42 | 1.35 | 1.28 | 1.21 | 1.15 |
|                   | 60                  | 1.97                        | 1.90 | 1.82 | 1.75 | 1.67 | 1.60 | 1.53 | 1.46 | 1.40 | 1.33 | 1.26 | 1.19 |
|                   | 70                  | 2.02                        | 1.94 | 1.87 | 1.80 | 1.72 | 1.65 | 1.58 | 1.51 | 1.44 | 1.38 | 1.31 | 1.24 |
|                   | 75                  | 2.04                        | 1.97 | 1.90 | 1.82 | 1.75 | 1.68 | 1.61 | 1.54 | 1.47 | 1.40 | 1.33 | 1.27 |
|                   | 80                  | 2.06                        | 1.99 | 1.91 | 1.84 | 1.77 | 1.70 | 1.63 | 1.56 | 1.49 | 1.42 | 1.35 | 1.29 |
|                   | 90                  | 2.10                        | 2.03 | 1.95 | 1.88 | 1.80 | 1.73 | 1.66 | 1.59 | 1.52 | 1.46 | 1.39 | 1.32 |
|                   | 100                 | 2.15                        | 2.07 | 1.99 | 1.92 | 1.85 | 1.77 | 1.70 | 1.63 | 1.56 | 1.49 | 1.43 | 1.38 |
|                   | 125                 | 2.21                        | 2.14 | 2.06 | 1.99 | 1.91 | 1.84 | 1.77 | 1.70 | 1.63 | 1.56 | 1.49 | 1.43 |
|                   | 150                 | 2.28                        | 2.20 | 2.13 | 2.05 | 1.98 | 1.91 | 1.84 | 1.77 | 1.70 | 1.63 | 1.56 | 1.50 |

Note: To determine capacity at any steam pressure and entering temperature, multiply rated capacity at 60 F entering air and 2 psig by constant from table.

When increasing steam pressure it is important to determine whether the heater is suitable for the increased pressure application, and whether the resulting increased outlet temperature is satisfactory.

of 60 F. This applies to all types of unit heaters, the steam or hot water type, the electric type and the direct fired type. There are, however, other factors which must be taken into account, especially when an attempt is made to compare one type of heater with another. These are the temperature of the heating element and the velocity of air through it. Consideration is given to these factors in the discussion of ratings for each type of unit heater in the following paragraphs.

**Steam.** Rating of steam unit heaters has been standardized by a code<sup>2</sup> in which the following items are the basis of rating: dry saturated steam at

2 psig pressure at the heater coil; air at 60 F (29.92 in. Hg barometric pressure) entering the heater; and heater operating free of external resistance to air flow.

The capacity of a heater increases as the steam pressure increases, and decreases as the entering air temperature increases. The heating capacity for any condition of steam pressure and entering air temperature other than standard may be calculated approximately from any given rating by the use of factors in Table 1 for the blow-through or draw-through types.

**Hot Water.** A standard for the rating of hot water type unit heaters has also been established by code<sup>3</sup> in which the following items are the basis of rating: entering water at 200 F; entering air at 60 F (29.92 in. Hg barometric pressure); and heater operating free of external resistance to air flow. This code also prescribes a method of translating the output in Btu and the temperature rise as obtained under test conditions to standard conditions of air and water temperature.

**Electric.** Electric type unit heaters are available in sizes up to at least 60 kw capacity. They consist of resistance type heating elements combined with fan and motor, together with a suitable casing. Electric unit heaters are rated on the energy input to the heater, expressed in terms of kilowatts, Btuh or EDR (Equivalent Direct Radiation).

**Gas-Fired.** Gas-fired unit heaters are built in both suspended and floor models, with either propeller or centrifugal type fans. They are rated in terms of both input and output in accordance with the approval requirements of the American Gas Association.

**Oil-Fired.** The oil-fired unit heater is usually equipped with a centrifugal fan or fans and is available in either the floor-mounted or in smaller sizes in the suspended type. Ratings are based on heat delivered at heater outlet in Btu per hour.

**Stoker-Fired.** The stoker-fired unit heater can be obtained in a wide range of capacities. Ratings are based on heat delivered at the heater outlet in Btu per hour.

#### Effect of Resistance Upon Capacity

Unit heaters are customarily rated as free delivery type units. If outside air intakes, air filters, or ducts on the inlet or discharge are used, a reduction in air and heating capacity will result because of this added resistance to air flow. The percentage of this reduction in capacity will depend upon the characteristics of the heater, and on the type, design, and speed of the fans, so that no specific percentage reduction can be assigned for all heaters at a given added resistance. The heat output to be expected under other than free delivery conditions should be secured from the manufacturer.

#### Location of Unit Heaters

Care should be taken in the location of unit heaters to insure free air circulation to the intake and proper heat distribution over the working level. Manufacturers' catalogs usually give suggestions for best arrangements of the various heaters. Types and makes of available heaters are shown in the Catalog Data Section of this volume.

Hot blasts in working zones should have their discharge outlets above the head line, and suspended heaters should be so adjusted that the heated air stream will not be objectionable.

In connection with the use of vertical type unit heaters, care must be

exercised in the selection of the heater. It has been found that the higher the unit is placed above the floor, the lower must be the outlet temperature of the air leaving the heater in order that the heated air may be forced into the occupied zone.

### Inlet, Outlet and Space Temperatures with Unit Heaters

In the selection of unit heaters for any particular design, consideration should be given to the temperature of air entering the heaters, as well as the temperature to be maintained in the working zone of the space. In general, the temperature differences per foot of elevation, when using unit heaters, are less than corresponding variations when using direct radiation.<sup>4</sup> High velocity units will maintain slightly lower temperature differences than low discharge velocity units. Correspondingly, units with lower discharge air temperature will maintain lower temperature differences than units with higher discharge temperatures. Directional control of the discharged air from a unit heater can be an important factor, added to qualities of reasonably good outlet velocity and outlet temperature, in effecting satisfactory distribution of heat and reducing floor-to-ceiling temperature difference.

Since the outlet temperature of air from a unit heater increases with the temperature of the heating medium, such as high pressure steam, heaters can be obtained with heating elements having less than the regular amount of heating surface in order to obtain, with the high temperature heating medium, approximately the same leaving air temperature as would be obtained from a lower temperature heating medium.

When some *outside air* is introduced, the temperature of the mixture of outside and recirculating air must be calculated and used as the entering air temperature at the heater. Unit heaters connected in this manner perform the function of unit ventilators. For a discussion of this function see the section of this chapter entitled *Unit Ventilators*.

For recirculating heaters located *at the floor* or with *intakes at the floor*, the temperature of air entering the heater should be assumed to be the same as that to be maintained in the room itself.

### Automatic Control of Unit Heaters

Thermostatic control of unit heaters may be accomplished either by starting and stopping the fan, or by controlling the flow of the heating medium to the heating element. Unit heaters may be used in summer as a means of circulating air to give some measure of comfort due to air motion. In such cases the heating element should be shut off from the source of heat. The thermostat should be provided with a by-pass switch which will permit the fan to be operated independently of the room temperature.

### Piping Connections For Steam Unit Heaters

Piping connections for steam unit heaters are similar to those for other types of fan blast heaters. The piping of unit heaters must conform strictly to the system requirements while at the same time permitting the heaters to function as intended. The basic piping principles for steam systems are discussed in Chapter 21.

Rapid condensation of steam, especially during heating-up periods, is characteristic of this type of equipment. The return piping must be planned to keep the heating coil free of rapid condensation, while the steam

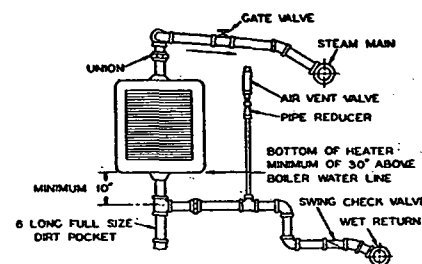


FIG. 5. UNIT HEATER CONNECTION TO LOW PRESSURE STEAM GRAVITY SYSTEM

piping must be ample to carry a full supply of steam to the unit to take the place of that condensed. Adequate sizes of piping are especially important where a unit heater fan is operated under start-and-stop control, and where all or part of the air is taken from the outside. In such installations the condensation rate may vary rapidly, and the necessity for ample pipe capacity is particularly important.

Piping connections for unit heaters as recommended by the *Industrial Unit Heater Association* are shown in Figs. 5 to 9.

In steam systems the branch from the supply main to the heater should pitch toward the main, and be connected to its top to prevent condensation in the main from draining through the heater where it might reduce capacity and cause noise.

The return piping from steam heaters should provide a minimum drop of 10 in. below the heater so that the head of water required to overcome resistances of check valves, traps, and strainers will not cause condensation to remain in the heater.

Dirt pockets shown in Figs. 5 to 7 are essential, and strainers are recommended as an additional means of retaining dirt and scale which might affect operation of check valves and traps. Return piping between the heater and strainer should be of the same size as the heater outlet. Strainers should always be installed in the steam supply line if the heater is equipped with the steam distributing type of coils.

An adequate air vent is required for closed low pressure gravity systems. The vertical pipe connection to the air vent should be at least  $\frac{3}{4}$  in. I.P.S. to permit separation of the water from the air passing to the vent.

In vacuum systems, if thermostatic instead of float and thermostatic traps are used, a cooling leg must be provided ahead of the trap.

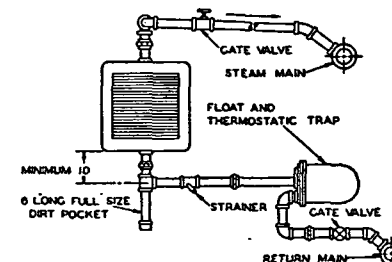


FIG. 6. UNIT HEATER CONNECTION FOR VACUUM OR VAPOR STEAM SYSTEM



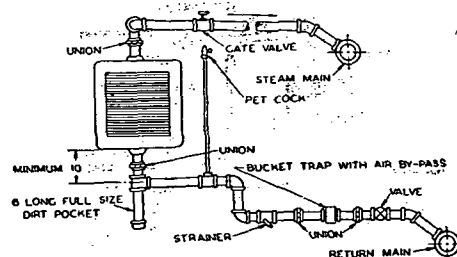


FIG. 7. UNIT HEATER CONNECTION TO HIGH PRESSURE STEAM SYSTEM

In high pressure systems it is customary to vent the air through a pet cock which is left slightly open at all times. Where possible it is advisable to install pressure reducing valves to permit operation of the heaters at lower pressure. Traps used must be suitable for the operating pressure encountered.

In connecting piping to hot water unit heaters, the piping should be pitched to permit escape of air to the high point in the piping where it can be vented to the atmosphere. An air vent at the heater is used to facilitate air removal or to vent the top of the heater. Provision should be made for complete drainage of the system if shutdown in freezing weather is possible.

#### Maintenance

Regular inspection based upon a schedule determined by the amount of dirt in the atmosphere will insure maximum economy in operation and maintenance of heating capacity.

Heating elements should be cleaned when necessary by brushing or blowing with high-pressure air, or by using a steam spray. Removal of the heating element and washing with a mild alkali solution, followed by thorough rinsing with water, may be necessary in certain installations.

Dirty fan blades may cause unbalance and vibration with consequent noise and damage to bearings. Hence, fan blades should be cleaned when necessary. Vibration may also be caused by improper fan position or loose set screws.

There is considerable difference in the attention required by the various types of motors used with unit heaters. This is particularly true of lubri-

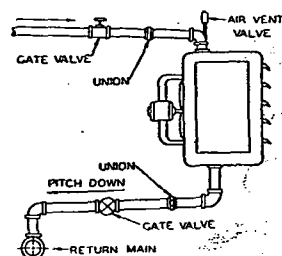


FIG. 8. CONNECTION OF HORIZONTAL UNIT HEATER TO HOT WATER SYSTEM

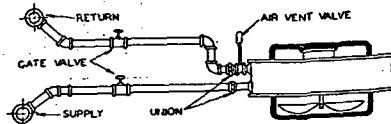


FIG. 9. CONNECTION OF VERTICAL UNIT HEATER TO HOT WATER SYSTEM

cation, the instructions for which must be carefully followed for trouble-free operation. Excessive lubrication may cause lubricant to reach and damage the rotor. An improper lubricant may cause failure of bearings. Instructions for care of the motor on any unit heater should therefore be obtained from the manufacturer and should be kept at the unit.

Fan bearings and drives must be given the lubrication and other attention specified by the manufacturer. If the unit is direct-connected, the couplings should be inspected periodically for wear and alignment. V-belt drives should have all belts replaced with a matched set if one belt shows wear.

Periodical inspection of traps, check valves, and air valves, and the replacement of worn parts are important maintenance items. Strainers should be cleaned regularly.

When filters are incorporated in the unit, they must be cleaned or replaced when dirty.

For prevention of corrosion in unit heaters, see Chapter 43, Corrosion and Water Formed Deposits, Causes and Prevention, in this edition, and also Bulletin 12, The Care and Maintenance of Steam and Hot Water Unit Heaters, published by the *Industrial Unit Heater Association*.

#### BOILER CAPACITY FOR STEAM UNIT HEATERS

The capacity of the boiler should be based on the rated capacity of the unit heaters at the lowest entering air temperature and highest fan speed that will occur, plus an allowance for pipe line losses. It is unwise to install a single unit heater as the sole load on any boiler, particularly if the unit heater motor is started and stopped by thermostatic control. The wide and sudden fluctuations of load that occur under such conditions would require closer attention to the boiler than is usually possible in a small installation. Where oil or gas fuel is used in the boiler, it is possible by means of a pressure operated switch to control the boiler, in response to this rapid fluctuation. In most cases, and particularly where the boiler is coal-fired, it is advisable to use two or more smaller units instead of one large unit heater.

Steam pressures below 5 lb can be used with safety for recirculating unit heaters when their heating surfaces are designed for those pressures, and when proper provision is made for returning the condensate. If units receive air that may be at a temperature below freezing, a steam pressure of not less than 5 lb should be maintained in the heating element, or a corresponding differential in pressure between the supply and return piping should be maintained by means of a vacuum.

#### UNIT VENTILATORS

A unit ventilator as defined earlier in this chapter, has the function of introducing outdoor air for ventilation and cooling in addition to heating. The typical unit is arranged to introduce outdoor air and recirculated air to the room in varying quantities and is equipped with a system of control that permits both the heating and cooling effect to be varied while the fans are operating continuously. Either steam or forced hot water may be employed as the heating medium. Unit ventilators are intended primarily for use in schools, meeting rooms, offices, or other applications where the density of occupancy indicates the need for ventilation. In normal operation, the discharge air temperature from a unit ventilator is varied in

accordance with the room demands. Where a heating effect is required, the air delivered is above room temperature. Where the heat generated within the room by occupants, sun, etc., is sufficient to cause overheating, the air delivery temperature must be below that of the rooms. It is customary to equip unit ventilators with control devices that prevent the delivery of air at a temperature that will cause cold drafts. Unit ventilators may be of the heating element or damper controlled type, constructed on the blow-through shown in Fig. 10, or draw-through principle as illustrated in Fig. 11.

### Ratings of Unit Ventilators

Unit ventilators are customarily cataloged with two ratings: the *anemometer rating* and the *standard air rating*. The anemometer air rating is

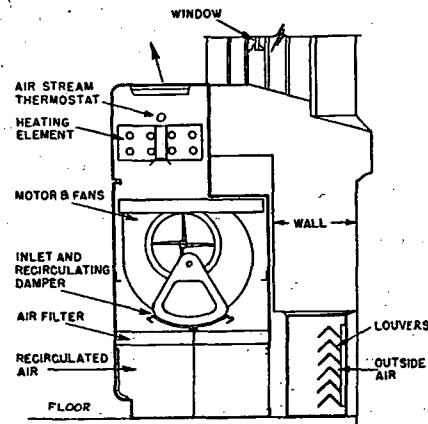


FIG. 10. TYPICAL BLOW-THROUGH TYPE UNIT VENTILATOR SHOWING ONE OF MANY ARRANGEMENTS OF DAMPERS AND HEATING ELEMENTS

peculiar to school house ventilation and was for many years the standard by which school officials checked and specified unit ventilator capacities. It originated as a convenient field measurement for checking air quantities, and is the basis of rating for ventilation requirements under many state and local building codes. The anemometer rating (air capacity) is obtained by averaging the air velocities obtained by an anemometer held over equal subdivisions of the outlet grille at a distance of 2 in. from the grille, and multiplying the average velocity by the gross area of the grille. (The average velocity is sometimes obtained by moving the anemometer over the outlet 2 in. from its face.) The anemometer rating is based on the final temperature of the air leaving the grille while the unit is delivering outdoor air and room air in the proper proportion and the heating element is supplied with steam or hot water as specified.

The standard air rating is obtained in accordance with the A.S.H.V.E. Standard Code for Testing and Rating Steam Unit Ventilators.<sup>5</sup> This code requires that the following rating information be supplied:

- Rating Factors to be Specified.* The rating of the unit ventilator shall specify:
- Final temperature at different entering air temperatures.

### Unit Heaters and Unit Ventilators

- Total EDR at different entering air temperatures.
- Air delivered by the unit in cubic feet per minute at the *standard basis of rating* with the fans operated at rated speed, with all air being blown through the heating unit, and with the standard louver and grille on the outlet.

The *Standard Basis of Rating* shall be as follows:

- Dry saturated steam at a temperature at the unit corresponding to an absolute pressure of 16.7 psi (218.5 F).
  - Entering air temperature of zero Fahrenheit degrees.
  - Volume delivered in cubic feet per minute converted to standard air at 70 F.
- Rating Tables for unit ventilators shall contain the following data in addition to the standard rating, for entering air temperatures from -30 F to +60 F:
- Inlet temperature, Fahrenheit degrees.
  - Final temperature, Fahrenheit degrees.
  - Total EDR at the specified entering temperature.
  - Surplus or heating EDR at the specified entering temperature.

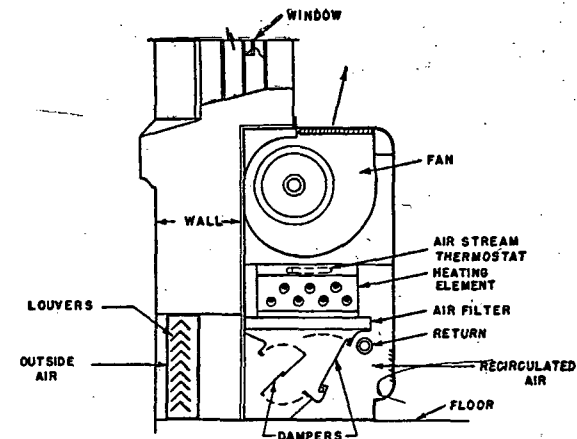


FIG. 11. TYPICAL DRAW-THROUGH TYPE UNIT VENTILATOR SHOWING ONE OF MANY ARRANGEMENTS OF DAMPERS AND HEATING ELEMENTS

*Surplus or Heating Equivalent Direct Radiation* for the purposes of this code shall be construed to mean difference between the total EDR at a specified inlet temperature and the EDR required to heat the air from that temperature to 70 F.

Table 2 shows the air handling capacities by the two methods of rating and the approximate room heating equivalent in EDR of an intermediate size of heating element. Heating elements are available for either a higher or lower capacity.

### Heating Capacity Requirements for Unit Ventilators

Since a unit ventilator has the dual function of introducing outdoor air for ventilation and maintaining a specified room temperature, the heat required by the unit may be similarly divided as (1) *heat required for ventilation* ( $H_v$ ) and (2) *surplus heat* ( $H_s$ ). The *surplus heat* is available for maintaining room temperatures. If auxiliary radiation is installed, the *surplus heat* requirement may be reduced by a corresponding amount. The sum of  $H_v$  and  $H_s$  is the total heat ( $H_t$ ) to be supplied by the unit ventilator.

These quantities of heat are related by the following equations:

$$\begin{aligned} H_v &= 0.24 W (t - t_o) & (1) \\ H_s &= 0.24 W (t_i - t_o) & (2) \\ H_t &= H_s - H_v = 0.24 W (t_i - t) & (3) \\ Q &= d 60 Q & (4) \\ H_t &= H_s + 0.24 d 60 Q (t - t_o) & (5) \end{aligned}$$

where

- $d$  = density of air, pounds per cubic foot (0.075 lb per cu ft for Standard Air by definition).  
 $H_s$  = surplus heat, Btu per hour.  
 $H_v$  = heat required to warm air for ventilation, Btu per hour.  
 $H_t$  = total heat requirements for both heating and ventilation, Btu per hour.  
 $Q$  = volume of air handled by the ventilating equipment, cubic feet per minute.  
 $t$  = temperature to be maintained in the room, Fahrenheit degrees.  
 $t_o$  = outside temperature, Fahrenheit degrees.  
 $t_i$  = temperature of the air leaving the unit, Fahrenheit degrees.  
 $W$  = weight of air circulated, pounds per hour.  
 $0.24$  = specific heat of air at constant pressure (approximate value).

TABLE 2. TYPICAL CAPACITIES OF UNIT VENTILATORS FOR AN ENTERING AIR TEMPERATURE OF ZERO

| CUBIC FEET OF AIR PER MINUTE |                     | TOTAL CAPACITY IN SQUARE FEET, EQUIVALENT DIRECT RADIATION | CAPACITY AVAILABLE FOR HEATING THE ROOM, SQUARE FEET EQUIVALENT DIRECT RADIATION | FINAL AIR TEMPERATURE F DEG |
|------------------------------|---------------------|------------------------------------------------------------|----------------------------------------------------------------------------------|-----------------------------|
| Anemometer Rating            | Standard Air Rating |                                                            |                                                                                  |                             |
| 750                          | 500                 | 214                                                        | 56                                                                               | 95                          |
| 1000                         | 750                 | 320                                                        | 84                                                                               | 95                          |
| 1260                         | 1000                | 427                                                        | 112                                                                              | 95                          |
| 1560                         | 1250                | 534                                                        | 141                                                                              | 95                          |

**Example 1:** The heat loss of a certain room is 24,000 Btu per hour, and the ventilating requirements are 1000 cfm. If the room temperature is to be 70 F and all air is taken from the outside at zero, what will be the total heat demand on the unit if it is required to provide for both the heating and ventilating requirements (combined system)?

**Solution:** Since the surplus heat is available to replace the heat loss of the room,

$$H_s = 24,000 \text{ Btu per hour.}$$

Substituting in Equation 5:

$$H_t = 24,000 + 0.24 \times 0.075 \times 60 \times 1000 (70 - 0) = 99,600 \text{ Btu per hour}$$

$$t_i = \frac{24,000}{0.24 \times 0.075 \times 60 \times 1000} + 70 = 92.2 \text{ F}$$

If in **Example 1** a 1000 cfm (Standard Air) unit were required, but only 25 percent of the air introduced were outdoor air, the solution is:

$$H_t = 24,000 + 0.24 \times 0.075 \times 60 \times 0.25 \times 1000 (70 - 0) = 42,900$$

$$t_i = \frac{24,000}{0.24 \times 0.075 \times 60 \times 1000} + 70 = 92.2$$

The only difference from **Example 1** is that, in the latter case, the ventilation load has been reduced.

### Applications of Unit Ventilators

Items to be considered in the application of unit ventilators are: (1) combination with other means of heating, (2) selection of unit ventilator size, (3) cycle of control, (4) location of units, and (5) method of venting and exhausting.

In a *split* system the unit ventilator heat output is supplemented by that of additional radiators or convectors, and consequently a corresponding reduction in required unit ventilator heating capacity may be made. With the split system, temperature control equipment should operate to close the supply to auxiliary radiation or convectors as the first step in the control cycle on a rising room temperature.

The *combined* system employs a unit ventilator with sufficient heating capacity for both ventilation and normal heat losses. In such a case no direct radiation is required. The cost of installation of a combined system is usually less than that of a split system. The unit ventilator is normally arranged to circulate outdoor air constantly or to circulate room air constantly up to full capacity; or to circulate mixed and variable quantities of room air and outdoor air automatically, depending on the thermal requirement of the room. The minimum amount of outdoor air for ventilation purposes may be governed by state or local codes or may be calculated by the engineer to meet the ventilating air needs of the particular application.

### Selection of Unit Ventilator Size

The primary consideration in the selection of the size of unit ventilator is the number of occupants in the space. Other factors to be considered are state and local code requirements, volume of the room, density of occupancy, and the usage of the room. A safe rule for determining air capacity is to allow a total air quantity of 30 cfm per person, or six to nine room air changes through the unit, whichever is greater. With this quantity of air handled, it is possible to obtain satisfactory cooling in mild weather. Since cooling is an important function, the unit ventilator must be selected to supply adequate air quantities.

After selecting the basic size of unit, the coil capacity to meet the heating requirement can be determined from the manufacturer's tables.

### Control of Unit Ventilators

Three cycles of control are available for use with unit ventilators. These cycles of control determine the sequence of operation of the dampers and heating element as described in Chapter 39, Automatic Controls.

### Location of Unit Ventilator

The location of the unit ventilator in a room is important. Wherever possible it should be placed against an outside wall and on the center line of the room. It is difficult to obtain proper air distribution if the unit is installed either on an inside wall or in a corner of the room. Standard units discharge the air stream upward, but for special cases units may be installed to discharge air horizontally. Units may be set against the wall or par-

tially recessed into the wall to save space without materially affecting the results.

### Air Exhaust Vents and Flues

The size and location of the air exhaust vent<sup>1</sup> outlet are important and in many cases, are regulated by laws for public buildings. Where no codes govern, the location and size of vents are left to the discretion of the engineer.

Best results have been obtained with a velocity through the vent openings nearly equal to that at which the air is introduced into the room, thus maintaining a slight pressure in the room. Calculated velocities at the vent openings of from 600 to 800 fpm produce the best diffusion results from this system. Many states, however, have regulations that will not permit velocities as high as 800 fpm. If a vent opening at or near the floor is near a desk or place where a person is seated, a velocity of 800 fpm in the vent opening will produce an objectionable draft. In such a case the velocity in the vent opening should not exceed 400 to 450 fpm, although duct velocities may be maintained at 600 to 800 fpm if codes permit.

In school buildings provided with wardrobes or cloakrooms, the vents may be so located that the air passes through these spaces, ventilating them with air which otherwise would be passed to the outside without being used to the best advantage. Many state and local codes for ventilation of public buildings make this arrangement mandatory.

### WINDOW VENTILATORS

A window ventilator consists of filter and switch controlled motor-driven fans enclosed in a cabinet to be mounted on the window sill. Such units accomplish ventilation, air cleaning, and air circulation, but have no means of heating the air. The direction of air discharge is manually adjustable for seasonal operation.

### REFERENCES

- <sup>1</sup> See *National Association of Fan Manufacturers* standard definitions in Chapter 33.
- <sup>2</sup> Standard Code for Testing and Rating Steam Unit Heaters—Adopted jointly by THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and the Industrial Unit Heater Association, Second Edition January 1950 (*IUHA Bulletin* No. 10).
- <sup>3</sup> Standard Code for Testing and Rating Hot Water Unit Heaters—Adopted jointly by THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and the Industrial Unit Heater Association, Second Edition April 1953 (*IUHA Bulletin* No. 11).
- <sup>4</sup> A.S.H.V.E. RESEARCH REPORT No. 958—Temperature Gradient Observations in a Large Heated Space, by G. L. Larson, D. W. Nelson and G. C. Cromer (A.S.H.V.E. TRANSACTIONS, Vol. 39, 1933, p. 243). A.S.H.V.E. RESEARCH REPORT No. 1011—Tests of Three Heating Systems in an Industrial Type of Building, by G. L. Larson, D. W. Nelson and John James (A.S.H.V.E. TRANSACTIONS, Vol. 41, 1935, p. 185).
- <sup>5</sup> A.S.H.V.E. Standard Code for Testing and Rating Steam Unit Ventilators (A.S.H.V.E. TRANSACTIONS, Vol. 38, 1932, p. 25) (Effective Jan. 1, 1934).
- <sup>6</sup> A.S.H.V.E. RESEARCH REPORT No. 936—Investigation of Air Outlets in Class Room Ventilation, by G. L. Larson, D. W. Nelson and R. W. Kubasta (A.S.H.V.E. TRANSACTIONS, Vol. 38, 1932, p. 463). A.S.H.V.E. RESEARCH REPORT No. 1017—Air Supply to Classrooms in Relation to Vent Flue Openings, by F. C. Houghton, Carl Gutberlet and M. F. Lichtenfels (A.S.H.V.E. TRANSACTIONS, Vol. 41, 1935, p. 279).

## CHAPTER 26

### UNIT AIR CONDITIONERS AND UNIT AIR COOLERS

Definitions, Classification of Unit Type Equipment, Component Parts of Unit Type Equipment, Sound Isolation, Modifications of Remote Units, Ratings of Unit Air Conditioners, Application of Unitary Equipment, Unit Air Coolers

THIS chapter presents the physical characteristics of air cooling units and air conditioning units; a suggested procedure for selection of units; and some of the factors involved in the application of unitary equipment. In general, factory produced unit equipment can be obtained to accomplish all of the functions possible from field assemblies, but the advantages of unit equipment are most apparent in small and moderate capacities. Above 12,000 cfm capacity, or approximately 40 tons of refrigeration capacity, handling and assembly costs generally favor the use of field assembled units. Multiple application of unitary equipment is frequently justified for large gross tonnage installations where zoning or a minimum amount of air distributing ducts is desirable.

### DEFINITIONS

The term *air conditioning* unit has been loosely used as a name for all types of factory produced air handling, cooling, or heating units. A joint committee<sup>1, 2, 3</sup> on Rating Refrigerating Equipment has defined the various types of unitary equipment:

1. A *Cooling Unit* is a specific air treating combination consisting of means for air circulation and cooling within prescribed temperature limits.<sup>1</sup>
2. An *Air Conditioning Unit* is a specific air treating combination consisting of means for ventilation, air circulation, air cleaning, and heat transfer, with control means for maintaining temperature and humidity within prescribed limits.<sup>1</sup>
3. A *Cooling Air Conditioning Unit* is a specific air treating combination consisting of means for ventilation, air circulation, air cleaning, and heat transfer, with control means for cooling and maintaining temperature and humidity within prescribed limits.<sup>1</sup>
4. A *Self-Contained Air Conditioning or Cooling Unit* is one in which a condensing unit is combined in the same cabinet with the other functional elements. Self-contained air conditioning units are classified<sup>4</sup> according to the method of rejecting condenser heat (water cooled, air cooled, and evaporatively cooled), method of introducing ventilation air (no ventilation, ventilation by drawing air from outside, ventilation by exhausting room air to the outside, or ventilation by a combination of the last two methods), and method of discharging air to the room (free delivery or pressure type).
5. A *Free Delivery Type Unit* takes in air and discharges it directly to the space to be treated without external elements which impose air resistance.<sup>1</sup>
6. A *Pressure Type Unit* is for use with one or more external elements which impose air resistance.<sup>1</sup>
7. A *Forced-Circulation Air Cooler* is a factory encased assembly of elements by which heat is transferred from air to refrigerants.<sup>1</sup>

### CLASSIFICATION OF UNIT TYPE EQUIPMENT

Field assembled apparatus as described in Chapter 30 can be designed in shape, size, and capacity for any application, with the refrigeration and heating system exactly balanced to a specific load condition.

To obtain the economies of factory production, component assemblies are available in the size ranges of greatest usage. In addition to assemblies

of high-side equipment in condensing units, the fan-coil units are factory made in various types as indicated by the preceding definitions.

If the condensing unit and cooling and heating coil surfaces are carefully selected, and if proper consideration is given to reduction of piping losses, the performance of the combined system will compare favorably with field assembled apparatus. A system in which the air handling unit is separated from the condensing unit, is called a remote system. The conditioning unit is designated as a remote unit. The usual capacities of remote units usually range from 2 to 100 tons.

The self-contained air conditioning or cooling units are widely used in capacities through 15 tons, and are available in larger sizes. Each model is designed for a specific cooling capacity and range of air delivery. Experience has demonstrated that well designed and properly applied equipment of this type produces excellent results in commercial comfort installations. In most designs of the larger self-contained units, the equipment can be adjusted to approximate the load calculations through a selection of the air quantity. An increase of air quantity in this type of equipment increases the sensible heat proportion, and a decrease of air quantity tends to provide a lower leaving dew point and a high proportion of moisture removal. However, the usual field practice is to adjust the fan speed for quietness and air distribution rather than for ratio of latent to sensible loads as indicated by a load estimate.

To meet the requirements of individual comfort in small rooms and offices, self-contained units, called room coolers, find extensive and economical application. These units are usually restricted to summer and intermediate season operation, and range from  $\frac{1}{2}$  to  $1\frac{1}{2}$  tons of refrigeration capacity.

A special application of remote units is found in the unit air cooler which is used extensively in refrigeration work. Its primary function is to reduce temperatures in insulated and sealed storage spaces, and humidity control is a secondary consideration. Because of the small temperature differences between the coil and room temperatures, unit coolers handle three to five times as much air per ton as remote units used in air conditioning.

The attic fan or exhaust fan is sometimes referred to as a cooling unit, but since it contains no element of heat transfer, it is treated in Chapter 33; Fans.

#### COMPONENT PARTS OF UNIT TYPE EQUIPMENT

The unitary equipment is designed for the air conditioning loads of most common occurrence. Highly special projects and projects of infrequent occurrence may require field-assembled equipment for best results. Field modifications generally prove inadvisable except by the most experienced engineering personnel. The basic design considerations of unitary equipment are discussed in the next following paragraphs.

**Remote Units.** Remote units can be obtained in two general classes, horizontal as shown in Fig. 1 and vertical as in Fig. 2. Their construction is essentially the same, except for the drain pan and filter locations.

**Casings.** Casings are generally constructed of sheet metal with angle iron frames and with removable panels for access to coil connections, blower bearings, filters, and drain. Casings should be air tight. Panels should be tight fitting with cam or similar fastenings for easy opening. Panel openings at coils for heavy units should be large enough to receive coils after the casing is suspended. Frames should be fitted with lugs

strong enough to suspend horizontal units. Non-metallic casings are of advantage in small remote units for reducing sound, particularly when propeller type fans are used.

**Insulation.** Remote units are available with waterproof and vermin-proof, sound and heat barrier insulation on the inside of the casing. They are also available with flanges and flanged access doors to permit insulation after installation.

**Drain Pans.** Because of the corrosive effect of mild picric, carbonic, and sulfurous acids absorbed by condensate, drain pans are usually made of 14 gage or heavier metal. They should be hot dipped galvanized after fabrication, or otherwise treated to resist corrosion. Some manufacturers extend the drain pan under the entire unit, but in any case it should extend far enough to catch any condensate carried over from the coils. The drain connection should be readily accessible for cleaning and, in air conditioning work, should be generously sized and trapped. Some municipal codes require a minimum size of  $1\frac{1}{4}$  IPS.

**Blowers.** The usual practice among manufacturers is to use blowers having external resistance capacity in keeping with the size and type of application for which the unit is designed. For example, the larger self-contained air conditioners have blower and motor arrangements for delivering the design air quantities against the larger external static pressures that are encountered when applying these units for use with supply and return-air duct systems. In a well designed unit, the relation of the blower and the coil surface is arranged, through testing, to assure adequate uniformity of air distribution over the heat transfer surface.

Some of the smaller suspended type units, Fig. 3, use propeller fans with a trailing edge blade in order to obtain required pressure characteristics with quiet operation. Since most of the motors driving these fans are direct-connected and use brushes for starting, adequate access should be provided for maintenance and inspection.

**Cooling Coils.** The cooling and dehumidifying coils used in unit air conditioners are essentially the same as those used in central station units. A proper balance of coil capacity to the other components of the packaged air conditioner is an essential of good design and performance. Ample coil capacity is a requirement for good operation at light loads and low air quantities.

Where multiple circuits are used in the larger coils, equal distribution of the cooling medium to the various circuits is vital in order to develop full capacity of the coil. The cooling coils also perform the function of dehumidification. To prevent carryover of condensate, some coil designs require eliminator sections even at the normal face velocities of 400 to 600 fpm.

In addition to condensing the moisture out of the air, the design and arrangement of the cooling coil should provide for quick and effective draining of the condensate into the pan. Proper manufacturing practices to provide for uniform fin spacing and laboratory development to determine coil-surface arrangements are among the requirements for good drainage from the cooling and dehumidifying coils of self-contained air conditioners.

**Heating Coils.** Heating coils of unit air conditioners are usually conventional blast coils, and can be obtained with or without non-freeze steam distribution features. They usually match the cooling coils in face area, and are one or two rows deep depending on the heating requirements. Where coils are selected for hot water and have more than two rows of

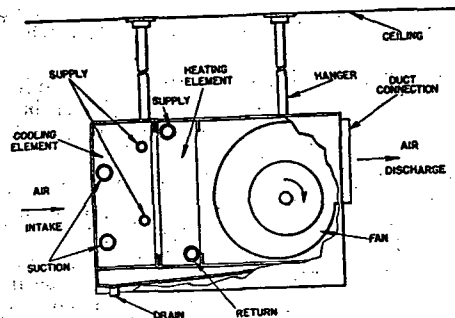


FIG. 1. HORIZONTAL REMOTE TYPE UNIT AIR CONDITIONER

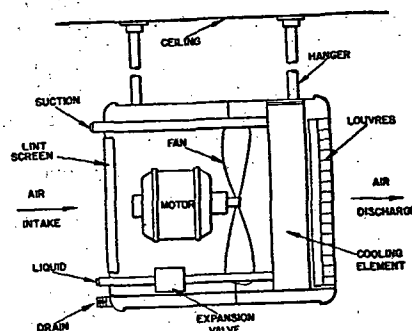


FIG. 3. SUSPENDED PROPELLER FAN TYPE UNIT AIR CONDITIONER

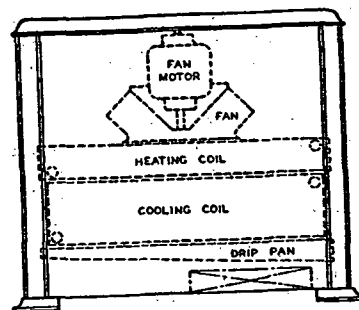


FIG. 5. REMOTE FLOOR TYPE ROOM UNIT AIR CONDITIONER

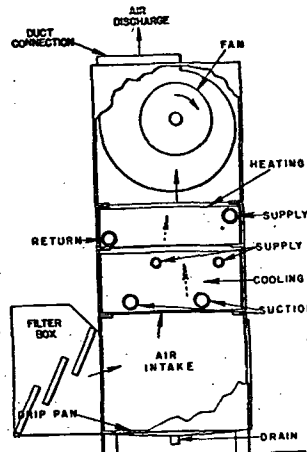


FIG. 2. VERTICAL REMOTE TYPE UNIT AIR CONDITIONER

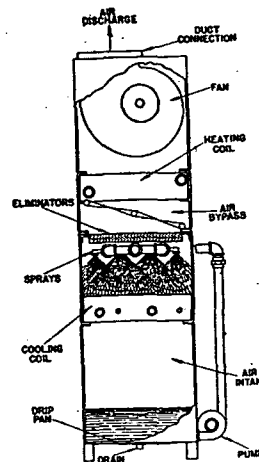


FIG. 4. SPRAY TYPE REMOTE UNIT AIR CONDITIONER

tubes, the air resistance and the space requirements of the cooling and heating coils should be carefully checked.

**Humidification.** Spray-type humidifiers are usually used in remote systems, but in some cases pan-type humidifiers or steam humidifiers are also used. Some condensation on the inside of the unit casing may occur with possible water damage if the unit is located in a cold space without adequate insulation. Spray-type humidifiers should be located so that no carryover of moisture occurs.

**Filters.** It is almost axiomatic that all units should have filters. Some small suspended units of 1 ton capacity or less, with low coil-face velocities and propeller fans, are equipped only with lint screens or operate without filters, but in them the coils must be periodically cleaned and there is constant danger of clogging of the drain, with the possibility of water damage. Filters used are usually of the throw-away type, although cleanable filters are available for most of the larger units. Care should be taken to insure adequate filter surface, since the cross-sectional area of the unit is seldom adequate for filter area. V-shaped or staggered filter arrangements are quite commonly used to increase filter area.

**Motors.** In some units where the motor is mounted inside, adequate access for maintenance and clearance for tightening belts are imperative. When motors are mounted in this manner, the heat equivalent of the motor input must be added to the heat load to be absorbed by the system, and this requires a lower exit air temperature at the coils. Usually, however, the motor is located outside of the casing where it is readily accessible for service. In this case, only the brake horsepower required by the fan is transformed into heat to be included in the load calculations.

In either application, motors should be selected with adequate horsepower to handle the design volume of air against the resistance of the system when the coils are wet, and then checked against the possible horsepower requirements for the increased volume of air obtained when the coils are dry.

### SOUND ISOLATION

Both suspended and vertical floor-mounted units can transmit vibration through the supports. Wherever such transmission of sound might be objectionable, the supports should be isolated through rubber-in-shear or other sound deadeners. (For design of suitable sound deadeners see section Controlling Vibration from Machine Mountings in Chapter 41.)

### OTHER TYPES OF UNITS

Features of various other types of remote air conditioners are given in the following paragraphs.

#### Spray-Type Unit

Fig. 4 shows a spray-type unit used by designers who prefer air washing and coil wetting features. These units are equipped with a pump that sprays water or brine over the coils. Due to the direct mixing of the condensate and the spray, provision must be made for overflow in summer and replacement of water evaporated in winter.

#### Dehumidifying Units

In a further modification of spray-type units, absorbent brine solutions such as lithium chloride are used to remove moisture from the air. As



explained in Chapter 38, the latent heat of the moisture removed is changed to sensible heat, so that coils must be used as after-coolers to obtain the right dry-bulb temperatures. Factory produced units are also available for use with solid adsorbents such as silica gel.

Another recent development as a manufactured item is the small refrigeration-type dehumidifying unit for the control of moisture in residential basements.

### Remote Room Units

For individual rooms, with cooling load requirements of  $\frac{1}{2}$  to  $1\frac{1}{2}$  tons, remote units are available in attractive casings for installation within the

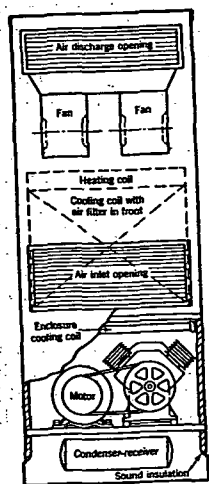


FIG. 6. SELF-CONTAINED WATER-COOLED AIR CONDITIONER

room. A suspended type is shown in Fig. 3 and a floor type, such as is usually installed in place of an existing radiator, is shown in Fig. 5. Furnished with chilled water from a central plant, these units offer a satisfactory method of conditioning existing offices, hotel, and apartment rooms. These units may be obtained with filters and outside air connections, but for most satisfactory application are used as supplements to central systems that supply properly conditioned and filtered air to the areas served.

Induction type units, using primary conditioned air under pressure to induce local circulation, are described in Chapter 30.

### Self-Contained Units

A typical large self-contained unit is shown in Fig. 6. It is essentially a remote vertical-type conditioner mounted on top of a sound-insulated enclosure containing the condensing unit. Air distribution is obtained by means of grilles mounted in the discharge plenum, when the unit is located in the conditioned area. Duct distribution of conditioned air can be

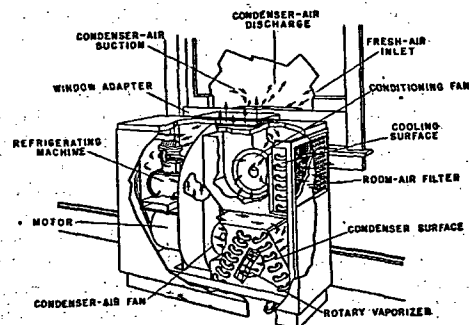


FIG. 7. SELF-CONTAINED AIR-COOLED UNIT AIR CONDITIONER

obtained by removing the plenum, connecting directly to the blower discharge, and safting the top of the unit.

The heat generated by the compression of refrigerant gases and that given off by the electric motor are removed from the compressor compartment in four ways: by the use of a water coil in the compressor compartment; by utilizing the cold suction gases; by drawing part of the return air through the compressor compartment, and finally by circulating room air through the compressor compartment by means of a fan attached to the motor shaft.

Most self-contained conditioners are constructed with enough sound-isolation material for installation directly in the conditioned spaces of the higher-sound-level commercial-type of applications. Special sound treatment means are to be supplied as part of the installation when applying these conditioners to spaces having low sound-level requirements. Conditioners may be installed outside the conditioned area and the connecting supply and return-air ducts can be acoustically treated as required for the specific installation.

### Self-Contained Room Cooling Units

Small self-contained units can be obtained with water-cooled condensers, but they are generally air cooled.

The air-cooled types are small in capacity, ranging from  $\frac{1}{4}$  to  $1\frac{1}{2}$  hp. Their principal application is for conditioning such spaces as hotel rooms, offices and residential living quarters. A duct connection between the unit and an outside window or ventilated air shaft is required to permit disposal of the heat extracted from the conditioned area. The unit may stand in front of the window or be mounted on the window sill. Various styles and types of windows encountered tend to increase the difficulty of making the window connections. The evaporation of condensate on the condenser coils, as a means of disposing of moisture, will tend to increase the condensing capacity and reduce the operating head pressure. Connections to an electrical outlet may be made through a conventional cord and plug or a permanent electrical connection, depending on local code rulings pertaining to the installation of small motors. The exterior finish of the unit in metal, wood or fabric is decorated to harmonize with office or bedroom furnishings. Some room air conditioners are being made for installation in special building openings provided in the walls as part of the initial construction.

A unit of the air-cooled condenser type for floor mounting is shown in Fig. 7. Of the two fans shown, the lower one acts as condenser air fan, and in some units this fan is arranged with slingers for discharging condensate on the condenser coil, while the upper fan discharges air into the conditioned area. A feature of most room air conditioners is that the condensate from the cooling coil is sprayed over the condenser surface and vaporized, thus eliminating the need for drain connections. A simple dampering arrangement is generally provided for exhausting some air from the room, in addition to introducing outside air and recirculating required amounts of air. It is possible to remove the equipment for winter storage or utilize the ventilating features for winter operation.

### Controls for Room Cooling Units

Control devices provided for self-contained cooling units generally will include all necessary means for automatic operation. Provision is also made for adding auxiliary external controls, when desired. Remote



units are not generally equipped with controls. Control systems for remote units, and auxiliary controls for self-contained units, are covered in the general treatment of Controls in Chapter 39.

#### RATINGS OF UNIT AIR CONDITIONERS

Two standards have been used for rating and testing of unit air conditioners: (1) Standard Method of Rating and Testing Air Conditioning Equipment,<sup>1</sup> covering all types of air conditioning units except the self-contained type and (2) Standard Method of Rating and Testing Self-Contained Air Conditioning Units for Comfort Cooling<sup>2</sup> covering the self-contained type. (ASRE Standard Methods of Rating and Testing Air Conditioners, ASRE Standard 16-53, covers rating and testing of all types which operate non-frosting when cooling and dehumidifying at standard rating conditions.)

The standard rating of a self-contained unit for the conditions specified in Table 1, includes all items which apply to the function of a unit as: (1) name of unit, (2) functions which unit performs, (3) data on cooling, (4) data on heating, (5) data on air flow, and (6) data on humidification.

The standard rating conditions for unit air conditioners, other than the self-contained type, are identical with those in Table 1, except that entering wet-bulb temperature for cooling is expressed as 50 percent relative humidity (66.7 F wet-bulb) instead of 67 F wet-bulb temperature. In addition, the saturated suction refrigerant temperature for comfort cooling is specified at 40 F. This condition is omitted from Table 1 for self-contained units because it is not separately controllable in the testing of a unit that includes the evaporator and condensing unit.

#### APPLICATION OF UNITARY EQUIPMENT

One of the chief advantages resulting from use of factory produced units is the saving in installation and field assembly labor, a factor that should always be kept in mind when selecting a location for these units. Because of their compactness, the tendency exists to put them in closets, storage rooms, and other inaccessible places, where installation is so difficult that much of this cost advantage is lost.

Access panels are provided on units for the proper servicing and maintenance of the equipment. Adequate outside clearance at these panels is essential. Wherever there is danger of freezing of coils or clogging with dirt, sufficient clearance should be available for replacing them without removing parts of the building.

The outstanding source of difficulties in unitary systems is usually dirty filters. The characteristics of the light weight fans used are such that air volume drops off rapidly with increase in static resistance. Since changing of filters is an unpleasant duty likely to be neglected unless it can be done easily, the operator should be at the same level as the filters, rather than under them, when they are being removed.

Variable-pitch motor pulleys are usually provided for adjustment of the air quantity. The fans and motors of most conditioners are selected for the usual range of external resistances commonly used with the specific size of conditioner. The larger conditioners are capable of serving larger areas and therefore require fan and motor capacity for the greater external duct resistances that may be imposed on such conditioners.

Where varying sizes of coils are used within the same casing, it is very important that coil safing be carefully installed to prevent bypassing of unconditioned air. If coils are not equipped with individual casings,

TABLE 1. STANDARD RATING BASIS FOR SELF-CONTAINED AIR CONDITIONING UNITS

| FUNCTIONS       | TYPES OF UNITS                                                                                      | RATING CONDITION |                                                                              |                                          |
|-----------------|-----------------------------------------------------------------------------------------------------|------------------|------------------------------------------------------------------------------|------------------------------------------|
|                 |                                                                                                     | Item             | Description                                                                  | Value                                    |
| All             | All                                                                                                 | a                | Barometric Pressure                                                          | 29.92 in. Hg                             |
| Cooling         | Water-Cooled, Air - Cooled and Evaporatively - Cooled Condensers                                    | b                | Unit Ambient and Air Entering Room—Air Inlet<br>(1) Dry-Bulb<br>(2) Wet-Bulb | 80 F<br>67 F                             |
|                 |                                                                                                     | c                | Ventilation Air                                                              | See Note                                 |
|                 |                                                                                                     | d                | Water Temperature Entering Unit                                              | 75 F                                     |
|                 |                                                                                                     | e                | Water Temperature Leaving Unit                                               | 95 F                                     |
|                 |                                                                                                     | f                | Air Entering Outside Air Inlet<br>(1) Dry-Bulb<br>(2) Wet-Bulb               | 95 F<br>75 F                             |
|                 |                                                                                                     | Heating          | All Types Provided with Heating Function                                     | g                                        |
| h               | Heating Medium, Pressure or Temperature<br>(1) Dry Saturated Steam<br>(2) Water In<br>(3) Water Out |                  |                                                                              | 16.7 lb per sq in. abs<br>180 F<br>160 F |
| Humidifying     | All Types Provided with Humidifying Function                                                        | i                | Unit Ambient                                                                 | 70 F                                     |
|                 |                                                                                                     | j                | Total Air Entering Unit<br>(1) Dry-Bulb<br>(2) Wet-Bulb                      | 70 F<br>53 F                             |
| Air Circulation | All                                                                                                 | k                | Filters                                                                      | New and Clean                            |

Note: Rating shall be based on both ventilation and recirculated room air entering at 80 F dry-bulb and 67 F wet-bulb temperature. (The Note as given in the code has been condensed in order to remove material not pertinent to this chapter).

additional safing may be required on top to prevent short circuiting air down through the upper edges of the fins. In this same category is the need for careful installation of the various sections of sectionalized units, using a sealing compound if necessary to prevent air leakage into the fan section of the unit.

Since the drain connection is usually made on the exit side of the coil, it is important that the drain line be properly sealed. This seal should be at least twice as deep as the suction on the fan in inches of water, to prevent gurgling sounds, and to insure a positive seal against infiltration of odors and moisture laden air. Drain pans should not be used to support the coils, unless they are designed to hold this weight without sagging. As the movement of air draws the condensate or excess humidification water toward the fan, drain connections are usually placed on the exit

side of the coil. The advantages of quick drainage are lost if improperly supported coils distort drain pans and cause water to accumulate in the center or back of the pan.

When the fans of vertical units are stopped, condensate that has been held up in the coils by fan suction, drops into the drain pan and splashes against the casing. If water damage is to be avoided, flashings should be provided to prevent this water from running out of the unit at the seams.

When locating unitary equipment, floor and beam loadings should be carefully checked. Suspended horizontal units can add 50 to 100 lb per square foot to the loading on the floor above. Should this floor be already heavily loaded, or be a roof structure designed for a 40 lb per square foot snow load, excess beam deflection may occur and cause cracking of plaster or concrete fire-proofing. A small fire, normally of little consequence, may cause a rupture of a heavily loaded structure and permit the equipment to drop with extensive property damage. Self-contained units should be carefully installed since their weights run as high as 200 lb per square foot. When they are installed in street floor shops, the extra precaution of placing a column beneath them in the basement is an inexpensive method of reducing vibration, as well as providing insurance against overloaded floor beams.

The services required for operation of unitary equipment should conform to the many restrictive, but necessary, local municipal codes. Existing buildings seldom are wired adequately for the electrical load imposed by the starting of an air conditioning compressor on any branch circuit. Even the smallest room cooler can draw enough current to reduce the voltage of a lighting circuit to the point where it is visibly apparent. This voltage drop may even affect the life of the unit due to the relatively slow starting. The cost of a separate electrical circuit of adequate capacity from the main panel is more than justified; it is a necessary expense in the majority of installations.

A water supply of adequate capacity and pressure is necessary to prevent overloading of electrical equipment by high head pressures. The average city water supply pressure is adequate for installations up to the third floor. Since most water cooled units require about 20 lb pressure, including control valve losses, it is important that any units served by gravity from roof tanks be checked carefully if located less than 40 ft below the tank.

Drain connections from condensers should flow to an open and properly trapped sink as required by most city codes. This prevents back pressures on the city water system in the event of condenser failure. A check valve should also be installed in the water supply as a further precaution against contamination.

When installing small remote or self-contained units with outside-air connections in buildings more than 6 stories high, the effect of wintertime stack action in elevator and stairwells requires special attention. This stack action is the cause of negative pressures on the lower floors, tending to draw cold air through the units, and positive pressures on the upper floors preventing adequate ventilation and disrupting air distribution. It can also cause annoying whistling at door openings and lead to serious complaints in hotels and offices. Wherever the removal of such units is impracticable, it is important that carefully fitted, felt-edged dampers be installed in the outside air intakes with adequate locking devices.

One further consideration when installing self-contained units in con-

ditioned areas is that any maintenance or repairs to be required in future years must be carried on in occupied space.

### UNIT AIR COOLERS

Unit air coolers are intended principally for product cooling, but are often used for cooling spaces to low temperatures. They differ from normal air conditioning units only in features required to produce lower temperatures. In using such units, dry-bulb temperatures should be considered first, after which room moisture conditions and air distribution should be considered, depending on the product being cooled or stored.

In recent years the unit cooler has almost entirely supplanted the gravity type prime-surface and finned-tube coil. It provides more positive control of air and better air distribution, is more efficient in performance, requires less space, is easier and less expensive to install, and is often less expensive in first cost. Early applications of unit coolers were limited to cold storage warehouses. In recent years they have been widely used in retail and wholesale markets for meat, fruit, and vegetables.

Products to be cooled or stores may be divided into four general classifications based on their sensitiveness to moisture loss.<sup>4, 5</sup> Selection of the proper temperature differential between storage-room air temperature and evaporating refrigerant temperature will produce adequate moisture control for all practical purposes. The differentials required for gravity circulation and for forced air circulation are different, the latter requiring closer differentials. The four classes and differentials which have been successfully used are as follows:

*Class 1*—Products requiring high room-moisture content, which are highly susceptible to moisture loss and are being stored for extended periods, for example, eggs.

|                        |               |
|------------------------|---------------|
| Gravity Circulation    | 18 F or less. |
| Forced Air Circulation | 6 to 9 F.     |

*Class 2*—Products similar to Class 1 but which are being stored only for a limited time as in retail stores where the turn-over is usually 3 days or less, for example, cut meats.

|                        |             |
|------------------------|-------------|
| Gravity Circulation    | 18 to 22 F. |
| Forced Air Circulation | 9 to 12 F.  |

*Class 3*—Products requiring moderate room moisture content and which are moderately susceptible to moisture loss, for example, carcass meats and some fruits.

|                        |             |
|------------------------|-------------|
| Gravity Circulation    | 21 to 27 F. |
| Forced Air Circulation | 12 to 20 F. |

*Class 4*—Products from which there is a very low moisture loss or none at all and where room moisture content is not important, for example, canned goods, furs, woolens, bottled goods, dried fruits, foods packaged in good moisture vapor barrier packages.

|                        |              |
|------------------------|--------------|
| Gravity Circulation    | 25 F and up. |
| Forced Air Circulation | 20 F and up. |

When using class 4 application, with finned evaporators and automatic defrosting at each cycle of the condensing unit, it is important to avoid using too wide differentials with very low refrigerant temperatures. In many applications, prime-surfaced evaporators prove unsuitable for this type of defrosting and will require some positive method of defrosting.

Unit coolers can perform satisfactorily in installations requiring accurate control of relative humidity, air motion, and dry-bulb temperature, and

thereby prevent excessive weight loss, mold and slime growth, and moisture absorption by hygroscopic materials such as dried fruits.

Unit coolers, especially in the smaller sizes, are very similar in appearance to unit heaters. Copper, aluminum, or steel prime or finned-surface tubes are used. Propeller or centrifugal fans either blow or draw room air over the tubes. The fan and coil are generally enclosed in a casing provided with a drip pan. The motor horsepower requirements are a function of resistance due to coil construction and arrangement, and air volume required. Fin spacing is based principally on operating temperatures. For operation below 35 F, fin spacing is preferably not more than four to the inch. Above 35 F it may run as high as 8 fins per in., depending on room temperature and refrigerant temperature used. Both direct expansion refrigerants and brine are used successfully as cooling mediums.

Unit coolers may be arranged for either free or duct delivery. Face velocities vary, depending principally upon the intended application of the unit. In the larger sizes particularly, speed adjustment of the fan is generally provided to permit variation of the air delivery. While unit coolers are usually installed in the storage space, remote installation combined with appropriate duct work may be required by space or other considerations. Units are available for floor, wall, or ceiling mounting, thus providing an upward, downward, or horizontal discharge. Power, refrigerant, and drip pan connections are required, plus additional connections for defrosting, if necessary.

For storage temperatures below 35 F, some positive means of defrosting is mandatory. At 35 F or higher storage temperatures, cycling of the condensing unit with low pressure control with proper settings will provide automatic defrosting each cycle. At above 35 F design refrigerant temperatures, frost and ice formation will not normally occur.

Various methods of defrosting are used. In one method, hot gas is supplied to the interior of the tubes uniformly throughout the coil. The entire refrigerant circuit is thus contacted to obtain complete defrosting of all frosted surfaces. Electric defrosting generally involves the incorporation of heating elements within the construction of the coil, or the use of strip heaters in a dampered closed-air circuit. Warm water may be sprayed over the coil surface for defrosting. With storage temperatures above 32 F, defrosting may be accomplished by shutting down the refrigeration system and circulating the room air over the coil. In every case, defrosting requires a cessation of refrigeration on the unit being defrosted. Where continuous operation of the system is desired, a brine spray over the coil may be used unless it might damage the product in storage, or cause too much corrosion of room fittings, ducts, etc.

### Ratings

As various means of expressing unit cooler capacity are utilized in the industry, different manufacturers suggest different methods of selection. The engineer should be aware of the conditions and factors which affect rating, selection, and performance of a cooler. These items are discussed in following paragraphs.

The refrigerating capacity of the unit may be either gross or net, the latter being less than the gross by an amount equal to the heat equivalent of the input to the unit cooler motor. In either case, the capacity should be given for a particular air volume. Air throw data are also valuable.

Dry or flooded rating conditions should be stated, as well as temperature level. The temperature level determines whether the coil surface is wetted

or frosted, and it will also establish the refrigerant side pressure drop for any given load applied to a specific unit cooler. The refrigerant-side pressure drop increases as the evaporating temperature decreases, and thus temperature level exercises a significant effect on the average coil-surface temperature and the consequent condensing unit selection.

Coil capacity rating is usually expressed as total heat absorbed with no distinction between sensible and latent heat. The *rating* expresses the capacity in terms of Btu per (hour) (Fahrenheit degree temperature differential *between the refrigerant and the air*). The term *basic rating* may be used. This is the Btu per hour absorbed with one Fahrenheit degree differential between room air and evaporator refrigerant temperature. When the total load has been obtained from the load calculations, a temperature differential between the air and the refrigerant is selected. It is based on product classification previously discussed. The extent of dehumidification will be a function of this temperature differential. Moisture conditions in the storage space are dependent upon the correct selection of this temperature differential. It offers a quick and sufficiently accurate practical basis for coil selection. Where close control of relative humidity is desired, heating coils or electric heaters for re-heat may have to be added. The use of air conditioning psychrometric techniques is only required for accurate humidity control.

Cooling equipment is usually rated on the basis of the overall room-to-refrigerant temperature differential instead of using the intermediate average coil-surface temperature. If the tentatively selected unit cooler does not possess the proper capacity, it may be possible to adjust the fan speed to a new air volume. At the new air volume and the new overall differential, the cooler may be able to deliver the necessary cooling capacity. If not, the procedure must be repeated with another size of unit cooler, the final selection being based on the proper balance between unit cooler and the condensing unit to maintain the Btu per hour heat removal and temperature difference at design room temperature desired.<sup>5</sup>

Procedures for rating and testing room coolers are given in an ASRE Standard<sup>3</sup> which establishes four groups of conditions (numbered I to IV) under which units may be rated. Many manufacturers establish and publish their ratings in accordance with this standard in which forced circulation air coolers are classified according to air side surface conditions as (1) dry coil, (2) sprayed coil, and (3) spray-no coil; or according to type of air delivery to room as (1) free delivery fan, or (2) pressure fan. Natural convection air coolers are classified according to type as (1) external baffle, (2) built-in-baffle, and (3) without baffle.

### Arrangement and Operation

The refrigerant is usually supplied to the evaporator through a thermostatic expansion valve, thus obtaining dry expansion in the evaporator. In other designs, float-valve feeding is used as a means of metering the refrigerant into the evaporator. The refrigerant circuit in the coil may be of the continuous-flow type from inlet to outlet, or it may have means for internal recirculation of the refrigerant. The coils having the *dry-expansion* or *continuous flow from inlet-to-outlet* circuits may be of the upward feed or the downward feed arrangements. Upward flow is generally regarded as producing more refrigerant holding capacity and more effective use of the surface. However, with some refrigerants and in some systems, the downward-feed system has been found to produce better oil-return characteristics. Many direct-expansion installations use liquid-vapor heat ex-

changers to increase the coil utilization without undue risk of returning liquid refrigerant to the compressor.

Where two or more evaporator coils are to be attached to a single condensing unit, and different evaporator temperatures are desired, a back pressure valve may be installed to limit the minimum evaporating temperature of the warmer coils. This valve also finds application where fluctuation in the evaporator temperature prevents accurate control of air temperature and humidity.

Except in product precooling, the objective of air distribution is to absorb the heat load as it comes into the room while maintaining a desirable degree of ventilation-air movement through hygroscopic cargos that are not vapor-barrier encased. In cold storage practice, this generally requires the securing of as uniform an air distribution as possible to every part of the product zone, with employment of diffusion of air over the product and avoiding direct blasts against the product. These requirements must be recognized when selecting the unit coolers and their outlets and when selecting the locations for the unit coolers. It is important to note that the quantity of air in motion in the refrigerated space is not only that passing through the coils. A quantity of air many times in excess of the air handled by the units is always set in motion by the induction effect of the moving cooled air. Therefore, in evaluating the velocity for any given area, the total air set in motion must be considered. It is a function of the type of outlet, the discharge air velocity, and the location of the unit relative to restrictive walls and product.

Unit location is also important from the standpoint of occupant comfort, low-velocity outlets being preferred for floor type units. High-velocity outlets are acceptable in fur storage vaults, ice cream hardening rooms and other spaces where air motion is not an important factor.

In general, unit air coolers should not be suspended in front of door openings, or close to them where moist warm air will be drawn directly into the unit each time the door is opened, thereby causing excessive frosting and loss of capacity. Better performance will be obtained by placing the unit air cooler in a location such that the air will be discharged toward the door. If the shape of the space is such that this location would result in excessive air velocity over the product, then the location of the unit air cooler should be changed so that the air is discharged parallel to the wall in which the door is located.

#### REFERENCES

<sup>1</sup> Prepared by a Joint Committee of the American Society of Refrigerating Engineers, AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Refrigerating Machinery Association, National Electrical Manufacturers' Association, and Air Conditioning Manufacturers' Association (A.S.R.E. Circular No. 13-42).\*

<sup>2</sup> Standard Method of Rating and Testing Self-Contained Air Conditioning Units for Comfort Cooling prepared by a Joint Committee of the American Society of Refrigerating Engineers, AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Refrigerating Machinery Association, National Electrical Manufacturers' Association, and Air Conditioning Manufacturers' Association (A.S.R.E. Circular No. 16).\*

<sup>3</sup> Proposed A.S.R.E. Standard Methods of Rating and Testing Forced-Circulation and Natural Convection Air Coolers for Refrigeration (A.S.R.E. Circular No. 25-44).

<sup>4</sup> Air Conditioning Refrigerating Data Book—Applications, Chapter 34 (American Society of Refrigerating Engineers).

<sup>5</sup> Reference 4, Chapter 33, Fig. 20 and text.

\* ASRE has combined Circulars No. 13-42 and No. 16 in ASRE Standard No. 16-53, Methods of Rating and Testing Air Conditioners.

#### CHAPTER 27

### PIPE, FITTINGS, WELDING

Pipe Materials, Types of Pipe, Commercial Pipe Dimensions, Threading Practice, Pipe Fittings, Flange Facings and Gaskets, Valves, Welding, Expansion and Flexibility, Hangers and Supports

**I**MPORTANT considerations in the selection and installation of pipe and fittings for heating, ventilating, and air conditioning are dealt with in this chapter.

#### PIPE MATERIALS

Use of corrosion-resistant materials for pipe, including special alloy steels, copper, and red brass, has increased considerably during the past few years. The following brief discussion indicates the variety of pipe materials and the types of pipe available.

**Wrought-Steel Pipe.** Because of its lower cost, the great bulk of wrought pipe used for heating and ventilating work at the present time is of wrought steel. The material used for steel pipe is a mild steel made by the acid-bessemer, the open-hearth, or the electric-furnace process. Ordinary wrought-steel pipe is made either by shaping sheets of metal into cylindrical form and welding the edges together, or by forming or drawing from a solid billet. The former is known as *welded pipe*, the latter as *seamless pipe*.

Many types of welded pipe are available, although the smaller sizes most frequently used in heating and ventilating work are made by the lap-weld, resistance-weld, or butt-weld process. While the lap-weld and resistance-weld processes produce a better weld than the butt type, lap-weld and resistance-weld pipe are seldom manufactured in nominal pipe sizes less than 2 in. Seamless pipe can be obtained in the small sizes at a somewhat higher cost, and is listed as pressure tubing below 2 in.

Seamless steel pipe is frequently used for high pressure work or where pipe is desired for close coiling, cold bending, or other severe forming operations. Its advantages are its greater strength which permits use of a thinner wall and, in the small sizes, its freedom from the occasional tendency of welded pipe to split at the weld when bent.

**Wrought-Iron Pipe.** Wrought-iron pipe may be identified by the spiral line marked into each length, either knurled into the metal or painted on it in red or other bright color. Otherwise, there is little difference in the appearance of wrought iron and steel pipe, although microscopic examination of polished and etched specimens will readily disclose different grain structures.

**Cast-Ferrous Pipe.** There are now available several types of cast-ferrous metal pipe made of a good grade of cast-iron with or without additions of nickel, chromium, or other alloy. This pipe is available in sizes from 1½

TABLE 1. DIMENSIONS AND PROPERTIES OF STEEL PIPE

| TABLE 1. DIMENSIONS AND PROPERTIES |                                    |              |              |                         |                                 |        |                        |        |                              |                               |                                                        |                                               |
|------------------------------------|------------------------------------|--------------|--------------|-------------------------|---------------------------------|--------|------------------------|--------|------------------------------|-------------------------------|--------------------------------------------------------|-----------------------------------------------|
| NOM-<br>INAL<br>SIZE               | ASTM <sup>2</sup><br>SCHED-<br>ULE | DIAMETER     |              | WALL THICK-<br>NESS IN. | SURFACE<br>AREA Sq<br>Ft/LIN Ft |        | SECTION AREA<br>Sq IN. |        | AREA<br>OF<br>METAL<br>Sq IN | VOL-<br>UME<br>GAL/<br>LIN FT | WEIGHT <sup>3</sup><br>(PLAIN<br>END)<br>LBS/LIN<br>FT | WORKING<br>PRESS-<br>URE <sup>4</sup><br>PSIA |
|                                    |                                    | O. D.<br>IN. | I. D.<br>IN. |                         | O. D.                           | I. D.  | O. D.                  | I. D.  |                              |                               |                                                        |                                               |
| 1/4                                | 40 (s)                             | 0.405        | 0.269        | 0.068                   | 0.106                           | 0.0704 | 0.129                  | 0.0568 | 0.0720                       | 0.00295                       | 0.244                                                  | 314 (a)                                       |
|                                    | 80 (x)                             | 0.405        | 0.215        | 0.095                   | 0.106                           | 0.0563 | 0.129                  | 0.0363 | 0.0925                       | 0.00189                       | 0.314                                                  | 1084 (a)                                      |
| 1/4                                | 40 (s)                             | 0.540        | 0.364        | 0.088                   | 0.141                           | 0.0953 | 0.229                  | 0.104  | 0.125                        | 0.00541                       | 0.424                                                  | 649 (a)                                       |
|                                    | 80 (x)                             | 0.540        | 0.302        | 0.119                   | 0.141                           | 0.0791 | 0.229                  | 0.0719 | 0.157                        | 0.00372                       | 0.535                                                  | 1353 (a)                                      |
| 3/8                                | 40 (s)                             | 0.675        | 0.493        | 0.091                   | 0.177                           | 0.129  | 0.358                  | 0.191  | 0.167                        | 0.00992                       | 0.567                                                  | 574 (a)                                       |
|                                    | 80 (x)                             | 0.675        | 0.423        | 0.126                   | 0.177                           | 0.111  | 0.358                  | 0.140  | 0.217                        | 0.00730                       | 0.738                                                  | 1191 (a)                                      |
| 1/2                                | 40 (s)                             | 0.840        | 0.622        | 0.109                   | 0.220                           | 0.163  | 0.554                  | 0.304  | 0.250                        | 0.0158                        | 0.850                                                  | 897 (a)                                       |
|                                    | 80 (x)                             | 0.840        | 0.546        | 0.147                   | 0.220                           | 0.143  | 0.554                  | 0.234  | 0.320                        | 0.0122                        | 1.09                                                   | 1268 (a)                                      |
| 3/4                                | XX                                 | 0.840        | 0.352        | 0.294                   | 0.220                           | 0.0660 | 0.554                  | 0.0499 | 0.504                        | 0.00259                       | 1.71                                                   | 3824 (a)                                      |
|                                    | 40 (s)                             | 1.050        | 0.824        | 0.113                   | 0.275                           | 0.216  | 0.866                  | 0.533  | 0.333                        | 0.0277                        | 1.13                                                   | 604 (a)                                       |
| 1                                  | 80 (x)                             | 1.050        | 0.742        | 0.154                   | 0.275                           | 0.194  | 0.866                  | 0.432  | 0.434                        | 0.0225                        | 1.47                                                   | 1078 (a)                                      |
|                                    | XX                                 | 1.050        | 0.434        | 0.308                   | 0.275                           | 0.114  | 0.866                  | 0.148  | 0.718                        | 0.00768                       | 2.44                                                   | 3134 (a)                                      |
| 1 1/4                              | 40 (s)                             | 1.315        | 1.049        | 0.133                   | 0.344                           | 0.275  | 1.36                   | 0.864  | 0.494                        | 0.0449                        | 1.68                                                   | 651 (a)                                       |
|                                    | 80 (x)                             | 1.315        | 0.957        | 0.179                   | 0.344                           | 0.251  | 1.36                   | 0.719  | 0.639                        | 0.0374                        | 2.17                                                   | 1083 (a)                                      |
| 1 1/2                              | XX                                 | 1.315        | 0.599        | 0.358                   | 0.344                           | 0.157  | 1.36                   | 0.282  | 1.08                         | 0.0146                        | 3.66                                                   | 2963 (a)                                      |
|                                    | 40 (s)                             | 1.660        | 1.380        | 0.140                   | 0.435                           | 0.361  | 2.16                   | 1.50   | 0.669                        | 0.0777                        | 2.27                                                   | 440 (a)                                       |
| 1 3/4                              | 80 (x)                             | 1.660        | 1.278        | 0.191                   | 0.435                           | 0.335  | 2.16                   | 1.28   | 0.881                        | 0.0666                        | 3.00                                                   | 805 (a)                                       |
|                                    | XX                                 | 1.660        | 0.896        | 0.382                   | 0.435                           | 0.235  | 2.16                   | 0.630  | 1.53                         | 0.0328                        | 5.21                                                   | 2318 (a)                                      |
| 2                                  | 40 (s)                             | 1.900        | 1.610        | 0.145                   | 0.497                           | 0.421  | 2.84                   | 2.04   | 0.800                        | 0.1058                        | 2.72                                                   | 417 (a)                                       |
|                                    | 80 (x)                             | 1.900        | 1.500        | 0.200                   | 0.497                           | 0.393  | 2.84                   | 1.77   | 1.07                         | 0.0918                        | 3.65                                                   | 756 (a)                                       |
| 2 1/4                              | XX                                 | 1.900        | 1.100        | 0.400                   | 0.497                           | 0.288  | 2.84                   | 0.950  | 1.89                         | 0.0494                        | 6.41                                                   | 2122 (a)                                      |
|                                    | 40 (s)                             | 2.375        | 2.067        | 0.154                   | 0.622                           | 0.541  | 4.43                   | 3.36   | 1.07                         | 0.174                         | 3.65                                                   | 376 (a)                                       |
| 2 1/2                              | 80 (x)                             | 2.375        | 1.939        | 0.218                   | 0.622                           | 0.508  | 4.43                   | 2.95   | 1.48                         | 0.153                         | 5.02                                                   | 690 (a)                                       |
|                                    | XX                                 | 2.375        | 1.503        | 0.436                   | 0.622                           | 0.393  | 4.43                   | 1.77   | 2.66                         | 0.0922                        | 9.03                                                   | 1861 (a)                                      |
| 3                                  | 40 (s)                             | 2.875        | 2.469        | 0.203                   | 0.753                           | 0.646  | 6.49                   | 4.79   | 1.70                         | 0.249                         | 5.79                                                   | 505 (a)                                       |
|                                    | 80 (x)                             | 2.875        | 2.323        | 0.276                   | 0.753                           | 0.608  | 6.49                   | 4.24   | 2.25                         | 0.220                         | 7.66                                                   | 806 (a)                                       |
| 3 1/4                              | XX                                 | 2.875        | 1.771        | 0.552                   | 0.753                           | 0.364  | 6.49                   | 2.46   | 4.03                         | 0.128                         | 13.7                                                   | 2048 (a)                                      |
|                                    | 40 (s)                             | 3.500        | 3.068        | 0.216                   | 0.916                           | 0.803  | 9.62                   | 7.39   | 2.23                         | 0.384                         | 7.57                                                   | 454 (a)                                       |
| 3 1/2                              | 80 (x)                             | 3.500        | 2.900        | 0.300                   | 0.916                           | 0.759  | 9.62                   | 6.61   | 3.02                         | 0.343                         | 10.3                                                   | 734 (a)                                       |
|                                    | XX                                 | 3.500        | 2.300        | 0.600                   | 0.916                           | 0.602  | 9.62                   | 4.15   | 5.47                         | 0.216                         | 18.5                                                   | 1829 (a)                                      |
| 4                                  | 40 (s)                             | 4.000        | 3.548        | 0.228                   | 1.05                            | 0.929  | 12.6                   | 9.89   | 2.68                         | 0.514                         | 9.11                                                   | 425 (a)                                       |
|                                    | 80 (x)                             | 4.000        | 3.364        | 0.318                   | 1.05                            | 0.881  | 12.6                   | 8.89   | 3.68                         | 0.462                         | 12.5                                                   | 692 (a)                                       |
| 4 1/4                              | XX                                 | 4.000        | 2.728        | 0.636                   | 1.05                            | 0.714  | 12.6                   | 5.85   | 6.72                         | 0.304                         | 22.9                                                   | 1699 (a)                                      |
|                                    | 40 (s)                             | 4.500        | 4.026        | 0.237                   | 1.18                            | 1.05   | 15.9                   | 12.7   | 3.17                         | 0.661                         | 10.8                                                   | 403 (a)                                       |
| 4 1/2                              | 80 (x)                             | 4.500        | 3.826        | 0.337                   | 1.18                            | 1.00   | 15.9                   | 11.5   | 4.41                         | 0.597                         | 14.9                                                   | 663 (a)                                       |
|                                    | XX                                 | 4.500        | 3.152        | 0.674                   | 1.18                            | 0.825  | 15.9                   | 7.80   | 8.10                         | 0.405                         | 27.5                                                   | 1602 (a)                                      |
| 5                                  | 40 (s)                             | 5.563        | 5.047        | 0.258                   | 1.46                            | 1.32   | 24.3                   | 20.0   | 4.30                         | 1.04                          | 14.6                                                   | 498 (b)                                       |
|                                    | 80 (x)                             | 5.563        | 4.813        | 0.375                   | 1.46                            | 1.26   | 24.3                   | 18.2   | 6.11                         | 0.945                         | 20.8                                                   | 825 (b)                                       |
| 5 1/4                              | XX                                 | 5.563        | 4.063        | 0.750                   | 1.46                            | 1.06   | 24.3                   | 13.0   | 11.3                         | 0.673                         | 38.6                                                   | 1951 (b)                                      |
|                                    | 40 (s)                             | 6.625        | 6.065        | 0.280                   | 1.73                            | 1.59   | 34.5                   | 28.9   | 5.58                         | 1.50                          | 18.0                                                   | 467 (b)                                       |
| 6                                  | 80 (x)                             | 6.625        | 5.761        | 0.432                   | 1.73                            | 1.51   | 34.5                   | 26.1   | 8.40                         | 1.35                          | 28.6                                                   | 825 (b)                                       |
|                                    | XX                                 | 6.625        | 4.897        | 0.864                   | 1.73                            | 1.28   | 34.5                   | 18.8   | 15.6                         | 0.978                         | 53.1                                                   | 1912 (b)                                      |
| 8                                  | 40 (s)                             | 8.625        | 8.071        | 0.277                   | 2.26                            | 2.11   | 58.4                   | 51.2   | 7.26                         | 2.66                          | 24.7                                                   | 351 (b)                                       |
|                                    | 80 (x)                             | 8.625        | 7.981        | 0.322                   | 2.26                            | 2.09   | 58.4                   | 50.0   | 8.40                         | 2.60                          | 28.6                                                   | 431 (b)                                       |
| 8 1/4                              | XX                                 | 8.625        | 7.625        | 0.500                   | 2.26                            | 2.00   | 58.4                   | 45.7   | 12.8                         | 2.37                          | 43.4                                                   | 743 (b)                                       |
|                                    | 40 (s)                             | 8.625        | 8.875        | 0.875                   | 2.26                            | 1.80   | 58.4                   | 37.1   | 21.3                         | 1.93                          | 72.4                                                   | 1460 (b)                                      |
| 10                                 | 80 (x)                             | 10.750       | 10.192       | 0.279                   | 2.81                            | 2.67   | 90.8                   | 81.6   | 9.18                         | 4.24                          | 31.2                                                   | 285 (b)                                       |
|                                    | XX                                 | 10.750       | 10.136       | 0.307                   | 2.81                            | 2.65   | 90.8                   | 80.7   | 10.1                         | 4.19                          | 34.2                                                   | 324 (b)                                       |
| 12                                 | 40 (s)                             | 10.750       | 10.020       | 0.365                   | 2.81                            | 2.62   | 90.8                   | 78.9   | 11.9                         | 4.10                          | 40.5                                                   | 405 (b)                                       |
|                                    | 80 (x)                             | 10.750       | 9.750        | 0.500                   | 2.81                            | 2.55   | 90.8                   | 74.7   | 16.1                         | 3.88                          | 54.7                                                   | 600 (b)                                       |
| 14                                 | 40 (s)                             | 12.750       | 12.090       | 0.330                   | 3.34                            | 3.17   | 128.                   | 115.   | 12.9                         | 5.96                          | 43.8                                                   | 299 (b)                                       |
|                                    | 80 (x)                             | 12.750       | 12.000       | 0.375                   | 3.34                            | 3.14   | 128.                   | 113.   | 14.6                         | 5.88                          | 49.6                                                   | 352 (b)                                       |
| 16                                 | XX                                 | 12.750       | 11.750       | 0.500                   | 3.34                            | 3.08   | 128.                   | 108.   | 19.2                         | 5.63                          | 65.4                                                   | 503 (b)                                       |
|                                    | 40 (s)                             | 14.000       | 13.250       | 0.375                   | 3.67                            | 3.46   | 154.                   | 138.   | 16.0                         | 7.17                          | 54.6                                                   | 458 (c)                                       |
| 18                                 | 80 (x)                             | 14.000       | 13.000       | 0.500                   | 3.67                            | 3.15   | 154.                   | 133.   | 21.2                         | 6.70                          | 72.1                                                   | 653 (c)                                       |
|                                    | XX                                 | 16.000       | 15.250       | 0.375                   | 4.18                            | 3.99   | 201.                   | 183.   | 18.4                         | 9.48                          | 82.4                                                   | 400 (c)                                       |
| 20                                 | 40 (s)                             | 16.000       | 15.000       | 0.500                   | 4.18                            | 3.93   | 201.                   | 177.   | 24.3                         | 9.18                          | 82.8                                                   | 570 (c)                                       |
|                                    | XX                                 | 18.000       | 17.250       | 0.375                   | 4.71                            | 4.52   | 254.                   | 234.   | 20.7                         | 12.1                          | 70.6                                                   | 355 (c)                                       |
| 22                                 | 80 (x)                             | 18.000       | 17.000       | 0.500                   | 4.71                            | 4.45   | 254.                   | 227.   | 27.4                         | 11.8                          | 93.5                                                   | 506 (c)                                       |
|                                    | XX                                 |              |              |                         |                                 |        |                        |        |                              |                               |                                                        |                                               |

TABLE 1. DIMENSIONS AND PROPERTIES OF STEEL PIPE (Concluded)

| NOM-<br>INAL <sup>1</sup><br>SIZE | ASTM <sup>2</sup><br>SCHED-<br>ULE | DIAMETER     |              | WALL THICK-<br>NESS IN. | SURFACE<br>AREA Sq<br>Ft/LIN Ft |       | SECTION AREA<br>Sq IN. |       | AREA OF<br>METAL<br>Sq IN | VOL-<br>UME<br>GAL/<br>LIN FT | WEIGHT <sup>3</sup><br>(PLAIN<br>END)<br>LBS/LIN<br>FT | WORKING<br>PRESS-<br>URE <sup>4</sup><br>PSIA |
|-----------------------------------|------------------------------------|--------------|--------------|-------------------------|---------------------------------|-------|------------------------|-------|---------------------------|-------------------------------|--------------------------------------------------------|-----------------------------------------------|
|                                   |                                    | O. D.<br>IN. | I. D.<br>IN. |                         | O. D.                           | I. D. | O. D.                  | I. D. |                           |                               |                                                        |                                               |
|                                   |                                    |              |              |                         |                                 |       |                        |       |                           |                               |                                                        |                                               |
| 20                                | 20 (s)                             | 20.000       | 19.250       | 0.375                   | 5.23                            | 4.51  | 314.                   | 291.  | 23.2                      | 15.2                          | 78.6                                                   | 319 (c)                                       |
|                                   | 30 (s)                             | 20.000       | 19.000       | 0.500                   | 5.23                            | 4.97  | 314.                   | 284.  | 30.6                      | 14.7                          | 104.2                                                  | 454 (c)                                       |
| 24                                | 20 (s)                             | 24.000       | 23.250       | 0.375                   | 6.29                            | 6.08  | 452.                   | 426.  | 26.8                      | 22.1                          | 94.6                                                   | 265 (c)                                       |
|                                   | 30 (s)                             | 24.000       | 23.000       | 0.500                   | 6.29                            | 6.03  | 452.                   | 415.  | 38.9                      | 21.5                          | 125.5                                                  | 378 (c)                                       |

\* 3/4 Double extra strong is no longer considered in ASTM specification but some pipe of this size is still manufactured.

<sup>1</sup> The sizes for wrought iron are approximately the same except wall thickness is slightly heavier. See ASTM A-72.

<sup>2</sup> American Society for Testing Materials Schedule. The numbers 30, 40, etc., refer to the ASTM Schedule; the letter (s) refers to the former designation Standard Weight; the letter (x) refers to the former designation Extra Strong; the letters XX refer to the former designation Double Extra Strong.

<sup>3</sup> Weight per foot is based on plain end pipe. Threaded and coupled (T and C) pipe is slightly heavier.

<sup>4</sup> Working pressure for welded joints—see formula in Table 3.

(a) Working pressure based on an allowable fiber stress of 6225 psi (for 250 F).

(b) Working pressure based on an allowable fiber stress of 8400 psi (for 250 F).

(c) Working pressure based on an allowable fiber stress of 12000 psi (for 250 F).

Note: Standard-weight pipe is generally furnished with threaded ends in random lengths of 16 to 22 ft., although when ordered with plain ends, 5 percent may be in lengths of 12 to 16 ft. Five percent of the total number of lengths ordered may be jointers which are two pieces coupled together. Extra-strong pipe is generally furnished with plain ends in random lengths of 12 to 22 ft., although 5 percent may be in lengths of 6 to 12 ft.

in. to 6 in., and in standard lengths of 5 or 6 ft, with external and internal diameters closely approximating those of extra strong wrought pipe. Cast-ferrous pipe may be obtained coupled, beveled for welding, or with ends plain or grooved for the several types of couplings. It is easily cut and threaded as well as welded. The fact that it is readily welded enables the manufacturers to supply the pipe in any lengths practicable for handling.

**Alloy Metal Pipe.** Both iron and steel pipe are available in the alloy class. In the case of iron pipe when copper and molybdenum are added, the material is known as alloy wrought-iron.

By common custom steel is considered to be an alloy when the maximum range of alloying elements exceed certain limits such as 1.65 percent manganese, 0.60 silicon, or 0.60 copper. Also, a steel is an alloy if any of the following elements are specified in minimal quantities or within limits: Al, B, Cr (up to 3.99), Co, Cu, Mo, Ni, Ti, W, V, Zr, or any other element added to obtain a certain alloying effect. Small quantities of certain elements are present in alloy steels and are considered as incidental and may be present to the following maximum amounts: copper—0.35 percent, nickel—0.25 percent, chromium—0.20 percent, and molybdenum—0.06 percent.

Commercially, steel is considered stainless when chromium exceeds 3.99 percent regardless of the inclusion of other alloying elements. With tubing, however, an alloy becomes stainless when it contains a minimum of 10.5 percent chromium.

The alloy and stainless steels are used for high temperature piping and for highly corrosive fluids and gases.

**Copper Pipe and Fittings.** Owing to inherent resistance to corrosion,

TABLE 2. DIMENSIONS AND PROPERTIES OF COPPER TUBE  
(All Types Except DWV are Based on ASTM B-88)

| NOM-<br>INAL<br>SIZE | TYPE           | DIAMETER     |              | WALL<br>THICK-<br>NESS<br>IN. | SURFACE<br>AREA Sq<br>Ft/LIN Ft |              | SECTION AREA<br>Sq IN. |              | AREA OF<br>METAL<br>Sq IN | VOLUME<br>GAL/LIN<br>Ft | WEIGHT <sup>a</sup><br>LBS/LIN<br>Ft | WORKING<br>PRESS-<br>URE <sup>b</sup><br>PSIA |
|----------------------|----------------|--------------|--------------|-------------------------------|---------------------------------|--------------|------------------------|--------------|---------------------------|-------------------------|--------------------------------------|-----------------------------------------------|
|                      |                | O. D.<br>IN. | I. D.<br>IN. |                               | O. D.<br>IN.                    | I. D.<br>IN. | O. D.<br>IN.           | I. D.<br>IN. |                           |                         |                                      |                                               |
| 1/4                  | K <sup>c</sup> | 0.375        | 0.305        | 0.035                         | 0.0982                          | 0.0798       | 0.110                  | 0.0730       | 0.0374                    | 0.00379                 | 0.145                                | 918                                           |
|                      | L <sup>c</sup> | 0.375        | 0.315        | 0.030                         | 0.0982                          | 0.0825       | 0.110                  | 0.0779       | 0.0324                    | 0.00404                 | 0.128                                | 764                                           |
| 3/8                  | K              | 0.500        | 0.402        | 0.049                         | 0.131                           | 0.105        | 0.196                  | 0.127        | 0.0695                    | 0.00660                 | 0.289                                | 938                                           |
|                      | L              | 0.500        | 0.430        | 0.035                         | 0.131                           | 0.113        | 0.196                  | 0.145        | 0.0512                    | 0.00753                 | 0.193                                | 677                                           |
| 1/2                  | K              | 0.625        | 0.527        | 0.049                         | 0.164                           | 0.138        | 0.306                  | 0.218        | 0.0887                    | 0.0113                  | 0.344                                | 779                                           |
|                      | L              | 0.625        | 0.545        | 0.040                         | 0.164                           | 0.143        | 0.306                  | 0.233        | 0.0735                    | 0.0121                  | 0.255                                | 625                                           |
| 3/4                  | K              | 0.750        | 0.652        | 0.049                         | 0.193                           | 0.171        | 0.441                  | 0.334        | 0.108                     | 0.0174                  | 0.418                                | 643                                           |
|                      | L              | 0.750        | 0.666        | 0.042                         | 0.193                           | 0.174        | 0.441                  | 0.348        | 0.0934                    | 0.0181                  | 0.362                                | 547                                           |
| 1                    | K              | 0.875        | 0.745        | 0.065                         | 0.229                           | 0.195        | 0.601                  | 0.436        | 0.165                     | 0.0227                  | 0.641                                | 747                                           |
|                      | L              | 0.875        | 0.785        | 0.045                         | 0.229                           | 0.206        | 0.601                  | 0.480        | 0.117                     | 0.0250                  | 0.455                                | 497                                           |
| 1 1/4                | K              | 1.125        | 0.995        | 0.065                         | 0.295                           | 0.260        | 0.994                  | 0.778        | 0.216                     | 0.0405                  | 0.839                                | 574                                           |
|                      | L              | 1.125        | 1.025        | 0.050                         | 0.295                           | 0.268        | 0.994                  | 0.852        | 0.169                     | 0.0442                  | 0.655                                | 432                                           |
| 1 1/2                | K              | 1.375        | 1.245        | 0.065                         | 0.360                           | 0.326        | 1.48                   | 1.22         | 0.268                     | 0.0634                  | 1.04                                 | 466                                           |
|                      | L              | 1.375        | 1.265        | 0.055                         | 0.360                           | 0.331        | 1.48                   | 1.26         | 0.228                     | 0.0655                  | 0.884                                | 387                                           |
|                      | M              | 1.375        | 1.291        | 0.042                         | 0.360                           | 0.338        | 1.48                   | 1.31         | 0.176                     | 0.0681                  | 0.682                                | 293                                           |
|                      | DWV            | 1.375        | 1.295        | 0.040                         | 0.360                           | 0.339        | 1.48                   | 1.32         | 0.163                     | 0.0684                  | 0.650                                | —                                             |
| 2                    | K              | 1.625        | 1.481        | 0.072                         | 0.425                           | 0.388        | 2.07                   | 1.72         | 0.351                     | 0.0894                  | 1.36                                 | 421                                           |
|                      | L              | 1.625        | 1.505        | 0.060                         | 0.425                           | 0.394        | 2.07                   | 1.78         | 0.295                     | 0.0925                  | 1.14                                 | 359                                           |
|                      | M              | 1.625        | 1.527        | 0.049                         | 0.425                           | 0.400        | 2.07                   | 1.83         | 0.243                     | 0.0950                  | 0.940                                | 289                                           |
|                      | DWV            | 1.625        | 1.541        | 0.042                         | 0.425                           | 0.403        | 2.07                   | 1.86         | 0.205                     | 0.0969                  | 0.809                                | —                                             |
| 2 1/2                | K              | 2.125        | 1.959        | 0.083                         | 0.556                           | 0.513        | 3.56                   | 3.01         | 0.532                     | 0.157                   | 2.06                                 | 376                                           |
|                      | L              | 2.125        | 1.985        | 0.070                         | 0.556                           | 0.520        | 3.56                   | 3.10         | 0.452                     | 0.161                   | 1.75                                 | 316                                           |
|                      | M              | 2.125        | 2.009        | 0.058                         | 0.556                           | 0.526        | 3.56                   | 3.17         | 0.377                     | 0.164                   | 1.46                                 | 255                                           |
|                      | DWV            | 2.125        | 2.041        | 0.042                         | 0.556                           | 0.534        | 3.56                   | 3.27         | 0.285                     | 0.142                   | 1.07                                 | —                                             |
| 3                    | K              | 2.625        | 2.435        | 0.095                         | 0.687                           | 0.638        | 5.41                   | 4.65         | 0.755                     | 0.242                   | 2.93                                 | 352                                           |
|                      | L              | 2.625        | 2.465        | 0.080                         | 0.687                           | 0.645        | 5.41                   | 4.77         | 0.640                     | 0.247                   | 2.48                                 | 293                                           |
|                      | M              | 2.625        | 2.495        | 0.065                         | 0.687                           | 0.653        | 5.41                   | 4.89         | 0.523                     | 0.254                   | 2.05                                 | 234                                           |
| 3 1/2                | K              | 3.125        | 2.907        | 0.109                         | 0.818                           | 0.761        | 7.67                   | 6.64         | 1.03                      | 0.345                   | 4.00                                 | 343                                           |
|                      | L              | 3.125        | 2.945        | 0.090                         | 0.818                           | 0.771        | 7.67                   | 6.81         | 0.858                     | 0.354                   | 3.33                                 | 278                                           |
|                      | M              | 3.125        | 2.981        | 0.072                         | 0.818                           | 0.780        | 7.67                   | 6.98         | 0.691                     | 0.362                   | 2.68                                 | 220                                           |
|                      | DWV            | 3.125        | 3.035        | 0.045                         | 0.818                           | 0.796        | 7.67                   | 7.23         | 0.435                     | 0.376                   | 1.69                                 | —                                             |
| 4                    | K              | 3.625        | 3.385        | 0.120                         | 0.949                           | 0.886        | 10.3                   | 9.00         | 1.32                      | 0.468                   | 5.12                                 | 324                                           |
|                      | L              | 3.625        | 3.425        | 0.100                         | 0.949                           | 0.897        | 10.3                   | 9.21         | 1.11                      | 0.478                   | 4.29                                 | 268                                           |
|                      | M              | 3.625        | 3.459        | 0.083                         | 0.949                           | 0.906        | 10.3                   | 9.40         | 0.924                     | 0.489                   | 3.58                                 | 218                                           |
| 5                    | K              | 4.125        | 3.857        | 0.134                         | 1.08                            | 1.01         | 13.3                   | 11.7         | 1.68                      | 0.607                   | 6.51                                 | 135                                           |
|                      | L              | 4.125        | 3.905        | 0.110                         | 1.08                            | 1.02         | 13.3                   | 12.0         | 1.39                      | 0.623                   | 5.38                                 | 256                                           |
|                      | M              | 4.125        | 3.935        | 0.095                         | 1.08                            | 1.03         | 13.3                   | 12.2         | 1.20                      | 0.634                   | 4.66                                 | 217                                           |
|                      | DWV            | 4.125        | 4.009        | 0.058                         | 1.08                            | 1.05         | 13.3                   | 12.6         | 0.67                      | 0.656                   | 2.87                                 | —                                             |
| 6                    | K              | 5.125        | 4.805        | 0.160                         | 1.34                            | 1.26         | 20.7                   | 18.1         | 2.50                      | 0.940                   | 9.67                                 | 307                                           |
|                      | L              | 5.125        | 4.875        | 0.125                         | 1.34                            | 1.28         | 20.7                   | 18.7         | 1.96                      | 0.971                   | 7.61                                 | 234                                           |
|                      | M              | 5.125        | 4.907        | 0.109                         | 1.34                            | 1.29         | 20.7                   | 18.9         | 1.72                      | 0.981                   | 6.65                                 | 203                                           |
| 8                    | K              | 6.125        | 5.741        | 0.192                         | 1.60                            | 1.50         | 29.4                   | 25.9         | 3.50                      | 1.35                    | 13.9                                 | 308                                           |
|                      | L              | 6.125        | 5.845        | 0.140                         | 1.60                            | 1.53         | 29.4                   | 26.8         | 2.63                      | 1.39                    | 10.2                                 | 221                                           |
|                      | M              | 6.125        | 5.881        | 0.122                         | 1.60                            | 1.54         | 29.4                   | 27.2         | 2.30                      | 1.42                    | 8.92                                 | 190                                           |
|                      | DWV            | 6.125        | 5.959        | 0.083                         | 1.60                            | 1.56         | 29.4                   | 27.9         | 1.58                      | 1.55                    | 6.10                                 | —                                             |
| 10                   | K              | 8.125        | 7.583        | 0.271                         | 2.13                            | 1.99         | 51.8                   | 45.2         | 6.69                      | 2.34                    | 25.9                                 | 320                                           |
|                      | L              | 8.125        | 7.725        | 0.200                         | 2.13                            | 2.02         | 51.8                   | 46.9         | 4.98                      | 2.43                    | 19.3                                 | 239                                           |
|                      | M              | 8.125        | 7.785        | 0.170                         | 2.13                            | 2.04         | 51.8                   | 47.6         | 4.25                      | 2.47                    | 16.5                                 | 200                                           |
| 12                   | K              | 10.125       | 9.449        | 0.338                         | 2.65                            | 2.47         | 80.5                   | 70.1         | 10.4                      | 3.65                    | 40.3                                 | 332                                           |
|                      | L              | 10.125       | 9.635        | 0.250                         | 2.65                            | 2.52         | 80.5                   | 72.8         | 7.76                      | 3.79                    | 30.1                                 | 241                                           |
|                      | M              | 10.125       | 9.701        | 0.212                         | 2.65                            | 2.54         | 80.5                   | 73.9         | 6.60                      | 3.84                    | 25.6                                 | 202                                           |
|                      | K              | 12.125       | 11.315       | 0.405                         | 3.17                            | 2.96         | 115.                   | 101.         | 14.9                      | 5.24                    | 57.8                                 | 334                                           |
|                      | L              | 12.125       | 11.565       | 0.280                         | 3.17                            | 3.03         | 115.                   | 105.         | 10.4                      | 5.45                    | 40.4                                 | 225                                           |
|                      | M              | 12.125       | 11.617       | 0.254                         | 3.17                            | 3.04         | 115.                   | 106.         | 9.47                      | 5.50                    | 36.7                                 | 204                                           |

<sup>a</sup> Weight per foot is based on tube without couplings.

<sup>b</sup> Working pressure is based on the American Standard Code for Pressure Piping, published by the ASME, revised November, 1952 for plain end tubing (sweet joints).

$$P = \frac{2s t_m}{D - 0.8 t_m} \quad \text{where } P = \text{allowable pressure, pounds per square inch.}$$

$$s = 6000 \text{ psi allowable fiber stress, pounds per square inch.}$$

$$t_m = \text{minimum wall thickness, inches.}$$

$$D = \text{maximum O. D., inches.}$$

<sup>c</sup> Types K and L furnished in both hard and soft temper, Type M in hard only.  
Standard straight lengths are 20 ft. Standard coils (1/4 to 1 1/2 inch) are 60 ft.

copper and red brass pipe have always been used in heating, ventilating, and water supply installations, but the cost with standard dimensions for threaded connections has been high. The introduction of fittings which permit erection by soldering or sweating, allows the use of tube with thinner walls than would be possible with threaded connections, thereby reducing the cost of installations.

### COMMERCIAL PIPE DIMENSIONS

Commercial pipe dimensions are covered in the following specifications of the *American Society for Testing Materials*: (1) steel—ASTM A-120 and A-53, (2) wrought-iron—ASTM A-72, and (3) copper tube—ASTM A-88.

Tables 1 and 2 are based on these specifications.

In addition to the specifications for these three materials, there are

TABLE 3. TABLE OF AVAILABILITY FOR STEEL PIPE

| MATERIAL            | SPECIFICATION | AVAILABLE SIZES<br>(INCLUSIVE)<br>INCHES DIAM. | ALLOWABLE FIBER<br>STRESS S <sup>a</sup> PSI |
|---------------------|---------------|------------------------------------------------|----------------------------------------------|
| Butt-weld           | A-120         | 1/2 to 4                                       | 6,225                                        |
|                     | A-53          | 1/2 to 4                                       | 6,750                                        |
| Lap-weld            | A-120         | 2 to 12                                        | 8,400                                        |
|                     | A-53          | 2 to 24                                        | 9,000                                        |
| Electric-resistance | A-53 Grade A  | 2 to 24                                        | 10,200 <sup>b</sup>                          |
|                     | A-53 Grade B  | 2 to 24                                        | 12,750 <sup>b</sup>                          |
| Seamless            | A-53 Grade A  | 2 to 24                                        | 12,000                                       |
|                     | A-53 Grade B  | 2 to 24                                        | 15,000                                       |
|                     | A-120         | 2 to 12                                        | 10,400                                       |

<sup>a</sup> For use in the equation

$$P = \frac{2S(t_m - c)}{D - 0.8(t_m - c)}$$

See American Standard Code for Pressure Piping, published by ASME, revised November, 1952.

Where P = working pressure, pounds per square inch.

S = fiberstress, pounds per square inch.

t<sub>m</sub> = 0.875 x wall thickness, inches.

D = O. D., inches.

c = joint factor = 0.05 for 1-in. and smaller size or 0.065 for larger than 1-in. size.

<sup>b</sup> For electric resistance welded pipe for applications where the temperature is below 650 F, and where pipe furnished under this classification is subjected to supplemental tests and/or heat treatments as agreed to by the supplier and the purchaser, and whereby such supplemental tests and/or heat treatments demonstrate the strength characteristics of the weld to be equal to the minimum tensile strength specified for the pipe, the S values equal to the corresponding seamless grades may be used.

standards for copper or red brass IPS, clay or concrete, and cast-iron pipe. Copies of the following specifications may be obtained from the *American Society for Testing Materials*: (1) steel, wrought-iron and cast-iron—Series A, (2) copper and red brass—Series B, and (3) clay and concrete—Series C.

Table 3 lists the sizes available in each of the specifications and classes of steel pipe. Note that butt-weld is not available above 4-in. size and that lap-weld, electric-resistance-weld, and seamless are not available below 2-in. size.

Listed in Table 3 is the formula for allowable working pressures as given in the *American Standard Code for Pressure Piping*.<sup>1</sup> In this formula is a factor c, which is intended as an allowance for corrosion, mechanical injury, manufacturing tolerances, etc. At times this factor seems too conservative; for example, with 1/2-in., Schedule 40, steel pipe, the allowable working pressure is 314 psi. Yet this pipe is tested at 700 psi. The reasoning in establishing the factor c which influences the working pressure, is that after nominal use the pipe may not be as sturdy as it was at the time



of manufacture. Note that the joint factor, *c*, is not included for plain end non-ferrous pipe as listed in Table 2.

In addition to IPS copper pipe, several varieties of copper tubing are in use with either flared or compression couplings or soldered joints. Dimensions of copper water tubing intended for plumbing, underground water service, fuel-oil lines, gas lines, etc., have been standardized by the U. S. Government and the American Society for Testing Materials.

TABLE 4. THREADING DATA FOR PIPE

| NOMINAL SIZE <sup>a</sup> | PIPE O. D.         | STANDARD WEIGHT               |                |                 | EXTRA AND DOUBLE EXTRA STRONG |                |                 |
|---------------------------|--------------------|-------------------------------|----------------|-----------------|-------------------------------|----------------|-----------------|
|                           |                    | THREADS PER INCH <sup>b</sup> | COUPLING O. D. | COUPLING LENGTH | THREADS PER INCH              | COUPLING O. D. | COUPLING LENGTH |
| 1/4                       | 0.405              | 27                            | 0.563          | 1 1/4           | 27                            | 0.563          | 1 1/4           |
| 1/2                       | 0.540              | 18                            | 0.719          | 1 1/4           | 18                            | 0.719          | 1 1/4           |
| 3/4                       | 0.675              | 18                            | 0.875          | 1 1/4           | 18                            | 0.875          | 1 1/4           |
| 1                         | 0.840              | 14                            | 1.063          | 1 1/4           | 14                            | 1.063          | 2 1/4           |
| 1 1/4                     | 1.050              | 14                            | 1.313          | 1 1/2           | 14                            | 1.313          | 2 1/4           |
| 1 1/2                     | 1.315              | 11 1/4                        | 1.576          | 2               | 11 1/4                        | 1.576          | 2 3/4           |
| 1 3/4                     | 1.660              | 11 1/4                        | 1.900          | 2 1/4           | 11 1/4                        | 2.054          | 2 3/4           |
| 2                         | 1.990              | 11 1/4                        | 2.200          | 2 1/4           | 11 1/4                        | 2.200          | 2 3/4           |
| 2 1/2                     | 2.375              | 11 1/4                        | 2.750          | 2 3/4           | 11 1/4                        | 2.875          | 2 3/4           |
| 3                         | 2.875              | 8                             | 3.250          | 3 1/4           | 8                             | 3.375          | 4 1/4           |
| 3 1/2                     | 3.500              | 8                             | 4.000          | 3 1/4           | 8                             | 4.000          | 4 1/4           |
| 4                         | 4.000              | 8                             | 4.625          | 3 1/4           | 8                             | 4.625          | 4 1/4           |
| 4 1/2                     | 4.500              | 8                             | 5.000          | 3 1/4           | 8                             | 5.200          | 4 1/4           |
| 5                         | 5.563 <sup>c</sup> | 8                             | 6.296          | 3 1/4           | 8                             | 6.296          | 4 1/4           |
| 6                         | 6.625              | 8                             | 7.390          | 4               | 8                             | 7.390          | 4 1/4           |
| 8                         | 8.625              | —                             | —              | —               | 8                             | 9.625          | 5 1/4           |
| 10                        | 10.750             | —                             | —              | —               | 8                             | 11.750         | 5 1/4           |
| 12                        | 12.750             | —                             | —              | —               | 8                             | 14.000         | 6 1/4           |
| 14                        | 14.000             | —                             | —              | —               | 8                             | 15.000         | 6 1/4           |
| 16                        | 16.000             | —                             | —              | —               | 8                             | 17.000         | 6 1/4           |
| 18                        | 18.000             | —                             | —              | —               | 8                             | 19.000         | 7 1/4           |
| 20                        | 20.000             | —                             | —              | —               | 8                             | 21.000         | 7 3/4           |

<sup>a</sup> All dimensions in inches.

<sup>b</sup> Taper of threads is 3/4 in. per ft on diameter on all sizes of pipe, and in couplings of 2 1/4 in. and over. Couplings 2 in. and smaller are straight tapped.

<sup>c</sup> 5.562 for copper and red brass pipe.

Note: The wall thickness and inside diameter shown in Table 1 do not apply to copper and red brass pipe.

Copper tube is classified in accordance with the wall thickness as follows:

Type K—Heavy Wall.

Type L—Medium Wall.

Type M—Light Wall.

Type DWV—Light Wall—for drainage, waste, and vent service.

In general, Type K is used for underground services and for general plumbing service where corrosion conditions are severe. Type L is used for general plumbing and heating service where conditions may be considered normal. Type M is used for sanitary drainage and other non-pressure applications, for heating, and sometimes for other services less severe than those for which Types K or L are recommended. Type DWV

is of lighter weight than Type M, and is used for sanitary drainage and other non-pressure applications. Type DWV tube may be used for all types of fill except cinders, where Type L is recommended. Where flexibility is essential as in hidden replacement work, or where as few joints as possible are desired as in fuel-oil lines, the soft temper is commonly used. In new or exposed work copper tube of a hard temper is generally used. All three types are extensively used with soldered fittings.

Standard dimensions, weights, and diameter and wall-thickness tolerances for these classes of copper tube are obtainable from Table 2. Copper pipe is also available with dimensions of steel pipe.

In refrigeration lines, used in connection with air conditioning equipment, copper tube is used extensively. For refrigeration use where tube absolutely free from scale and dirt is required, bright annealed copper tube that has been cleaned, dehydrated and sealed is used. This tube is available in a variety of sizes and wall thicknesses.

TABLE 5. NORMAL ENGAGEMENT OF TIGHT-FIT MALE AND FEMALE PIPE THREADS

For American Standard and API Pipe Threads

| PIPE SIZE | ENGAGED LENGTH* IN. | PIPE SIZE | ENGAGED LENGTH* IN. | PIPE SIZE | ENGAGED LENGTH* IN. |
|-----------|---------------------|-----------|---------------------|-----------|---------------------|
| 1/4       | 1/4                 | 1 1/4     | 1 1/4               | 4         | 1 1/4               |
| 1/2       | 3/8                 | 1 1/2     | 1 1/4               | 5         | 1 1/4               |
| 3/4       | 3/8                 | 2         | 3/4                 | 6         | 1 1/4               |
| 1         | 1/2                 | 2 1/2     | 1 1/4               | 8         | 1 1/4               |
| 1 1/4     | 1/2                 | 3         | 1                   | 10        | 1 1/4               |
| 1 1/2     | 1 1/4               | 3 1/2     | 1 1/4               | 12        | 1 1/4               |

\* Dimension shown is the normal tight-fit thread engagement from the leading edge of the female thread back to the leading edge of the male thread. No allowance has been made for threading variations.

## THREADING PRACTICE

In all threaded pipe for heating and ventilating installations the American Standard taper pipe thread, ASA B2.1-1942 is used. This thread is cut with a taper of 1 in 16 measured on the diameter of the pipe so as to secure a tight joint. The number of threads per inch varies with the pipe size. Threads for fittings are the same, except that it is regular practice to furnish straight tapped couplings for Schedule 40 pipe 2 in. and smaller. For steam pressures in excess of 25 psi, it is recommended that taper-tapped couplings be used to obtain a tight joint. These may be secured by ordering *line pipe*<sup>2</sup> which is used for oil piping, the couplings of which are provided with taper-tapped threads and may be used with regular mill-threaded standard weight pipe. Thread lengths should be in accordance with ASA B2.1. Right-hand threads are used unless otherwise ordered. To facilitate drainage, some elbows have the thread tapped at an angle to provide a pitch of the connecting pipe of 1/4 in. to the foot. These elbows are known to the trade as pitch elbows and are commercially available. All threaded pipe joints should be made up with a thread paste suitable for the service for which the pipe is to be used.

Table 4 contains pertinent threading data for standard weight, extra strong and double extra strong steel, and wrought-iron pipe. The normal engagement of pipe threads is given in Table 5.



TABLE 6. PIPE FITTINGS

|                            |                       |                                 |                        |
|----------------------------|-----------------------|---------------------------------|------------------------|
| ELBOWS                     |                       |                                 |                        |
| 90, 60, 45 & 22½° Standard | 90 & 45° Street       | 90 & 45° Male union             |                        |
| 90 & 45° Female union      | 90 & 45° Butt-welding | 90 & 45° Socket-welding         |                        |
| 90 & 45° Flanged           | 90° Side outlet       | 90° Rolling                     |                        |
| 90° side Outlet rolling    | Base                  | Drop                            |                        |
| TEES                       |                       |                                 |                        |
| Standard                   | Service               | Four-way                        |                        |
| Flanged                    | Flanged side outlet   | Male union                      |                        |
| Female union               | Female union outlet   | Flanged reducing                |                        |
| Flanged base               | Butt-welding          | Socket-welding                  |                        |
| Railing                    | Side outlet railing   | Drop                            |                        |
| COUPLINGS                  |                       |                                 |                        |
| Wrought                    | Cast                  | Socket-welding                  |                        |
| CROSSES                    |                       |                                 |                        |
| Screwed                    | Flanged               | Butt-welding                    |                        |
| Y-BENDS                    |                       |                                 |                        |
| 45° Screwed                | 45° Flanged           | 45° Double screwed True flanged |                        |
| RETURN BENDS               |                       |                                 |                        |
| Butt-welding               | Back outlet           | Screwed                         | Union end              |
| REDUCERS                   |                       |                                 |                        |
| Standard                   | Eccentric             | Flanged taper                   | Flanged eccentric      |
| Butt-welding               | Socket-welding        | Eccentric butt-welding          |                        |
| BUSHINGS                   |                       |                                 |                        |
| Outside hexagon            | Eccentric             | Face                            |                        |
| CAPS                       |                       |                                 |                        |
| Standard                   | Socket-welding        | Butt-welding                    |                        |
| PLUGS                      |                       |                                 |                        |
| Countersunk                | Square head           | Bar                             |                        |
| NIPPLES                    |                       |                                 |                        |
| Close                      | Long                  | Tank                            |                        |
| UNIONS                     |                       |                                 |                        |
| Female                     | Male & female         | Flange                          | Tongue & groove flange |
| FLANGES                    |                       |                                 |                        |
| Blind                      | Screwed               | Welding neck                    |                        |
| Floor                      | Slip-on               | Reducing                        |                        |

## PIPE FITTINGS

Pipe is joined by butt welding one length to another or by the use of fittings. Pipe fittings are made in a variety of forms (the common types are listed in Table 6), and are screwed, flanged or welded. The type of fitting to be used is determined by the pressure of the fluid being carried, or by the use of the pipe line. The materials generally used are steel, cast iron, malleable iron (heat treated cast iron), copper, brass, stainless steel, alloy steel, or bronze. The material used also depends upon the pressure or characteristics of the fluid.

Fittings are designated and sized in accordance with *American Standards Association* specifications and are identified by their nominal pipe sizes.

In the case of reducing tees, crosses, and Y-branches (laterals), the size of the largest run opening is given first, followed by the size of the opening at the opposite end of the run. Where the fitting is a tee or Y-branch

## Pipe, Fittings, Welding

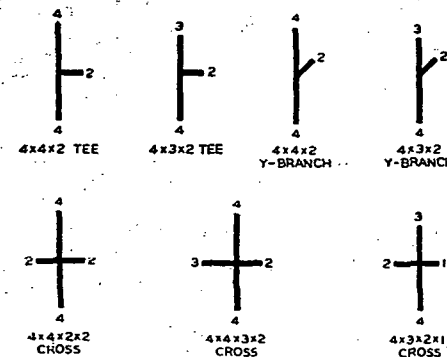


FIG. 1. DESCRIPTION OF TEES AND LATERALS (ASA B16.3—1951)

(lateral), the size of the outlet is given last. Where the fitting is a cross, the largest side-outlet opening is the third dimension given followed by the opening opposite. The straight line sketches, Fig. 1, illustrate how the reducing fittings are designated.

Where an external thread is wanted the word *male* follows the size of that opening.

Allowable pressures for solder type fittings are given in Table 7. Allowable pressures for ferrous screwed, flanged, and welding fittings are covered in the following ASA specifications:

| TYPE OF FITTING                   | SPECIFICATION | SATURATED STEAM PRESSURE PSIG* |
|-----------------------------------|---------------|--------------------------------|
| Cast Iron—Flanged                 | B16.1         | 125                            |
| Cast Iron—Flanged                 | B16b          | 250                            |
| Cast Iron—Flanged                 | B16b1         | 800                            |
| Cast Iron—Flanged (refrigeration) | B16.16        | 300                            |
| Cast Iron—Screwed                 | B16.4         | 125 and 150                    |
| Malleable Iron—Screwed            | B16.3         | 150                            |
| Malleable Iron—Screwed            | B16.19        | 300                            |
| Brass or Bronze—Screwed           | B16.15        | 125                            |
| Brass or Bronze—Screwed           | B16.17        | 250                            |
| Steel—Flanged                     | B16.5         | 2500                           |

\* Pressure may reduce with increasing sizes. This pressure is the maximum allowed in this specification for saturated steam. Higher pressures may be allowed with lower temperatures.

Steel welding (butt or socket type) fittings may be used for the same pressure as the pipe, providing wall thickness (or schedule number), and also the material, are the same as the pipe on which they are used.

Screwed fittings include: couplings, elbows (45° or 90°), return bends (close and open), tees, crosses, laterals (Y-branches), plugs, caps, lock nuts, flanges, bushings, and reducing fittings (elbows, tees and couplings). Reducing fittings and bushings may be eccentrically tapped to permit drainage of condensate.

Sometimes nipples are erroneously called fittings. Actually a nipple is a piece of pipe less than 12 in. long that has been threaded on both ends. Pipe 12 in. or longer is regarded as *cut pipe*. Nipples are classified as

close or full thread, shoulder, short, and long. A close nipple is about twice the length of the pipe thread since the threads actually meet. A shoulder nipple has a shoulder between the threads and is further classified as short or long. All shoulder nipples are cut to specific lengths and sold in that manner.

As a general rule, flanged joints are used when it is expected that the line will be disassembled quite often. There are three ways to attach the flange to the pipe; screwed, welded or lapped. Types of contact surface will be discussed.

Tables 8 to 14 give data on various types of ferrous fittings.

Fittings for copper tubing are available in soldered, flared, or compression types (see Figure 2). Fittings for copper pipe of IPS dimensions are

TABLE 7. SERVICE PRESSURE RATINGS FOR WROUGHT COPPER OR BRONZE SOLDER JOINT FITTINGS\*

| TYPE OF SOLDER                                               | SERVICE TEMP., F | MAXIMUM SERVICE PRESSURE, PSIG |                             |                             |                 |   |
|--------------------------------------------------------------|------------------|--------------------------------|-----------------------------|-----------------------------|-----------------|---|
|                                                              |                  | Water                          |                             |                             | Steam All       |   |
|                                                              |                  | 1/4 to 1 in. <sup>b</sup>      | 1 1/4 to 2 in. <sup>b</sup> | 2 1/4 to 4 in. <sup>b</sup> |                 |   |
| 50-50 Tin-lead (ASTM B32 Alloy Grade 50A)                    | 100              | 200                            | 175 <sup>c</sup>            | 150 <sup>d</sup>            | —               | — |
|                                                              | 150              | 150                            | 125 <sup>c</sup>            | 100 <sup>d</sup>            | —               | — |
|                                                              | 200              | 100                            | 90 <sup>c</sup>             | 75 <sup>d</sup>             | —               | — |
|                                                              | 250              | 85                             | 75 <sup>c</sup>             | 50 <sup>d</sup>             | 15 <sup>e</sup> | — |
| 95-5 Tin-antimony or 95-5 Lead-tin (ASTM B32 Alloy Grade 5A) | 100              | 500                            | 400                         | 300                         | —               | — |
|                                                              | 150              | 400                            | 350                         | 275                         | —               | — |
|                                                              | 200              | 300                            | 250                         | 200                         | —               | — |
|                                                              | 250              | 200                            | 175                         | 150                         | 15              | — |
| Solders with melting point 1100 F or above                   | 350              | 270                            | 190                         | 155                         | 120             | — |

Note: Ratings other than specified here may be used upon the recommendation of the manufacturer as to the proper solders that should be used.

\* Extracted from American Standard for Wrought Copper and Bronze Solder Joint Fittings, B16.22-1951.

<sup>b</sup> Standard water tube sizes except 1.8 in., which is 1/4 in. OD seamless copper tubing for refrigerator service, etc. (ASTM B88).

<sup>c</sup> These pressures may be used for cast-brass fittings (ASA B16.18-1950) for sizes 2 in. and smaller.

<sup>d</sup> These pressures may be used for cast-brass fittings (ASA B16.18-1950) for sizes 2 1/4 in. and above.

<sup>e</sup> Also allowable for cast-brass fittings (ASA B16.18-1950).

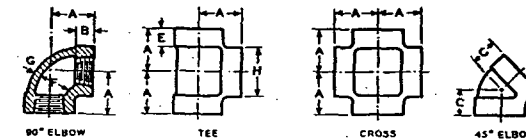
available in screwed or soldered types. Table 15 gives size data for screwed fittings and Tables 16 and 17 for solder-type fittings for copper tube and pipe.

The compression type fitting is generally limited to small sizes of tubing, while the flared and soldered types are used in both large and small sizes. An American Standard, ASA 40.2-1936, has been prepared to standardize dimensions of brass fittings for flared copper tubes. Flared tube fittings are widely used in refrigeration work where SAE dimensions and a 45 deg flare render most fittings interchangeable, although for refrigeration use, thread fits and tolerances on thread gages must be maintained within close limits. Brass fittings with SAE dimensions are not interchangeable with the American Standard fittings for water tubes.

#### FLANGE FACINGS AND GASKETS

There are many types of flange facings. The simplest, and the one most commonly used, is the plain face. This type of face is used with fittings shown in Table 9. Other facings, with varying complexity, are used for

TABLE 8. DIMENSIONS OF SCREWED CAST-IRON 90- AND 45-DEG ELBOWS, TEES, AND CROSSES (CLASS 125) (Straight Sizes)



| NOMINAL<br>PIPE SIZE | CENTER<br>TO END,<br>ELBOWS,<br>TEES, AND<br>CROSSES | CENTER TO<br>END,<br>45-DEG<br>ELBOWS | LENGTH<br>OF<br>THREAD,<br>MIN | WIDTH<br>OF<br>BAND,<br>MIN | INSIDE DIAM-<br>ETER OF<br>FITTING |        | METAL<br>THICKNESS | OUTSIDE<br>DIAMETER<br>OF BAND,<br>MIN |
|----------------------|------------------------------------------------------|---------------------------------------|--------------------------------|-----------------------------|------------------------------------|--------|--------------------|----------------------------------------|
|                      |                                                      |                                       |                                |                             | F                                  |        |                    |                                        |
|                      |                                                      |                                       |                                |                             | Max                                | Min    |                    |                                        |
| 1/4                  | 0.81                                                 | 0.73                                  | 0.32                           | 0.38                        | 0.584                              | 0.540  | 0.110              | 0.93                                   |
| 3/8                  | 0.95                                                 | 0.80                                  | 0.36                           | 0.44                        | 0.719                              | 0.675  | 0.120              | 1.12                                   |
| 1/2                  | 1.12                                                 | 0.88                                  | 0.43                           | 0.50                        | 0.897                              | 0.840  | 0.130              | 1.34                                   |
| 3/4                  | 1.31                                                 | 0.98                                  | 0.50                           | 0.56                        | 1.107                              | 1.050  | 0.155              | 1.63                                   |
| 1                    | 1.50                                                 | 1.12                                  | 0.58                           | 0.62                        | 1.385                              | 1.315  | 0.170              | 1.95                                   |
| 1 1/4                | 1.75                                                 | 1.29                                  | 0.67                           | 0.69                        | 1.730                              | 1.660  | 0.185              | 2.39                                   |
| 1 1/2                | 1.94                                                 | 1.43                                  | 0.70                           | 0.75                        | 1.970                              | 1.900  | 0.200              | 2.68                                   |
| 2                    | 2.25                                                 | 1.68                                  | 0.75                           | 0.84                        | 2.445                              | 2.375  | 0.220              | 3.28                                   |
| 2 1/2                | 2.70                                                 | 1.95                                  | 0.92                           | 0.94                        | 2.975                              | 2.875  | 0.240              | 3.86                                   |
| 3                    | 3.08                                                 | 2.17                                  | 0.98                           | 1.00                        | 3.600                              | 3.500  | 0.260              | 4.62                                   |
| 3 1/2                | 3.42                                                 | 2.39                                  | 1.03                           | 1.06                        | 4.100                              | 4.000  | 0.280              | 5.20                                   |
| 4                    | 3.79                                                 | 2.61                                  | 1.08                           | 1.12                        | 4.600                              | 4.500  | 0.310              | 5.79                                   |
| 5                    | 4.50                                                 | 3.05                                  | 1.18                           | 1.18                        | 5.663                              | 5.563  | 0.330              | 7.05                                   |
| 6                    | 5.13                                                 | 3.46                                  | 1.28                           | 1.28                        | 6.725                              | 6.625  | 0.430              | 8.28                                   |
| 8                    | 6.56                                                 | 4.28                                  | 1.47                           | 1.47                        | 8.725                              | 8.625  | 0.550              | 10.63                                  |
| 10                   | 8.08*                                                | 5.16                                  | 1.68                           | 1.68                        | 10.850                             | 10.750 | 0.690              | 13.12                                  |
| 12                   | 9.50*                                                | 5.97                                  | 1.88                           | 1.88                        | 12.850                             | 12.750 | 0.800              | 15.47                                  |

From American Standard Dimensions of Cast-Iron Screwed Fittings, Class 125. ASA B16.4-1949.

All dimensions given in inches.

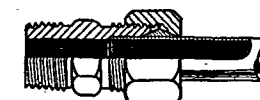
\* This applies to elbows and tees only.



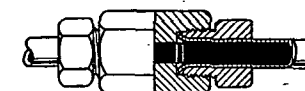
SOLDER-TYPE FITTING



REFRIGERATOR TYPE FLARED-TUBE FITTINGS



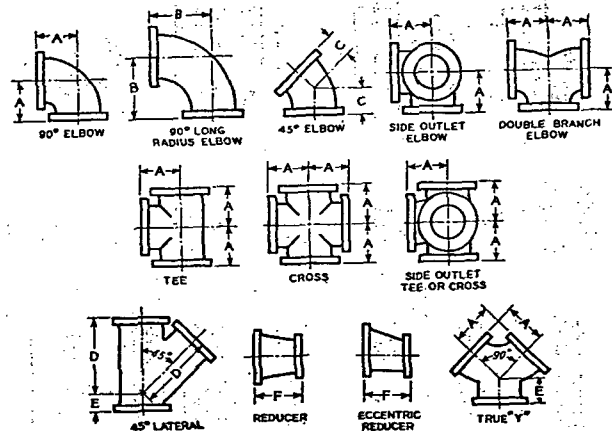
SAE COMPRESSION TUBE FITTINGS



FLARED-TUBE FITTINGS

FIG. 2. COPPER OR BRASS TUBE FITTINGS

TABLE 9. DIMENSIONS OF FLANGED CAST-IRON ELBOWS, DOUBLE BRANCH ELBOWS, TEES, CROSSES, LATERALS, TRUE Y'S (STRAIGHT SIZES), AND REDUCERS (CLASS 125)



| NOMINAL PIPE SIZE | INSIDE DIAM. OF FITTINGS | CENTER TO FACE 90 DEG ELBOW, TEES, CROSSES, TRUE Y AND DOUBLE BRANCH ELBOW A | CENTER TO FACE 90 DEG LONG RADIUS ELBOW B | CENTER TO FACE 45 DEG ELBOW C | CENTER TO FACE LATERAL D | SHORT CENTER TO FACE TRUE Y AND LATERAL E | FACE TO FACE REDUCER F | DIAM. OF FLANGE | THICKNESS OF FLANGE (MIN) | WALL THICKNESS |
|-------------------|--------------------------|------------------------------------------------------------------------------|-------------------------------------------|-------------------------------|--------------------------|-------------------------------------------|------------------------|-----------------|---------------------------|----------------|
| 1                 | 1                        | 3 1/4                                                                        | 5                                         | 1 3/4                         | 5 1/4                    | 1 3/4                                     | .....                  | 4 1/4           | 3/16                      | 9/16           |
| 1 1/4             | 1 1/4                    | 3 3/4                                                                        | 5 1/2                                     | 2                             | 6 1/4                    | 1 3/4                                     | .....                  | 4 5/8           | 3/8                       | 9/16           |
| 1 1/2             | 1 1/2                    | 4                                                                            | 6                                         | 2 1/4                         | 7                        | 2                                         | .....                  | 5               | 3/8                       | 9/16           |
| 2                 | 2                        | 4 1/2                                                                        | 6 1/2                                     | 2 1/2                         | 8                        | 2 1/2                                     | 5                      | 6               | 3/8                       | 9/16           |
| 2 1/2             | 2 1/2                    | 5                                                                            | 7                                         | 3                             | 9 1/4                    | 2 1/2                                     | 5 1/2                  | 7               | 3/8                       | 9/16           |
| 3                 | 3                        | 5 1/2                                                                        | 7 3/4                                     | 3                             | 10                       | 3                                         | 6                      | 7 1/2           | 3/4                       | 3/8            |
| 3 1/2             | 3 1/2                    | 6                                                                            | 8 1/2                                     | 3 1/2                         | 11 1/4                   | 3                                         | 6 1/2                  | 8 1/2           | 3/4                       | 7/16           |
| 4                 | 4                        | 6 1/2                                                                        | 9                                         | 4                             | 12                       | 3                                         | 7                      | 9               | 3/4                       | 7/16           |
| 4 1/2             | 4 1/2                    | 7 1/2                                                                        | 10 1/4                                    | 4 1/2                         | 13 1/2                   | 3 1/2                                     | 8                      | 10              | 3/4                       | 7/16           |
| 5                 | 5                        | 8                                                                            | 11 1/2                                    | 5                             | 14 1/2                   | 3 1/2                                     | 9                      | 11              | 1                         | 9/16           |
| 6                 | 6                        | 9                                                                            | 12                                        | 6                             | 15 1/2                   | 4                                         | 10                     | 12              | 1 1/8                     | 1              |
| 8                 | 8                        | 11                                                                           | 14                                        | 8                             | 17 1/2                   | 5 1/2                                     | 12                     | 14              | 1 1/4                     | 1 1/8          |
| 10                | 10                       | 13                                                                           | 16 1/4                                    | 10                            | 19 1/2                   | 7                                         | 14                     | 16              | 1 1/2                     | 1 1/8          |
| 12                | 12                       | 15                                                                           | 18 1/2                                    | 12                            | 21 1/2                   | 8                                         | 16                     | 18              | 1 3/4                     | 1 1/8          |
| 14 OD             | 14                       | 17                                                                           | 20 1/2                                    | 14                            | 23 1/2                   | 9                                         | 18                     | 20              | 1 3/4                     | 1 1/8          |
| 16 OD             | 16                       | 19                                                                           | 22 1/2                                    | 16                            | 25 1/2                   | 10                                        | 20                     | 22              | 1 3/4                     | 1 1/8          |
| 18 OD             | 18                       | 21                                                                           | 24 1/2                                    | 18                            | 27 1/2                   | 11                                        | 22                     | 24              | 1 3/4                     | 1 1/8          |
| 20 OD             | 20                       | 23                                                                           | 26 1/2                                    | 20                            | 29 1/2                   | 12                                        | 24                     | 26              | 1 3/4                     | 1 1/8          |
| 24 OD             | 24                       | 27                                                                           | 30 1/2                                    | 24                            | 33 1/2                   | 14                                        | 28                     | 30              | 1 3/4                     | 1 1/8          |
| 30 OD             | 30                       | 33                                                                           | 36 1/2                                    | 30                            | 40 1/2                   | 18                                        | 34                     | 36              | 1 3/4                     | 1 1/8          |
| 36 OD             | 36                       | 39                                                                           | 42 1/2                                    | 36                            | 46 1/2                   | 22                                        | 40                     | 42              | 1 3/4                     | 1 1/8          |
| 42 OD             | 42                       | 45                                                                           | 48 1/2                                    | 42                            | 52 1/2                   | 26                                        | 46                     | 48              | 1 3/4                     | 1 1/8          |
| 48 OD             | 48                       | 51                                                                           | 54 1/2                                    | 48                            | 58 1/2                   | 30                                        | 50                     | 52              | 1 3/4                     | 1 1/8          |

From American Standard for Cast Iron Pipe Flanges and Flanged Fittings, Class 125, ASA B16.1-1948.  
All dimensions given are in inches.

\* Does not apply to true Y's or double-flanged elbows.

higher pressures. They include: male and female face (an insert type face), tongue-and-groove (an adaptation of the male and female type), lapped pipe to flange, lapped pipe to pipe, and ring and groove using neck flanges.

As it is too expensive to machine flange faces sufficiently to provide water-

tight joints, a gasket is usually inserted between the contact faces of the flanges. The flange bolts then draw the faces up so tight that the gasket deforms into the face imperfections and thereby provides a tight joint.

Gaskets are made of numerous materials, such as cork, paper, fiber, asbestos, metal (iron, steel, copper, etc.), and combinations of metal and some soft material. The proper gasket material to use depends upon the service of the pipe. The material should not be detrimentally affected by the chemical and thermal conditions of the fluid being carried.

TABLE 10. DIMENSIONS OF STEEL BUTT-WELDING FITTINGS



| NOMINAL PIPE SIZE | LONG RADIUS ELBOWS        |                               |                               | 180-DEG RETURNS           |                 |                | STRAIGHT TEES             |                     |                        |
|-------------------|---------------------------|-------------------------------|-------------------------------|---------------------------|-----------------|----------------|---------------------------|---------------------|------------------------|
|                   | Outside Diameter at Bevel | Center-to-End 90-Deg Elbows A | Center-to-End 45-Deg Elbows B | Outside Diameter at Bevel | Center-to-End O | Back to Face K | Outside Diameter at Bevel | Center-to-End Run C | Center-to-End Outlet M |
| 1                 | 1.315                     | 1 1/4                         | 7/8                           | 1.315                     | 3               | 2 3/4          | 1.315                     | 1 1/4               | 1 1/4                  |
| 1 1/4             | 1.660                     | 1 1/2                         | 1                             | 1.660                     | 3 1/4           | 2 3/4          | 1.660                     | 1 1/2               | 1 1/2                  |
| 1 1/2             | 1.900                     | 2 1/4                         | 1 1/4                         | 1.900                     | 4 1/2           | 3 1/4          | 1.900                     | 2 1/4               | 2 1/4                  |
| 2                 | 2.375                     | 3                             | 1 3/4                         | 2.375                     | 6               | 4 1/4          | 2.375                     | 2 3/4               | 2 3/4                  |
| 2 1/2             | 2.875                     | 3 3/4                         | 1 3/4                         | 2.875                     | 7 1/4           | 5 1/4          | 2.875                     | 3                   | 3                      |
| 3                 | 3.500                     | 4 1/2                         | 2                             | 3.500                     | 9               | 6 1/4          | 3.500                     | 3 3/4               | 3 3/4                  |
| 3 1/2             | 4.000                     | 5 1/4                         | 2 1/4                         | 4.000                     | 10 1/4          | 7 1/4          | 4.000                     | 3 3/4               | 3 3/4                  |
| 4                 | 4.500                     | 6                             | 2 1/2                         | 4.500                     | 12              | 8 1/4          | 4.500                     | 4 1/2               | 4 1/2                  |
| 5                 | 5.563                     | 7 1/4                         | 3 1/4                         | 5.563                     | 15              | 10 1/4         | 5.563                     | 4 1/2               | 4 1/2                  |
| 6                 | 6.625                     | 9                             | 3 3/4                         | 6.625                     | 18              | 12 1/4         | 6.625                     | 5 1/2               | 5 1/2                  |
| 8                 | 8.625                     | 12                            | 5                             | 8.625                     | 24              | 16 1/4         | 8.625                     | 7                   | 7                      |
| 10                | 10.750                    | 15                            | 6 1/4                         | 10.750                    | 30              | 20 3/4         | 10.750                    | 8 1/2               | 8 1/2                  |
| 12                | 12.750                    | 18                            | 7 1/4                         | 12.750                    | 36              | 24 3/4         | 12.750                    | 10                  | 10                     |
| 14                | 14.000                    | 21                            | 8 3/4                         | 14.000                    | 42              | 28             | 14.000                    | 11                  | Not standard           |
| 16                | 16.000                    | 24                            | 10                            | 16.000                    | 48              | 32             | 16.000                    | 12                  |                        |
| 18                | 18.000                    | 27                            | 11 1/4                        | 18.000                    | 54              | 36             | 18.000                    | 13 1/2              |                        |
| 20                | 20.000                    | 30                            | 12 1/2                        | 20.000                    | 60              | 40             | 20.000                    | 15                  |                        |
| 24                | 24.000                    | 36                            | 15                            | 24.000                    | 72              | 48             | 24.000                    | 17                  |                        |

From American Standard for Steel Butt-Welding Fittings, ASA B16.9-1951.

All dimensions are in inches.

Dimension A is equal to 1/2 of dimension O.

## VALVES

Valves are made with the same end connections as fittings. A brief description of each type follows.

1. *Flanged Ends:* Made in sizes from 1/2 in. up. Used whenever line fittings are flanged and if frequent removal is contemplated. Flanged valves facilitate installation when large sizes are used.

2. *Screwed Ends:* Most common type end. Can be used for all pressures. Usually confined to smaller size because of difficulty in making large screwed joints.

*Welding Ends:* Available in steel only. Generally employed for high temperature—high pressure work. Difficult to disassemble in a welded line. This type in-

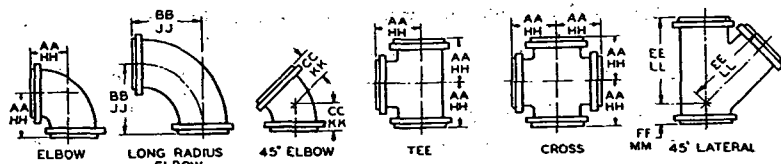
cludes butt-welding or socket-welding. See Tables 10 and 13 for size of fittings available in each class. The valves are made in the same size range.

3. **Brazing Ends:** These ends are available on brass valves. The ends have a special shape to facilitate use of brazing alloys. These valves are used for higher temperatures than solder end valves.

4. **Solder Ends:** For use with copper tubing in plumbing, heating and air conditioning. Should not be used at high temperatures.

5. **Flared Ends:** For use with light wall tubing—either metal or plastic—and for

TABLE 11. DIMENSIONS OF STEEL FLANGED FITTINGS FOR PRIMARY SERVICE PRESSURE RATING OF 150 PSI (GAGE)



| 1                 | 2                               | 3                             | 4                                                                       | 5                                                         | 6                                                 | 7                                                      | 8                                                                   | 9                                                          | 10                                           | 11                             |
|-------------------|---------------------------------|-------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------|---------------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------------|------------------------------------------------------------|----------------------------------------------|--------------------------------|
| NOMINAL PIPE SIZE | OUTSIDE DIAMETER OF FLANGE<br>O | THICKNESS OF FLANGE, MIN<br>C | 1/4 IN. RAISED FACE (FLANGE EDGE)                                       |                                                           |                                                   |                                                        |                                                                     |                                                            | RING JOINT                                   |                                |
|                   |                                 |                               | Center to Contact Surface of Raised Face, Elbow, Tee, Cross, and True Y | Center to Contact Surface of Raised Face, Long Radius Ell | Center to Contact Surface of Raised Face, 45° Ell | Long Center to Contact Surface of Raised Face, Lateral | Short Center to Contact Surface of Raised Face, Lateral, and True Y | Contact Surface to Contact Surface of Raised Face, Reducer | Center to End, Elbow, Tee, Cross, and True Y | Center to End, Long Radius Ell |
|                   |                                 |                               | AA                                                                      | BB                                                        | CC                                                | EE                                                     | FF                                                                  | GG                                                         | HH                                           | JJ                             |
| 1                 | 4 1/4                           | 3/16                          | 3 3/4                                                                   | 5                                                         | 1 3/4                                             | 5 3/4                                                  | 1 3/4                                                               | 4 1/2                                                      | 3 3/4                                        | 5 1/4                          |
| 1 1/4             | 4 9/8                           | 1/8                           | 3 3/4                                                                   | 5 1/2                                                     | 2                                                 | 6 1/4                                                  | 1 3/4                                                               | 4 1/2                                                      | 4                                            | 5 3/4                          |
| 1 1/2             | 5                               | 9/16                          | 4                                                                       | 6                                                         | 2 3/4                                             | 7                                                      | 2                                                                   | 4 3/4                                                      | 4 1/4                                        | 6 1/4                          |
| 2                 | 6                               | 5/8                           | 4 1/4                                                                   | 6 1/2                                                     | 3 1/2                                             | 8                                                      | 2 1/2                                                               | 5                                                          | 4 3/4                                        | 6 3/4                          |
| 2 1/4             | 7                               | 1 1/4                         | 5                                                                       | 7                                                         | 3                                                 | 9 1/4                                                  | 2 1/2                                                               | 5 1/2                                                      | 5 1/4                                        | 7 1/4                          |
| 3                 | 7 1/4                           | 3/4                           | 5 1/4                                                                   | 7 3/4                                                     | 3                                                 | 10                                                     | 3                                                                   | 6                                                          | 5 3/4                                        | 8                              |
| 3 1/4             | 8 1/4                           | 1 3/8                         | 6                                                                       | 8 1/4                                                     | 3 1/2                                             | 11 1/4                                                 | 3                                                                   | 6 1/2                                                      | 6 1/4                                        | 8 3/4                          |
| 4                 | 9                               | 1 1/2                         | 6 1/2                                                                   | 9                                                         | 4                                                 | 12                                                     | 3                                                                   | 7                                                          | 6 3/4                                        | 9 1/4                          |
| 5                 | 10                              | 1 5/8                         | 7 1/2                                                                   | 10 1/4                                                    | 4 1/2                                             | 13 1/2                                                 | 3 1/2                                                               | 8                                                          | 7 3/4                                        | 10 1/2                         |
| 6                 | 11                              | 1                             | 8                                                                       | 11 1/2                                                    | 5                                                 | 14 1/2                                                 | 3 1/2                                                               | 9                                                          | 8 3/4                                        | 11 1/4                         |
| 8                 | 13 1/4                          | 1 1/4                         | 9                                                                       | 14                                                        | 5 1/2                                             | 17 1/2                                                 | 4 1/2                                                               | 11                                                         | 9 3/4                                        | 14 1/4                         |
| 10                | 16                              | 1 3/4                         | 11                                                                      | 16 1/4                                                    | 6 1/2                                             | 20 1/2                                                 | 5                                                                   | 12                                                         | 11 3/4                                       | 16 3/4                         |
| 12                | 19                              | 1 3/4                         | 12                                                                      | 19                                                        | 7 1/2                                             | 24 1/2                                                 | 5 1/2                                                               | 14                                                         | 12 3/4                                       | 19 1/4                         |
| 14                | 21                              | 1 3/4                         | 14                                                                      | 21 1/2                                                    | 7 1/2                                             | 27                                                     | 6                                                                   | 16                                                         | 14 1/4                                       | 21 3/4                         |
| 16                | 23 1/4                          | 1 7/8                         | 15                                                                      | 24                                                        | 8                                                 | 30                                                     | 6 1/2                                                               | 18                                                         | 15 3/4                                       | 24 1/4                         |
| 18                | 25                              | 1 3/4                         | 16 1/2                                                                  | 26 1/2                                                    | 8 1/2                                             | 32                                                     | 7                                                                   | 19                                                         | 16 3/4                                       | 26 1/4                         |
| 20                | 27 1/4                          | 1 11/16                       | 18                                                                      | 29                                                        | 9 1/2                                             | 35                                                     | 8                                                                   | 20                                                         | 18 1/4                                       | 29 1/4                         |
| 24                | 32                              | 1 7/8                         | 22                                                                      | 34                                                        | 11                                                | 40 1/2                                                 | 9                                                                   | 24                                                         | 22 3/4                                       | 34 1/4                         |

From American Standard for Steel Pipe Flanges and Flanged Fittings, 150, 300, 400, 600, 900, 1500 and 2500 Lb. ASA B16.5-1953.

All dimensions given in inches.

\* Actual diameter is same for sizes 1 to 12 in. and is 3/4 in. less than nominal for sizes 14 to 24 in.

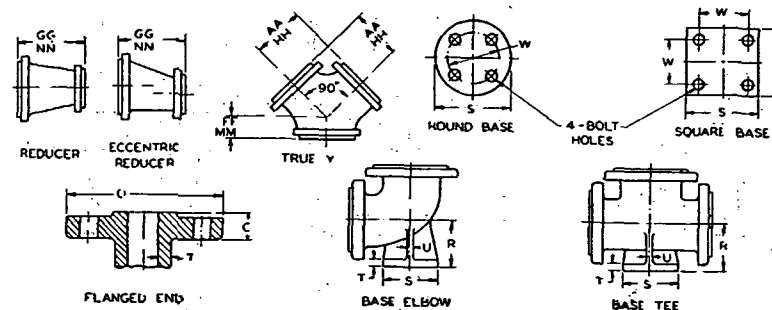
sizes 2 in. and below. A flaring tool flares the tube end, and a ring nut pulls the flared tubing up against a seat on the valve. This makes a lap joint.

6. **Hub Ends:** Generally used for water supply and sewage piping. This type joint is used with cast iron pipe. The joint is a socket type made by inserting the pipe in the hub, then caulking with oakum. After caulking, the joint is sealed with molten lead.

Valves are made of brass, iron, steel, and to some extent malleable iron.

Brass should not be used for work requiring temperatures above 550 F. The brass used in valves is similar to that used in brass pipe and contains some tin and lead as well as copper and zinc.

TABLE 11. DIMENSIONS OF STEEL FLANGED FITTINGS FOR PRIMARY SERVICE PRESSURE RATING OF 150 PSI (GAGE) (Concluded)



| 1                 | 12                          | 13                          | 14                                       | 15             | 16                                          | 17                | 18                | 19                          | 20                     |
|-------------------|-----------------------------|-----------------------------|------------------------------------------|----------------|---------------------------------------------|-------------------|-------------------|-----------------------------|------------------------|
| NOMINAL PIPE SIZE | RING JOINT.                 |                             |                                          | CENTER TO BASE | DIAM. OF ROUND BASE OR WIDTH OF SQUARE BASE | THICKNESS OF BASE | THICKNESS OF RIBS | BASE DRILLING               |                        |
|                   | Center to End, 45-Deg Elbow | Long Center to End, Lateral | Short Center to End, Lateral, and True Y |                |                                             |                   |                   | Bolt Circle or Bolt Spacing | Diam. of Drilled Holes |
|                   |                             |                             |                                          |                |                                             |                   |                   |                             |                        |
| KK                | LL                          | MM                          | R                                        | S              | T                                           | U                 | W                 |                             |                        |
| 1                 | 2                           | 6                           | 2                                        |                |                                             |                   |                   |                             |                        |
| 1¼                | 2¼                          | 6¼                          | 2                                        |                |                                             |                   |                   |                             |                        |
| 1½                | 2½                          | 7¼                          | 2¼                                       |                |                                             |                   |                   |                             |                        |
| 2                 | 2¾                          | 8¼                          | 2¾                                       | 4½             | 4½                                          | 1½                | 1½                | 3½                          | ¾                      |
| 2¼                | 3¼                          | 9¾                          | 2¾                                       | 4½             | 4½                                          | 1½                | 1½                | 3½                          | ¾                      |
| 3                 | 3¼                          | 10¼                         | 3¼                                       | 4¾             | 5                                           | 1½                | 1½                | 3¾                          | ¾                      |
| 3¾                | 3¾                          | 11¾                         | 3¼                                       | 5¼             | 5                                           | 1½                | 1½                | 3¾                          | ¾                      |
| 4                 | 4¼                          | 12¼                         | 3¼                                       | 5½             | 6                                           | 1½                | 1½                | 4¼                          | ¾                      |
| 5                 | 4¾                          | 13¾                         | 3¾                                       | 6¼             | 7                                           | 1½                | 1½                | 5¼                          | ¾                      |
| 6                 | 5¼                          | 14¾                         | 3¾                                       | 7              | 7                                           | 1½                | 1½                | 5½                          | ¾                      |
| 8                 | 5¾                          | 17¾                         | 4¾                                       | 8¾             | 9                                           | 1½                | 1½                | 7½                          | ¾                      |
| 10                | 6¾                          | 20¾                         | 5¼                                       | 9¾             | 9                                           | 1½                | 1½                | 7¾                          | ¾                      |
| 12                | 7¾                          | 24¾                         | 5¾                                       | 11¼            | 11                                          | 1                 | 1                 | 9½                          | ¾                      |
| 14                | 7¾                          | 27¾                         | 6¼                                       | 12½            | 11                                          | 1                 | 1                 | 9½                          | ¾                      |
| 16                | 8¼                          | 30¾                         | 6¾                                       | 13¾            | 11                                          | 1                 | 1                 | 9½                          | ¾                      |
| 18                | 8¾                          | 32¾                         | 7¾                                       | 15             | 13½                                         | 1½                | 1½                | 11¾                         | ¾                      |
| 20                | 9¾                          | 35¾                         | 8¼                                       | 16             | 13½                                         | 1½                | 1½                | 11¾                         | ¾                      |
| 24                | 11¼                         | 40¾                         | 9¼                                       | 18½            | 13½                                         | 1½                | 1½                | 11¾                         | ¾                      |

Cast iron is generally provided in some alloying state, especially in the larger sizes. Cast iron is not suitable for service (above 450 F).

Malleable iron, which is a cast iron heat treated to provide some ductility, is used to some extent, primarily in place of cast iron.

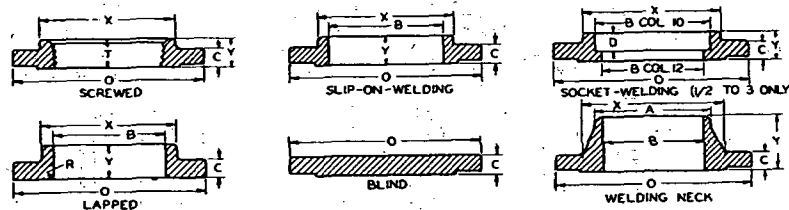
Steel is used either in the cast or forged state. For corrosive service, alloy and stainless steel are used. Steel is used for high temperature—high

pressure work. Steel is the only valve material that can stand appreciable expansion stresses.

The characteristics of valves restrict their use. The five main uses for valves are listed below:

1. *Stopping flow*: The most general use for valves. Gate valves are generally used for this purpose. The gate valve operates by a disc moving at right angles to the

TABLE 12. DIMENSIONS OF STEEL FLANGES FOR PRIMARY SERVICE  
PRESSURE RATING OF 150 PSI (GAGE)



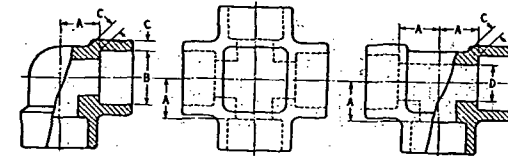
| 1                  | 2                          | 3                        | 4               | 5                                 | 6                    | 7            | 8     | 9                     | 10                           | 11          | 12                          | 13                                              | 14              |
|--------------------|----------------------------|--------------------------|-----------------|-----------------------------------|----------------------|--------------|-------|-----------------------|------------------------------|-------------|-----------------------------|-------------------------------------------------|-----------------|
| NOMINAL PIPE SIZE. | OUTSIDE DIAMETER OF FLANGE | THICKNESS OF FLANGE, MIN | DIAMETER OF HUB | HUB DIAMETER BEGINNING OF CHAMFER | LENGTH THROUGH HUB Y |              |       | THREAD LENGTH SCREWED | BORE B                       |             |                             | CORNER RADIUS OF BORE OF LAPPED FLANGE AND PIPE | DEPTH OF SOCKET |
| O                  | C                          | X                        | A               | Screwed Slip-On Socket Welding    | Lapped               | Welding Neck | T     |                       | Slip-On Socket Welding, Min  | Lapped, Min | Welding Neck Socket Welding |                                                 |                 |
|                    |                            |                          |                 |                                   |                      |              |       |                       |                              |             |                             |                                                 |                 |
| 1/2                | 3 1/2                      | 3/16                     | 1 1/2           | 0.84                              | 5/8                  | 5/8          | 1 1/4 | 3/4                   | 0.88                         | 0.90        | 0.62                        | 3/4                                             | 3/4             |
| 3/4                | 3 7/8                      | 3/16                     | 1 1/2           | 1.05                              | 5/8                  | 5/8          | 2 1/4 | 3/4                   | 1.09                         | 1.11        | 0.82                        | 3/4                                             | 3/4             |
| 1                  | 4 1/4                      | 3/16                     | 1 1/2           | 1.32                              | 1 1/4                | 1 1/4        | 2 1/4 | 1 1/4                 | 1.36                         | 1.38        | 1.05                        | 3/4                                             | 3/4             |
| 1 1/4              | 4 5/8                      | 3/16                     | 2 1/4           | 1.66                              | 1 1/4                | 1 1/4        | 2 1/4 | 1 1/4                 | 1.70                         | 1.72        | 1.38                        | 3/4                                             | 3/4             |
| 1 1/2              | 5                          | 3/16                     | 2 1/4           | 1.90                              | 3/4                  | 3/4          | 2 1/4 | 3/4                   | 1.95                         | 1.97        | 1.61                        | 3/4                                             | 3/4             |
| 2                  | 6                          | 3/8                      | 3 1/4           | 2.38                              | 1                    | 1            | 2 1/4 | 1                     | 2.44                         | 2.46        | 2.07                        | 3/4                                             | 1 1/4           |
| 2 1/2              | 7                          | 3/8                      | 3 3/4           | 2.88                              | 1 1/4                | 1 1/4        | 2 1/4 | 1 1/4                 | 2.94                         | 2.97        | 2.47                        | 3/4                                             | 3/4             |
| 3                  | 7 1/4                      | 3/8                      | 4 1/4           | 3.50                              | 1 1/4                | 1 1/4        | 3 1/4 | 1 1/4                 | 3.57                         | 3.60        | 3.07                        | 3/4                                             | 3/4             |
| 3 1/4              | 8 1/4                      | 3/8                      | 4 3/4           | 4.00                              | 1 1/4                | 1 1/4        | 2 1/4 | 1 1/4                 | 4.07                         | 4.10        | 3.55                        | 3/4                                             | 3/4             |
| 4                  | 9                          | 3/8                      | 5 1/4           | 4.50                              | 1 1/4                | 1 1/4        | 3     | 1 1/4                 | 4.57                         | 4.60        | 4.03                        | 3/4                                             | 3/4             |
| 5                  | 10                         | 3/8                      | 5 3/4           | 5.56                              | 1 1/4                | 1 1/4        | 3 1/4 | 1 1/4                 | 5.66                         | 5.69        | 5.05                        | 3/4                                             | 3/4             |
| 6                  | 11                         | 1                        | 6 3/4           | 6.63                              | 1 1/4                | 1 1/4        | 3 1/4 | 1 1/4                 | 6.72                         | 6.75        | 6.07                        | 3/4                                             | 3/4             |
| 8                  | 13 1/4                     | 1 1/4                    | 9 1/4           | 8.63                              | 1 1/4                | 1 1/4        | 4     | 1 1/4                 | 8.72                         | 8.75        | 7.98                        | 3/4                                             | 3/4             |
| 10                 | 16                         | 1 1/2                    | 12              | 10.75                             | 1 1/4                | 1 1/4        | 4 1/2 | 1 1/4                 | 10.88                        | 10.92       | 10.02                       | 3/4                                             | 3/4             |
| 12                 | 19                         | 1 3/4                    | 14 3/4          | 12.75                             | 2 1/4                | 2 1/4        | 5     | 2 1/4                 | 12.88                        | 12.92       | 12.00                       | 3/4                                             | 3/4             |
| 14                 | 21                         | 1 3/4                    | 15 3/4          | 14.00                             | 2 1/4                | 3 1/4        | 5     | 2 1/4                 | 14.14                        | 14.18       |                             | 3/4                                             | 3/4             |
| 16                 | 23 1/2                     | 1 3/4                    | 18              | 16.00                             | 2 1/4                | 3 1/4        | 5     | 2 1/4                 | 16.16                        | 16.19       |                             | 3/4                                             | 3/4             |
| 18                 | 25 1/2                     | 1 3/4                    | 19 1/2          | 18.00                             | 2 1/4                | 3 1/4        | 5 1/2 | 2 1/4                 | 18.18                        | 18.20       |                             | 3/4                                             | 3/4             |
| 20                 | 27 1/2                     | 1 3/4                    | 22              | 20.00                             | 2 1/4                | 4 1/4        | 5 1/4 | 2 1/4                 | 20.20                        | 20.25       |                             | 3/4                                             | 3/4             |
| 24                 | 32                         | 1 3/4                    | 26 1/4          | 24.00                             | 3 1/4                | 4 3/4        | 6     | 3 1/4                 | 24.25                        | 24.25       |                             | 3/4                                             | 3/4             |
|                    |                            |                          |                 |                                   |                      |              |       |                       | To be specified by purchaser |             |                             |                                                 |                 |

From American Standard for Steel Pipe Flanges and Flanged Fittings, ASA B16.5-1953.  
All dimensions given in inches.

path of the fluid. The fluid flows straight through the valve, hence, a gate valve offers the minimum resistance when it is fully open. The gate is moved by a stem screw attached to the handle. Gate valves are poor regulators because at nearly closed position (where best regulation is obtained) the fluid velocity either causes vibration and noise, or else tends to erode the disc.

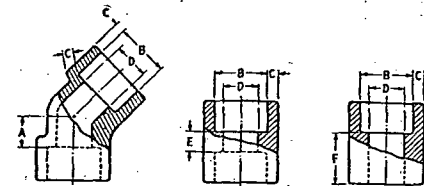
2. *Throttling flow*: This is best accomplished by globe or angle valves. These valves cause the fluid to change direction, and consequently, offer considerable fluid resistance even when in the open position. Both the globe and angle valves operate by closing a plug into a fitted seat. The angle valve is similar to the globe valve

TABLE 13. DIMENSIONS OF SOCKET WELDING FITTINGS  
A. DIMENSIONS OF SOCKET WELDING ELBOWS, TEES, AND CROSSES



| NOM-<br>INAL<br>PIPE<br>SIZE | DEPTH<br>OF<br>SOCKET<br>MIN | CENTER TO<br>BOTTOM OF<br>SOCKET |              | BORE<br>DIAM-<br>ETER OF<br>SOCKET,<br>MIN | SOCKET WALL THICKNESS<br>MIN |             |              | BORE DIAMETER<br>OF FITTING |             |              |
|------------------------------|------------------------------|----------------------------------|--------------|--------------------------------------------|------------------------------|-------------|--------------|-----------------------------|-------------|--------------|
|                              |                              | Sched<br>40 and<br>80            | Sched<br>160 |                                            | Sched<br>40                  | Sched<br>80 | Sched<br>160 | Sched<br>40                 | Sched<br>80 | Sched<br>160 |
|                              |                              | A                                |              |                                            | B                            | C           |              |                             | D           |              |
| 1/4                          | 3/4                          | 3/16                             | .....        | 0.420                                      | 0.125                        | 0.125       | .....        | 0.269                       | 0.215       | .....        |
| 1/2                          | 3/4                          | 3/16                             | .....        | 0.555                                      | 0.125                        | 0.149       | .....        | 0.364                       | 0.302       | .....        |
| 3/4                          | 3/4                          | 1/2                              | .....        | 0.690                                      | 0.125                        | 0.158       | .....        | 0.493                       | 0.423       | .....        |
| 1                            | 3/4                          | 3/4                              | 3/4          | 0.855                                      | 0.136                        | 0.184       | 0.234        | 0.622                       | 0.546       | 0.466        |
| 1 1/4                        | 3/4                          | 3/4                              | 3/4          | 1.065                                      | 0.141                        | 0.193       | 0.273        | 0.824                       | 0.742       | 0.614        |
| 2                            | 3/4                          | 3/4                              | 1 1/4        | 1.330                                      | 0.166                        | 0.224       | 0.313        | 1.049                       | 0.957       | 0.815        |
| 2 1/2                        | 3/4                          | 3/4                              | 1 1/2        | 1.675                                      | 0.175                        | 0.239       | 0.313        | 1.380                       | 1.278       | 1.160        |
| 3                            | 3/4                          | 3/4                              | 1 3/4        | 1.915                                      | 0.181                        | 0.250       | 0.351        | 1.610                       | 1.500       | 1.338        |
| 4                            | 3/4                          | 1 1/4                            | 1 3/4        | 2.406                                      | 0.193                        | 0.273       | 0.429        | 2.087                       | 1.939       | 1.689        |
| 5                            | 3/4                          | 1 3/4                            | 2 1/4        | 2.906                                      | 0.254                        | 0.345       | 0.469        | 2.469                       | 2.323       | 2.125        |
| 6                            | 3/4                          | 2 1/4                            | 2 1/2        | 3.535                                      | 0.270                        | 0.375       | 0.546        | 3.068                       | 2.900       | 2.626        |

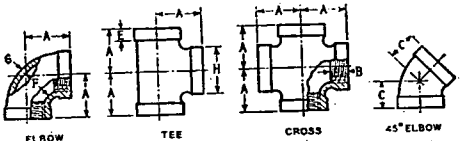
B. DIMENSIONS OF SOCKET WELDING 45-DEG ELBOWS, COUPLINGS, AND HALF COUPLINGS



| NOM-<br>INAL<br>PIPE<br>SIZE | DEPTH<br>OF<br>SOCKET,<br>MIN | CENTER TO<br>BOTTOM OF<br>SOCKET FOR<br>45-DEG ELBS |              | COU-<br>PLINGS<br>DISTANCE<br>BETWEEN<br>BOTTOMS<br>OF<br>SOCKETS | HALF<br>COU-<br>PLINGS,<br>BOTTOM<br>OF<br>SOCKET<br>TO<br>OPPOSITE<br>FACE | BORE<br>DIAM-<br>ETER OF<br>SOCKET,<br>MIN | SOCKET WALL<br>THICKNESS<br>MIN |             |              | BORE DIAMETER<br>OF FITTING |             |              |
|------------------------------|-------------------------------|-----------------------------------------------------|--------------|-------------------------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------|---------------------------------|-------------|--------------|-----------------------------|-------------|--------------|
|                              |                               | Sched<br>40 and<br>80                               | Sched<br>160 |                                                                   |                                                                             |                                            | Sched<br>40                     | Sched<br>80 | Sched<br>160 | Sched<br>40                 | Sched<br>80 | Sched<br>160 |
|                              |                               | A                                                   |              |                                                                   |                                                                             |                                            | E                               | F           | B            | C                           |             |              |
| 1/4                          | 3/4                           | 5/16                                                | .....        | 3/4                                                               | 3/8                                                                         | 0.420                                      | 0.125                           | 0.125       | .....        | 0.269                       | 0.215       | .....        |
| 1/2                          | 3/4                           | 5/16                                                | .....        | 3/4                                                               | 3/8                                                                         | 0.555                                      | 0.125                           | 0.149       | .....        | 0.364                       | 0.302       | .....        |
| 3/4                          | 3/4                           | 5/16                                                | .....        | 3/4                                                               | 1/4                                                                         | 0.690                                      | 0.125                           | 0.158       | .....        | 0.493                       | 0.423       | .....        |
| 1                            | 3/4                           | 5/16                                                | 1/2          | 3/4                                                               | 1/2                                                                         | 0.855                                      | 0.136                           | 0.184       | 0.234        | 0.622                       | 0.546       | 0.466        |
| 1 1/4                        | 3/4                           | 1/2                                                 | 5/8          | 3/4                                                               | 1 1/4                                                                       | 1.085                                      | 0.141                           | 0.193       | 0.273        | 0.824                       | 0.742       | 0.614        |
| 2                            | 1 1/2                         | 1 1/4                                               | 1 1/2        | 1 1/2                                                             | 1 1/2                                                                       | 1.330                                      | 0.166                           | 0.224       | 0.313        | 1.049                       | 0.957       | 0.815        |
| 1 1/2                        | 1 1/2                         | 1 1/4                                               | 1 1/2        | 1 1/2                                                             | 1 1/2                                                                       | 1.675                                      | 0.175                           | 0.239       | 0.313        | 1.350                       | 1.278       | 1.160        |
| 1 3/4                        | 1 1/2                         | 1 1/4                                               | 1            | 1 1/2                                                             | 1 1/2                                                                       | 1.915                                      | 0.181                           | 0.250       | 0.351        | 1.610                       | 1.500       | 1.338        |
| 2                            | 1 3/4                         | 1 1/2                                               | 1 1/2        | 1 3/4                                                             | 1 3/4                                                                       | 2.406                                      | 0.193                           | 0.273       | 0.429        | 2.067                       | 1.939       | 1.689        |
| 2 1/2                        | 1 3/4                         | 1 1/2                                               | 1 1/2        | 1 3/4                                                             | 1 3/4                                                                       | 2.906                                      | 0.254                           | 0.345       | 0.469        | 2.469                       | 2.323       | 2.125        |
| 3                            | 1 3/4                         | 1 1/2                                               | 1 1/2        | 1 3/4                                                             | 1 3/4                                                                       | 3.535                                      | 0.270                           | 0.375       | 0.546        | 3.068                       | 2.900       | 2.626        |

From American Standard for Steel Socket-Welding Fittings, ASA B16.11-1946.  
All dimensions are in inches.

TABLE 14. DIMENSIONS OF MALLEABLE 90-DEG ELBOWS, TEES, CROSSES, AND 45-DEG ELBOWS (STRAIGHT SIZES, 150 LB)



| NOMINAL PIPE SIZE | CENTER TO END, ELBOWS, TEES, AND CROSSES, A | CENTER TO END, 45-DEG ELBOWS, C | LENGTH OF THREAD, MIN, B | WIDTH OF BAND, MIN, E | INSIDE DIAMETER OF FITTING, F |       | METAL THICKNESS, G | OUTSIDE DIAMETER OF BAND, MIN, H |
|-------------------|---------------------------------------------|---------------------------------|--------------------------|-----------------------|-------------------------------|-------|--------------------|----------------------------------|
|                   |                                             |                                 |                          |                       | F                             |       |                    |                                  |
|                   |                                             |                                 |                          |                       | Min                           | Max   |                    |                                  |
| 1/8               | 0.69                                        | ...                             | 0.25                     | 0.200                 | 0.405                         | 0.435 | 0.090              | 0.693                            |
| 1/4               | 0.81                                        | 0.73                            | 0.32                     | 0.215                 | 0.540                         | 0.584 | 0.095              | 0.844                            |
| 3/8               | 0.95                                        | 0.80                            | 0.36                     | 0.230                 | 0.675                         | 0.719 | 0.100              | 1.015                            |
| 1/2               | 1.12                                        | 0.88                            | 0.43                     | 0.249                 | 0.840                         | 0.897 | 0.105              | 1.197                            |
| 3/4               | 1.31                                        | 0.98                            | 0.50                     | 0.273                 | 1.050                         | 1.107 | 0.120              | 1.458                            |
| 1                 | 1.50                                        | 1.12                            | 0.58                     | 0.302                 | 1.315                         | 1.385 | 0.134              | 1.771                            |
| 1 1/4             | 1.75                                        | 1.29                            | 0.67                     | 0.341                 | 1.660                         | 1.730 | 0.145              | 2.153                            |
| 1 1/2             | 1.94                                        | 1.43                            | 0.70                     | 0.368                 | 1.900                         | 1.970 | 0.155              | 2.427                            |
| 2                 | 2.25                                        | 1.68                            | 0.75                     | 0.422                 | 2.375                         | 2.445 | 0.173              | 2.963                            |
| 2 1/2             | 2.70                                        | 1.95                            | 0.92                     | 0.478                 | 2.875                         | 2.975 | 0.210              | 3.589                            |
| 3                 | 3.08                                        | 2.17                            | 0.98                     | 0.548                 | 3.500                         | 3.600 | 0.231              | 4.285                            |
| 3 1/2             | 3.42                                        | 2.39                            | 1.03                     | 0.604                 | 4.000                         | 4.100 | 0.248              | 4.843                            |
| 4                 | 3.79                                        | 2.61                            | 1.08                     | 0.661                 | 4.500                         | 4.600 | 0.265              | 5.401                            |
| 5                 | 4.50                                        | 3.05                            | 1.18                     | 0.780                 | 5.563                         | 5.663 | 0.300              | 6.583                            |
| 6                 | 5.13                                        | 3.46                            | 1.28                     | 0.900                 | 6.625                         | 6.725 | 0.335              | 7.767                            |

From American Standard for Malleable-Iron Screwed Fittings, 150 Lb. ASA B16.3-1951.  
All dimensions given in inches.

TABLE 15. DIMENSIONS OF BRASS OR BRONZE SCREWED 90-DEG ELBOWS, TEES, CROSSES, 45-DEG ELBOWS, AND COUPLINGS (STRAIGHT SIZES 125 LB)

COUPLINGS

90° ELBOW      TEE      CROSS      45° ELBOW      CAST      WROUGHT

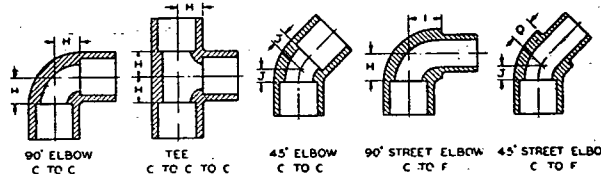
| NOMINAL<br>PIPE<br>SIZE | CENTER<br>TO END<br>ELBOWS,<br>TEES,<br>CROSSES | LENGTH<br>OF<br>THREAD,<br>MIN | CENTER<br>TO END<br>45-DEG<br>EL-<br>BOWS | DIAMETER<br>WROUGHT<br>COUPLING | BAND<br>LENGTH,<br>MIN | INSIDE<br>DIAMETER<br>OF CAST<br>FITTING |      | METAL<br>THICK-<br>NESS,<br>MIN | BAND<br>DIAMETER,<br>MIN | END TO END<br>STRAIGHT<br>COUPLING |         |  |  |
|-------------------------|-------------------------------------------------|--------------------------------|-------------------------------------------|---------------------------------|------------------------|------------------------------------------|------|---------------------------------|--------------------------|------------------------------------|---------|--|--|
|                         |                                                 |                                |                                           |                                 |                        | Min                                      | Max  |                                 |                          | Cast                               | Wrought |  |  |
|                         |                                                 |                                |                                           |                                 |                        |                                          |      |                                 |                          |                                    |         |  |  |
|                         |                                                 |                                |                                           |                                 |                        | F                                        |      |                                 |                          | W                                  |         |  |  |
| A                       | B                                               | C                              | D                                         | E                               |                        |                                          |      | G                               | H                        |                                    |         |  |  |
| 1/8                     | 0.54                                            | 0.25                           | 0.42                                      | 9/16                            | 0.14                   | 0.41                                     | 0.44 | 0.08                            | 0.67                     | 0.80                               | 0.83    |  |  |
| 1/4                     | 0.71                                            | 0.32                           | 0.56                                      | 1 1/16                          | 0.16                   | 0.54                                     | 0.58 | 0.08                            | 0.81                     | 0.97                               | 1.03    |  |  |
| 3/8                     | 0.82                                            | 0.36                           | 0.63                                      | 1 1/8                           | 0.17                   | 0.68                                     | 0.72 | 0.09                            | 1.00                     | 1.05                               | 1.11    |  |  |
| 1/2                     | 1.01                                            | 0.43                           | 0.78                                      | 1 3/8                           | 0.19                   | 0.84                                     | 0.90 | 0.09                            | 1.17                     | 1.29                               | 1.36    |  |  |
| 3/4                     | 1.18                                            | 0.50                           | 0.89                                      | 1 7/8                           | 0.23                   | 1.05                                     | 1.11 | 0.10                            | 1.42                     | 1.43                               | 1.50    |  |  |
| 1                       | 1.43                                            | 0.58                           | 1.06                                      | .....                           | 0.27                   | 1.32                                     | 1.39 | 0.11                            | 1.72                     | 1.68                               | .....   |  |  |
| 1 1/4                   | 1.69                                            | 0.67                           | 1.22                                      | .....                           | 0.31                   | 1.66                                     | 1.73 | 0.12                            | 2.10                     | 1.88                               | .....   |  |  |
| 1 1/2                   | 1.84                                            | 0.70                           | 1.30                                      | .....                           | 0.34                   | 1.90                                     | 1.97 | 0.13                            | 2.38                     | 1.92                               | .....   |  |  |
| 2                       | 2.12                                            | 0.75                           | 1.45                                      | .....                           | 0.41                   | 2.38                                     | 2.45 | 0.15                            | 2.92                     | 2.20                               | .....   |  |  |
| 2 1/2                   | 2.70                                            | 0.92                           | 1.95                                      | .....                           | 0.48                   | 2.88                                     | 2.98 | 0.17                            | 3.49                     | 2.83                               | .....   |  |  |
| 3                       | 3.08                                            | 0.98                           | 2.17                                      | .....                           | 0.55                   | 3.50                                     | 3.60 | 0.19                            | 4.20                     | 3.18                               | .....   |  |  |
| 4                       | 3.79                                            | 1.08                           | 2.61                                      | .....                           | 0.66                   | 4.50                                     | 4.60 | 0.22                            | 5.31                     | 3.69                               | .....   |  |  |

From American Standard for Brass or Bronze Screwed Fittings, 125 Lb. ASA B16.15-1947.  
All dimensions given in inches.

except that the outlet face is at an angle of 90 deg from the inlet face. An angle valve takes the place of a globe valve and an elbow.

3. *Checking flow:* Preventing back flow is called checking, hence, a *check valve* is used. The basic principle of all check valves is that a reversal of flow will close the valve. Check valves are either *swing check* or *lift check*. With a swing check the fluid presses on a hinged flap. If the flow stops or reverses, the flap swings down and seats itself to close the valve. A lift check operates similarly except that the flap is replaced by a plug that is lifted—through guides—by the force of the fluid flow. The fluid changes direction of flow, as in a globe valve, and transmits a vertical

TABLE 16. DIMENSIONS OF CAST BRASS SOLDER-JOINT ELBOWS, TEES AND 45-DEG ELBOWS (Straight Sizes)



| STANDARD WATER TUBE SIZE | LAYING LENGTH* TEE AND ELBOW, H | CENTER TO EXTERNAL SHOULDER 90-DEG STREET ELBOW, I | LAYING LENGTH 45-DEG ELBOW, J | CENTER TO EXTERNAL SHOULDER 45-DEG STREET ELBOW, Q |
|--------------------------|---------------------------------|----------------------------------------------------|-------------------------------|----------------------------------------------------|
| 1/8                      | 1/4                             | 3/8                                                | ...                           | ...                                                |
| 1/4                      | 3/8                             | 1/2                                                | 3/8                           | 3/8                                                |
| 3/8                      | 1/2                             | 5/8                                                | 1/2                           | 5/8                                                |
| 1/2                      | 3/4                             | 3/4                                                | 3/4                           | 3/4                                                |
| 1                        | 1                               | 1                                                  | 1                             | 1                                                  |
| 1 1/4                    | 1 1/4                           | 1 1/4                                              | 1 1/4                         | 1 1/4                                              |
| 1 1/2                    | 1 1/2                           | 1 1/2                                              | 1 1/2                         | 1 1/2                                              |
| 2                        | 1 3/4                           | 1 3/4                                              | 1 3/4                         | 1 3/4                                              |
| 2 1/2                    | 1 3/4                           | 1 3/4                                              | 1 3/4                         | 1 3/4                                              |
| 3                        | 1 3/4                           | 1 3/4                                              | 1 3/4                         | 1 3/4                                              |
| 3 1/2                    | 2                               | ...                                                | 3/8                           | ...                                                |
| 4                        | 2 1/4                           | 2 3/4                                              | 1 3/4                         | ...                                                |
| 5                        | 3 1/4                           | ...                                                | 1 3/4                         | ...                                                |
| 6                        | 3 3/4                           | ...                                                | 1 3/4                         | ...                                                |
| 8                        | 4 3/4                           | ...                                                | 2 1/4                         | ...                                                |

From American Standard for Cast-Brass Solder-Joint Fittings, ASA B16.18-1950.  
All dimensions given in inches.

\* Not standardized for wrought fittings. Consult manufacturer for dimensions.

thrust. If the flow stops, gravity pulls the plug downward and closes the valve. A reversal of flow will close the valve.

Two other types of valves are the relief valve and the pressure regulating valve. Relief valves are usually spring loaded in order that some predetermined pressure can force the valve to open and relieve the pressure. Pressure regulators are used to reduce a high incoming pressure to a required service pressure. These valves are designed to eliminate a fluctuation in the incoming pressure and thereby maintain a steady, lower service pressure (see Chapter 21).

Table 18 contains data on the dimensions of flanged and welding end valves. Dimensions of other type valves can be obtained by writing to the *Manufacturers Standardization Society of the Valve and Fitting Industry*.

## WELDING

Erection of piping in heating and ventilating installations by means of fusion welding has been commonly accepted in the past few years as an alternate method to the screwed and flanged joint. Since the question of economy of welding as against the use of screwed and flanged fittings is dependent on the individual job, the use of welding is generally recommended on the basis of: greatly reduced cost of maintenance and repair;

TABLE 17. DIMENSIONS OF CAST BRASS SOLDER-JOINT COUPLINGS  
(Straight, Reducing and Eccentric Sizes)

| STRAIGHT                 |                  | REDUCING                 |                  | ECCENTRIC                |                  |
|--------------------------|------------------|--------------------------|------------------|--------------------------|------------------|
| STANDARD WATER TUBE SIZE | LAYING LENGTH* M | STANDARD WATER TUBE SIZE | LAYING LENGTH* N | STANDARD WATER TUBE SIZE | LAYING LENGTH* W |
| 1/4                      | 1 1/2            | 3/4 x 1/2                | 3/4              | 3/4 x 1/2                | 3/4              |
| 3/8                      | 1 1/2            | 1 x 3/4                  | 3/4              | 1 x 3/4                  | 1 1/4            |
| 1/2                      | 1 1/2            | 1 1/4 x 1                | 3/4              | 1 1/4 x 1                | 3/4              |
| 3/4                      | 1 1/2            | 1 1/4 x 3/4              | 3/4              | 1 1/4 x 3/4              | 3/4              |
| 1                        | 1 1/2            | 1 1/2 x 1 1/4            | 3/4              | 1 1/2 x 1 1/4            | 1 1/4            |
| 1 1/4                    | 1 1/2            | 1 1/2 x 1                | 3/4              | 1 1/2 x 1                | 1 1/4            |
| 1 1/2                    | 1 1/2            | 1 1/2 x 3/4              | 3/4              | 2 x 1 1/4                | 1 1/4            |
| 2                        | 1 1/2            | 2 x 1 1/4                | 3/4              | 2 x 1 1/4                | 1 1/4            |
| 2 1/2                    | 1 1/2            | 2 x 1                    | 3/4              | 2 1/2 x 2                | 1 1/4            |
| 3                        | 1 1/2            | 2 x 3/4                  | 3/4              | 3 x 2 1/4                | 1 1/4            |
| 3 1/2                    | 1 1/2            | 2 x 3/4                  | 3/4              | 3 x 2                    | 1 1/4            |
| 4                        | 1 1/2            | 2 1/4 x 2                | 3/4              | 4 x 3                    | 2                |
| 4 1/2                    | 1 1/2            | 2 1/4 x 1 1/4            | 3/4              |                          |                  |
| 5                        | 1 1/2            | 2 1/4 x 1 1/4            | 3/4              |                          |                  |
| 6                        | 1 1/2            | 2 1/4 x 1 1/4            | 3/4              |                          |                  |
| 8                        | 1 1/2            | 2 1/2 x 1                | 3/4              |                          |                  |
| .....                    | .....            | 3 x 2 1/4                | 3/4              | .....                    | .....            |
| .....                    | .....            | 3 x 2                    | 3/4              | .....                    | .....            |
| .....                    | .....            | 4 x 3                    | 1 1/4            | .....                    | .....            |
| .....                    | .....            | 4 x 2 1/4                | 1 1/4            | .....                    | .....            |
| .....                    | .....            | 4 x 2                    | 1 1/4            | .....                    | .....            |
| .....                    | .....            | 6 x 4                    | 1 1/4            | .....                    | .....            |
| .....                    | .....            | 8 x 6                    | 1 1/4            | .....                    | .....            |

From American Standard for Cast-Brass Solder-Joint Fittings, ASA B16.18-1950.

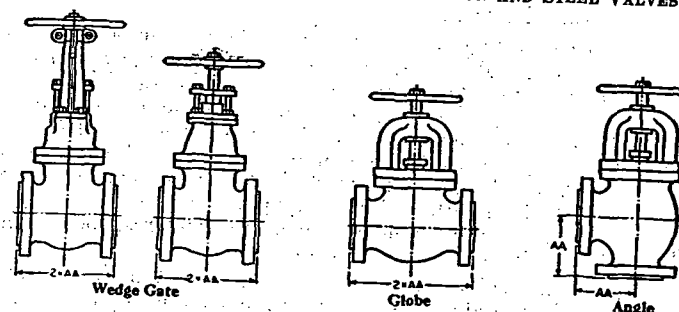
All dimensions given in inches.

\* Not standardized for wrought fittings. Consult manufacturer for dimensions.

reduced weight resulting from the use of a lighter-weight pipe; or increased economy in pipe insulation, hangers, and supports rather than any economy that might be effected in actual erection by welding on low to medium pressure heating jobs.

Fusion welding, commonly used in erection of piping, is defined as the process of joining metal parts in the molten, or molten and vapor states, without the application of mechanical pressure or blows. Fusion welding embraces gas welding and electric arc welding, both of which are commonly

TABLE 18. DIMENSIONS OF FLANGED CAST-IRON AND STEEL VALVES



| NOMINAL PIPE SIZE    | CONTACT SURFACE TO CONTACT SURFACE DIMENSIONS, (2 X AA) |                  |                  |                             |                  |                  |                  |                  |                  |                   |
|----------------------|---------------------------------------------------------|------------------|------------------|-----------------------------|------------------|------------------|------------------|------------------|------------------|-------------------|
|                      | CAST-IRON                                               |                  |                  |                             | STEEL            |                  |                  |                  |                  |                   |
|                      | 125                                                     | 175 <sup>1</sup> | 250 <sup>1</sup> | 800 <sup>1</sup> Hy-draulic | 150 <sup>1</sup> | 300 <sup>1</sup> | 400 <sup>1</sup> | 600 <sup>1</sup> | 900 <sup>1</sup> | 1500 <sup>1</sup> |
| WEDGE GATE VALVES    |                                                         |                  |                  |                             |                  |                  |                  |                  |                  |                   |
| 1                    | .....                                                   | .....            | .....            | .....                       | .....            | .....            | 8 1/4            | 8 1/4            | *10              | 10                |
| 1 1/4                | .....                                                   | .....            | .....            | .....                       | .....            | .....            | 9                | 9                | *11              | 11                |
| 1 1/2                | .....                                                   | .....            | .....            | .....                       | .....            | .....            | 9 1/4            | 9 1/4            | *12              | 12                |
| 2                    | 7                                                       | 7 1/4            | 8 1/4            | 11 1/4                      | 7                | 7 1/4            | 8 1/4            | 11 1/4           | *14 1/4          | 14 1/4            |
| 2 1/4                | 7 1/4                                                   | 8                | 9 1/4            | 13                          | 7 1/4            | 8 1/4            | 11 1/4           | 14 1/4           | *16 1/4          | 16 1/4            |
| 3                    | 8                                                       | 9 1/4            | 11 1/4           | 14                          | 8                | 8 1/4            | 11 1/4           | 14 1/4           | *18 1/4          | 18 1/4            |
| 3 1/4                | 8 1/4                                                   | 10               | 11 1/4           | .....                       | 8 1/4            | 11 1/4           | 14 1/4           | 18 1/4           | .....            | .....             |
| 4                    | 9                                                       | 10 1/4           | 12               | 17                          | 9                | 12               | 16               | 17               | 18               | 21 1/4            |
| 5                    | 10                                                      | 11 1/4           | 15               | .....                       | 10               | 15               | 18               | 20               | 22               | 26 1/4            |
| 6                    | 10 1/4                                                  | 12               | 15 1/4           | 22                          | 10 1/4           | 15 1/4           | 19 1/4           | 22               | 24               | 27 1/4            |
| 8                    | 11 1/4                                                  | 14 1/4           | 16 1/4           | 26                          | 11 1/4           | 16 1/4           | 23 1/4           | 26               | 29               | 32 1/4            |
| 10                   | 13                                                      | 16 1/4           | 18               | 31                          | 13               | 18               | 26 1/4           | 31               | 33               | 39                |
| 12                   | 14                                                      | 17 1/4           | 19 1/4           | 33                          | 14               | 19 1/4           | 30               | 33               | 36               | 44 1/4            |
| 14 OD                | 15                                                      | .....            | 22 1/4           | .....                       | 15               | 30               | 32 1/4           | 35               | 40 1/4           | .....             |
| 16 OD                | 16                                                      | .....            | 24               | .....                       | 16               | 33               | 35 1/4           | 39               | 44 1/4           | .....             |
| 18 OD                | 17                                                      | .....            | 26               | .....                       | 17               | 36               | 38 1/4           | 43               | 48               | .....             |
| 20 OD                | 18                                                      | .....            | 28               | .....                       | 18               | 39               | 41 1/4           | 47               | 52               | .....             |
| 24 OD                | 20                                                      | .....            | 31               | .....                       | 20               | 45               | 48 1/4           | 55               | 61               | .....             |
| GLOBE & ANGLE VALVES |                                                         |                  |                  |                             |                  |                  |                  |                  |                  |                   |
| 1/2                  | .....                                                   | .....            | .....            | .....                       | .....            | .....            | 7 1/4            | 7 1/4            | .....            | .....             |
| 3/4                  | .....                                                   | .....            | .....            | .....                       | .....            | .....            | 8 1/4            | 8 1/4            | 10               | 10                |
| 1                    | .....                                                   | .....            | .....            | .....                       | .....            | .....            | 9                | 9                | 11               | 11                |
| 1 1/4                | .....                                                   | .....            | .....            | .....                       | .....            | .....            | 9 1/4            | 9 1/4            | 12               | 12                |
| 2                    | 8                                                       | .....            | 10 1/4           | .....                       | 8                | 10 1/4           | 11 1/4           | 11 1/4           | 14 1/4           | 14 1/4            |
| 2 1/4                | 8 1/4                                                   | .....            | 11 1/4           | .....                       | 8 1/4            | 11 1/4           | 13               | 13               | 16 1/4           | 16 1/4            |
| 3                    | 9 1/4                                                   | .....            | 12 1/4           | .....                       | 9 1/4            | 12 1/4           | 14               | 14               | 15               | 18 1/4            |
| 3 1/4                | 10 1/4                                                  | .....            | 13 1/4           | .....                       | 10 1/4           | 13 1/4           | 14               | 14               | 15               | 18 1/4            |
| 4                    | 11 1/4                                                  | .....            | 14               | .....                       | 11 1/4           | 14               | 16               | 17               | 18               | 21 1/4            |
| 5                    | 13                                                      | .....            | 15 1/4           | .....                       | 14               | 15 1/4           | 18               | 20               | 22               | 26 1/4            |
| 6                    | 14                                                      | .....            | 17 1/4           | .....                       | 16               | 17 1/4           | 19 1/4           | 22               | 24               | 27 1/4            |
| 8                    | 19 1/4                                                  | .....            | 21               | .....                       | 19 1/4           | 22               | 23 1/4           | 26               | 29               | 32 1/4            |

From American Standard for Face-to-Face Dimensions of Ferrous Flanged and Welding End Valves, ASA B16.10-1939.

All dimensions given in inches.

Where dimensions are not given, the sizes either are not made or there is insufficient demand to warrant the expense of unification.

Female and groove joint facings have bottom of groove in same plane as flange edge, and center to contact surface dimensions for these facings are reduced by the amount of the raised face.

<sup>1</sup> These are pressure designations which refer to the primary service ratings in lb per sq. in. of the connecting end flanges.

<sup>2</sup> The connecting end flanges of 175 lb valves are the same as those on 250 lb valves.

<sup>3</sup> The contact surface to contact surface dimensions and connecting end flanges for 400 lb valves 3 in. size and smaller, are identical with those of 600 lb valves; and the contact surface to contact surface dimensions and connecting end flanges for 900 lb valves 2 1/4 in. size and smaller, are identical with those of 1500 lb valves.



used to produce acceptable welds. Welding processes and procedure are described in various publications.

Welding application requires the same basic knowledge of design as do the other types of assembly, but, in addition, requires a generous knowledge of welding principles and particularly the welding qualities of metal, its reaction to extremely high temperatures, and the ability to select and use only the best quality welding rods. This requirement applies equally to employer and employee, with the employer accepting all of the responsibility. Thus the employer should select his welding mechanics with good judgment, provide them with first-class equipment and tools, arrange for their training and use of acceptable workmanship standards, and at regular intervals subject their work to prescribed tests.

Rules for fusion welding of pipe joints, the qualification of welding operators, welding procedures, and testing are contained in the Standard Manual on Pipe Welding<sup>3</sup> and in publications of other groups.<sup>4, 5</sup> In general, the wall thickness and chemical analysis of the pipe are the governing factors, not the working pressure. There are a number of safety codes which govern the installation of welded piping in many cities and states.

A complete line of manufactured steel welding fittings is now available, and a dimensional standard has been prepared under the procedure of the American Standards Association, (see Table 10) to unify heretofore divergent dimensions for the same type welding fittings produced by different manufacturers. Standard dimensions for steel butt-welding elbows, tees, caps, and lapped-joint stub ends are given in Table 10. Dimensions for eccentric and concentric reducers are not shown in Table 10, but are included in the standard.

Steel butt-welding fittings have beveled ends. For wall thicknesses less than  $\frac{3}{16}$  in., the bevel may be either  $37\frac{1}{2}$  deg. or cut square. For wall thicknesses of  $\frac{3}{16}$  in. to and including  $\frac{1}{4}$  in. the bevel is  $37\frac{1}{2}$  deg. For walls larger than  $\frac{1}{4}$  in. but not greater than  $1\frac{1}{4}$  in., the bevel is U-shaped with a slope of 20 deg. above the  $\frac{3}{16}$  in. radius fillet. For walls greater than  $1\frac{1}{4}$  in., the welding ends are prepared as agreed between the manufacturer and the purchaser.

Flange fittings may be welded from sizes  $\frac{1}{2}$  to 24 in. inclusive (see Table 12).

Socket-welding fittings also are commercially available. These fittings have a machined recess for inserting the pipe which is attached by a fillet weld between the pipe wall and socket end. Use of socket-welding fittings generally is restricted to nominal pipe sizes 3 in. and smaller in which range commercial fittings are available. This type of fitting has gained rapid acceptance owing to its ease of installation, low cost, and ability to make a pressure tight joint without weakening the pipe, as is the case with threading. Dimensions for socket-welding fittings, in accordance with ASA Standard B16.11-1946, are given in Table 13.

### EXPANSION AND FLEXIBILITY

Changes in temperature cause a change in dimensions of any matter. The metals that are used for pipe have the same characteristics in that they expand with increasing temperature. If the metal is constrained so

### Pipe, Fittings, Welding

that it cannot expand, then an internal compressive stress is set up in the material.

This stress can be calculated, just as any other stress, by using Hooke's Law.

$$F = \frac{eEA}{L} \quad (1)$$

where

$F$  = Force of constraint, pounds.

$e$  = Deformation, inches.

$E$  = Modulus of elasticity, pounds per square inch.

$A$  = Area of metal, square inches.

$L$  = Length of metal, inches.

This equation is valuable in determining the internal stress of the pipe and also the constraining force on the anchors. This equation assumes that

TABLE 19. THERMAL STRESSES DUE TO TOTAL CONSTRAINT

| TEMPERATURE CHANGE, F DEG | THERMAL STRESSES, PSI |              |           |                 |        |          |
|---------------------------|-----------------------|--------------|-----------|-----------------|--------|----------|
|                           | Steel                 | Wrought Iron | Cast Iron | Brass or Bronze | Copper | Aluminum |
| 20                        | 3900                  | 3800         | 1428      |                 |        |          |
| 40                        | 7800                  | 7600         | 2856      | 2760            | 2960   | 2700     |
| 60                        | 11700                 | 11400        | 4284      | 5520            | 5960   | 5400     |
| 80                        | 15600                 | 15200        | 5712      | 8280            | 8940   | 8100     |
| 100                       | 19500                 | 19000        | 7140      | 11040           | 11920  | 10800    |
|                           |                       |              |           | 13800           | 14900  | 13500    |

\* For temperatures between 32 and 400° F.

the stress is less than the yield strength of the metal. In other words, the metal will return to its original dimension when the temperature returns to its original level.

Materials such as cast iron are not ductile, hence the yield strength is approximately equal to the ultimate strength. These materials have excellent compressive strength but poor tensile strength. For this reason, it is difficult to bend these materials appreciably. Cast iron, for example, could be put in tension and, from Table 19, it is seen that for a temperature change of 100 deg., a compressive stress of 7140 psi would be developed. If the pipe were straight, this stress would be handled easily. If, however, the stress caused a bending moment, then fracture might occur.

The values of stress found in Table 19 were determined by using Equation 1 and substituting Equation 2 for  $e$

$$e = \alpha L \Delta t \quad (2)$$

where

$\alpha$  = coefficient of linear expansion, inches per inch.

$\Delta t$  = temperature change, Fahrenheit degrees.

This gives Equation 3

$$F = \alpha EA \Delta t \quad (3)$$

Values for  $\alpha$  and  $E$  are given in Table 20 for various pipe materials, to

facilitate determination of the stress in an actual pipe. The following example illustrates the computation of stress.

**Example:** What is the force set up by a 1 in. schedule 40 steel pipe if the thermal expansion from a 100 deg temperature increase is fully constrained?

**Answer:** From Table 1, determine that for a 1" schedule 40 steel pipe, the metal area = 0.494 sq. ins. Then, from Table 20,  $aE = 195$  psi, and from Equation 3

$$F = 195 \times 0.494 \times 100 \\ = 9630 \text{ lbs.}$$

It is interesting to note that length does not enter into the determination of the constraining force. This is so because the stress is a *unit length* function and so is the expansion; therefore, they cancel each other. In other words, if a weight stretches a 10-foot wire 0.10 in., then that same weight would stretch a 100 foot wire one inch. In both cases the elongation was 1 part in 1200. The realization that thermal stress is independent of length is important, but often overlooked. Nonetheless,

TABLE 20. PHYSICAL PROPERTIES FOR DETERMINING THERMAL STRESS  
(Temperatures between 32 and 400 F)

|                                                             | STEEL | WROUGHT IRON | CAST IRON | BRASS OR BRONZE | COPPER | ALUMINUM |
|-------------------------------------------------------------|-------|--------------|-----------|-----------------|--------|----------|
| Coefficient of Linear Expansion, $\alpha \times 10^6$ ..... | 6.5   | 6.8          | 5.95      | 9.85            | 9.3    | 13.5     |
| Modulus of Elasticity, $E$ ,<br>psi $\times 10^{-4}$ .....  | 30    | 28           | 12        | 14              | 16     | 10       |
| Product of $aE$ , psi.....                                  | 195   | 190          | 71.4      | 138             | 149    | 135      |

**Example:** The coefficient of expansion for steel = 0.000065 in./in. and the modulus of elasticity = 30,000,000 psi. Therefore  $aE = 195$  psi.

that concept explains the feasibility of utilizing the inherent flexibility of the pipe to take care of expansion.

Regardless of the length of pipe between anchors, it is possible to take care of the expansion by putting the force of expansion into the pipe as internal stress.

If the pipe is not straight, then the force of expansion will cause a bending moment. The pipe will then be under a combined stress. The stresses will be longitudinal and transverse, and to a small extent radial. All of these stresses tend to fracture the pipe, and therefore must be added to make up what is called *allowable combined stress*. The *Code for Pressure Piping*, ASA B31.1, published by the ASME, sets up very definite limits for the allowable combined stresses for various pipe materials. For temperatures below 400 F and for piping that is for neither district heating nor power, any standard pipe material may be used. For high temperature or high pressure work, some text on expansion and flexibility should be consulted. It is beyond the scope of this chapter to develop the theory of expansion caused by high temperatures.

For the simpler problems encountered for temperatures 400 F and less, which the heating engineer is more apt to encounter, there are four methods of allowing for expansion.

The first method is to use *packless* expansion joints. These joints in-

clude types of bellows expansion joints, rubber, corrugated copper and other metals.

Rubber type joints are generally used in vacuum or low pressure steam lines. Maximum temperature is generally 180 F. If oil is present in the line, rubber type joints will be attacked. Travel of these joints is up to 1 inch. The travel to be expected can be calculated by using Equation 2.

The second type of expansion joint is called a *slip* joint. This joint allows for expansion by a sliding of a female member over a male member. The joint is kept tight by means of packing. The packing determines the limit of the temperature to which the joint may be subjected. The main disadvantage to this joint is that it must be continually inspected for a deterioration of the packing. By using double slip joints, the travel may go to several feet, but generally a single joint allows about a foot of expansion. It is common practice to use slip joints up to 250 psi.

The most common method of allowing for expansion in heating systems is to use the swivel joint. This is the third method. The swivel joint was first used with screwed fittings, but it is also used now with welded fittings. With welded elbows, the swivel introduces torsional stress in the elbow and in the swing piece. This type of joint is adequate for taking up the

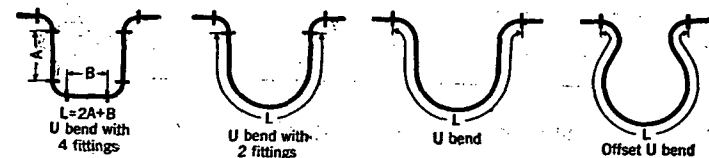


FIG. 3. MEASUREMENT OF  $L$  ON VARIOUS PIPE BENDS

expansion in a header, and preventing fracture of the riser or heating element.

The fourth method is to allow the flexibility of the pipe to absorb the stress of expansion. A technique used to reduce the stress in the expanded pipe is to *cold spring* it before hooking it up. Cold springing can be used to absorb about one-half the stress. The technique is to install the pipe with an opposite stress. For example, if the pipe were to have a compression of 2000 psi, then the pipe would be installed with 1000 psi of tension. For refrigeration, the pipe would be cold sprung in compression.

For conditions not requiring rigorous analysis, it is permissible to use expansion bends designed by means of Equation 4

$$L = 6.16 \sqrt{D\Delta} \quad (4)$$

where

$L$  = length of pipe, feet.

$D$  = O. D. of pipe, inches.

$\Delta$  = deformation, inches (see Equation 2) fiber stress  $\leq 16,000$  pounds per square inch.

Equation 4 can be used for bends with two fittings, regular U-bend, and offset U-bend, as shown in Fig. 3. It gives the length of pipe,  $L$ , that

must be used in the U-bend to take up the deformation,  $\Delta$ . When welding fittings are used, the radii should be six times the outside diameter of the pipe. One other restriction is that the pipe should not be heavier than extra strong.

Manufacturers of pipe, or pipe fittings, often publish excellent treatises on the simplification of expansion problems. It is suggested that the engineer obtain such publications and also a text or handbook<sup>4</sup> on the subject before attempting to solve a problem on flexibility.

### HANGERS AND SUPPORTS

In the preceding section, Equation 3 was developed to give the force of total constraint. This equation is appropriate regardless of the sign of  $\Delta t$ , positive or negative. It did not, however, allow for any bending moment but was for straight compression or tension.

TABLE 21. EQUATIONS FOR BENDING STRESS AND DEFLECTION BETWEEN SUPPORTS

| TYPE OF SUPPORT              | BENDING STRESS, PSI<br>$S$  | DEFLECTION, INCHES<br>$Y$  |
|------------------------------|-----------------------------|----------------------------|
| Single span (free ends)..... | $S = \frac{0.75 WL^2 D}{I}$ | $Y = \frac{22.5 WL^4}{EI}$ |
| Continuous Line.....         | $S = \frac{0.5 WL^2 D}{I}$  | $Y = \frac{4.5 WL^4}{EI}$  |

where

$W$  = Total weight (pipe, fluid, etc) pounds per foot.

$D$  = O. D. of pipe, inches.

$L$  = Length of span, feet.

$E$  = Modulus of elasticity, pounds per square inch.

$I$  = Moment of inertia, (inches)<sup>4</sup>.

$I = \frac{\pi}{64} (OD^4 - ID^4)$ , O. D. and I. D. in inches.

If the compressive force is great enough, or if the line is long enough, a slight eccentricity of the load application will cause a buckling of the line. This buckling is identical with the action of a column under excessive compression. In fact, a pipe line in compression is identical to a column. Column criteria can therefore be used for selecting the action of supports to resist lateral thrust.

A common equation for determining safe column loads is Euler's formula:

$$S = \pi^2 E \left( \frac{k}{l} \right)^2 \quad (\text{for cast iron see Equation 6}) \quad (5)$$

where

$S$  = allowable column load, pounds per square inch.

$k$  = radius of gyration, inches.

$l$  = column length, inches.

$$k^2 = \frac{I}{A} = \frac{OD^4 + ID^4}{16}$$

This equation is not used for column construction but is sufficiently accurate for the work of a heating engineer.

The equation is modified for cast iron because of its poor tensile strength. It is generally acceptable to use one-half the value of  $S$  from Equation 5 for cast iron, so it becomes

$$S^i = \frac{\pi^2 E}{2} \left( \frac{k}{l} \right)^2 \quad \text{for cast iron.} \quad (6)$$

It is permissible to allow the  $l/k$  ratio for steel to go as high as 120, but for cast iron the desirable maximum is taken as 70. It is not to be understood that a fracture will occur at  $l/k$  ratios in excess of those given, rather it is to be understood that lateral support should be given for those ratios and for those magnitudes of stress. If an expansion joint is used, this will, of course, relieve the compressive stress.

*Example:* For the problem given in the above section, the constraining force for a 1 in. pipe was 9630 lb. What is a required spacing for lateral support for this pipe?

*Answer:* Using Euler's formula, Equation 5 gives

$$S = \pi^2 E \left( \frac{k}{l} \right)^2$$

so

$$l = \pi k \sqrt{E/S}$$

For a 1 in. Schedule 40 steel pipe

$k = 0.4205$  inches.

$E = 30,000,000$  pounds per square inch.

$S = 9630 \div 0.494 = 19500$  psi

$l = 51.8$  inches.

Therefore, lateral supports on six foot centers would be adequate.

The other type of load requiring some support is the bending stress due to the weight of the pipe, its insulation, and of the fluid being carried. There is also the bending moment that may be caused by the flexure of the pipe. For this chapter however, the flexure loading will not be treated for the reason of complexity, as previously stated for the problem of expansion.

Since hangers should always be designed to take the bending moment (including buckling) from the pipe, it is necessary to design the hangers or supports for the maximum bending stress. Even with perfect support spacing there will be some sagging; therefore, the supports should be on a gradient if it is necessary to prevent pockets. Such a condition arises for condensate piping.

Typical bending and deflection equations are given in Table 21 in order that supports can be properly sized, and if necessary, pitched. These equations are typical beam equations. If more complex loadings exist, proper beam equations can be applied. Such equations are found in standard texts on mechanics of materials.

By application of the equations given in this section and the section of expansion and flexibility, it is possible to determine the proper location and type of support for straight lines. The types are anchors and hangers.

Anchors are used to guide the expansion (sliding anchors) or to fix the pipe. They are needed to take the stress out of the line and translate the stresses to the foundations. In that way all stress can be taken out of

TABLE 22. APPLICATION OF PIPE, TUBE AND FITTINGS FOR HEATING AND AIR CONDITIONING

| APPLICATION                                                                                                                                                                                              | BETTER CLASS                                                                                                                         | FOR ECONOMY                                                                                                       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| Chilled Water <sup>a</sup><br>Small Installations<br>Large Installations<br>4-in. and smaller<br>5-in. and larger                                                                                        | Type K or L hard copper<br>Type K or L hard copper<br>Black steel, Sch. 40                                                           | Black steel, Sch. 40<br>Black steel, Sch. 40<br>Black steel, Sch. 40                                              |
| Cooling Tower <sup>a</sup><br>Small Installations<br>Large Installations                                                                                                                                 | Type K, hard copper<br>Wrought iron or black steel, Sch. 40                                                                          | Type L, hard copper.<br>Black steel, Sch. 40<br>Type L, hard copper.<br>Black steel, Sch. 40                      |
| Underground Water <sup>a</sup><br>Small Installations<br>2-in. and smaller<br>Large Installations<br>3½-in. and smaller<br>4-in. and larger                                                              | Type K, soft copper<br>Type K, soft copper or<br>Cast iron, Class 150<br>Cast iron, Class 150                                        | Type K, soft copper.<br>Black steel, Sch. 40<br>Galvanized steel, Sch. 40<br>Galvanized steel, Sch. 40            |
| City Water Inside Building <sup>a</sup><br>Small Installations<br>Large Installations                                                                                                                    | Type L, hard copper<br>Type K or L, hard copper                                                                                      | Galvanized steel, Sch. 40<br>Galvanized steel, Sch. 40<br>or Type L, hard copper                                  |
| Underground Rain Water Conductors<br>Small Installations<br>Under paved areas<br>Large Installations<br>8-in. and smaller<br>10- to 24-in.<br>30-in. and larger<br>5 feet outside bldg. and under paving | Vitrified clay or cast iron soil<br>Cast iron soil<br>Cast iron soil XH<br>Vitrified clay<br>Concrete<br>Cast iron soil XH           | Vitrified clay or cast iron soil<br>Cast iron soil<br>Vitrified clay<br>Concrete<br>Concrete<br>Cast iron soil XH |
| Interior Rain Water Conductors<br>Small Installations<br>Large Installations                                                                                                                             | Black wrought iron, Sch. 40<br>Cast iron soil XH                                                                                     | Black steel, Sch. 40 or<br>Galvanized steel, Sch. 40<br>Cast iron soil XH or Galvanized steel, Sch. 40            |
| Panel Heating <sup>a</sup><br>Small Installations<br>Large Installations<br>2-in. and smaller<br>2½-in. and larger                                                                                       | Type K or L soft copper.<br>Mild black steel. Wrought iron<br>Type K soft copper. Mild black steel. Wrought iron<br>Mild black steel | Type L soft copper. Mild black steel<br>Type L soft copper. Mild black steel<br>Mild black steel                  |
| Hot Water Heating <sup>a</sup><br>Small Installations<br>Large Installations<br>1½-in. and smaller<br>2-in. and larger                                                                                   | Type K, hard copper. Black steel, Sch. 40<br>Type K hard copper. Black steel, Sch. 40<br>Black steel, Sch. 40                        | Black steel, Sch. 40<br>Black steel, Sch. 40<br>Black steel, Sch. 40                                              |

TABLE 22. APPLICATION OF PIPE, TUBE AND FITTINGS FOR HEATING AND AIR CONDITIONING (Concluded)

| APPLICATION                                                                                                                                                                                                                             | BETTER CLASS                                                                                                       | FOR ECONOMY                                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| Refrigerant <sup>b</sup><br>3½-in. and smaller<br>4-in. and larger                                                                                                                                                                      | Type K or L hard copper<br>Black steel, weld                                                                       | Type L hard copper<br>Black steel, weld                                                                                        |
| Steam Heating<br>Small Installations<br>90 psi and less<br>Large Installations<br>100 psi and over<br>Return Pipe<br>All sizes                                                                                                          | Black steel, Sch. 40<br>Black steel, Sch. 80. XH fittings<br>Black wrought iron. Standard fittings                 | Black steel, Sch. 40.<br>Standard fittings.<br>Black steel, Sch. 40. XH fittings<br>Black steel, Sch. 40.<br>Standard fittings |
| Receiver Vent<br>All Sizes                                                                                                                                                                                                              | Galvanized wrought iron.<br>Standard fittings                                                                      | Black steel, Sch. 40.<br>Standard fittings                                                                                     |
| Sanitary <sup>a</sup><br>Small Installations<br>Waste:<br>1½-in. and smaller<br>2-in. and larger<br>Vents:<br>2½-in. and smaller<br>3-in. and larger<br>Large Installations<br>Waste:<br>2-in. and larger<br>Vents:<br>2-in. and larger | Galvanized wrought iron<br>Cast iron XH<br>Galvanized wrought iron<br>Cast iron XH<br>Cast iron XH<br>Cast iron XH | Galvanized steel, Sch. 40.<br>Cast iron SW<br>Galvanized steel, Sch. 40<br>Cast iron SW<br>Cast iron SW<br>Cast iron SW        |
| Gas Fired<br>All Sizes                                                                                                                                                                                                                  | Black steel, Sch. 40. Malleable iron fittings                                                                      | Black steel, Sch. 40. Malleable iron fittings                                                                                  |

<sup>a</sup> Fittings for copper water pipe may be either wrought copper or cast brass.

<sup>b</sup> Refrigerant fittings on copper pipe must be wrought copper. All welded fittings should be long turn.

<sup>c</sup> Panel heating copper fittings should be soldered with 95-5 solder. Steel fittings should be welded. Installation tested to 300 psi hydrostatic for two (2) hours.

<sup>d</sup> All underground feed and return lines buried in slab, should be equipped with fittings as outlined for panel heating.

<sup>e</sup> House sewer to main should be cast iron XH.

the line before it can be transferred to such equipment as boilers or pumps. By means of solid anchors, the anchors can be used to divide the piping into isolated sections that cannot transmit the stresses to other sections. Hangers are used to support the piping and to take out the bending stresses. They are of the spring, roller, or rod type. Such types generally allow the free movement of the pipe and yet maintain full support.

The *Code for Pressure Piping*, ASA B31.1, has strict requirements for the materials used in hangers and supports. The structural properties have a safety factor of five, and consequently there is little chance of failure due to a sudden change of load.

There is a type of support for almost every conceivable requirement. Complete information can best be obtained from a hanger manufacturer.

#### APPLICATION OF PIPE, TUBE AND FITTINGS

In the application of pipe, tube and fittings it is necessary to comply with regulations contained in local codes and ordinances. Table 22 is

offered as a guide to current practice in heating and air conditioning. It is based on practice in a number of consulting engineers' offices and information extracted from Reference 7. It should be borne in mind that selection of material to be used will also be influenced by the familiarity of local artisans with methods of using different materials.

### REFERENCES

- <sup>1</sup> American Standard Code for Pressure Piping, ASA B-31.1—1942, American Standards Association.
- <sup>2</sup> See API Specification 5L for Line Pipe, American Petroleum Institute.
- <sup>3</sup> Standard Manual on Pipe Welding (Heating, Piping and Air Conditioning Contractors National Association, Second Edition, 1951). Welding Handbook (American Welding Society, 1942).
- <sup>4</sup> ASME Power Boiler Code, American Society of Mechanical Engineers.
- <sup>5</sup> Marine Engineering Regulations of the Coast Guard, American Bureau of Shipping.
- General Specifications for Inspection of Material, Appendix VII, Welding, U. S. Navy. Specifications for Welding, Appendix 5, Part 1—General—for Vessels of the U. S. Navy, Bureau of Ships, April, 1940.
- <sup>6</sup> See (1) Piping Handbook, by Sabin Crocker (McGraw-Hill Co.); (2) A Manual for The Design of Piping for Flexibility by the Use of Graphs, by E. A. Wert, S. Smith, E. T. Cope (The Detroit Edison Company).
- <sup>7</sup> Control Valves and Positioners, by C. S. Beard (Industry and Power, Vol. 64 March, 1953, p. 67-101).

### CHAPTER 28

## PIPE AND INDUSTRIAL INSULATION

Heat Losses from Bare and Insulated Surfaces and Pipes, Thermal Conductivities of Various Insulations, Low Temperature Pipe Insulation, Insulation of Pipes to Prevent Freezing, Economical Thickness of Pipe Insulation, Underground Pipe Insulation

**H** EAT LOSSES from or to uninsulated surfaces of pipes, ducts, vessels, or furnaces may be of considerable magnitude if the temperature of the surrounding medium differs appreciably from that of the surface. Losses are increased by motion of the surrounding air or by contact of the hot or cold surface with bodies of high thermal conductivity. Good design, therefore, must include careful consideration of such heat losses and provision for adequate insulation wherever indicated.

### HEAT LOSSES FROM BARE SURFACES

The basic principles of heat loss from surfaces are discussed in Chapter 5. In that chapter radiation and convection are treated separately. Table 1, Section A, of Chapter 9 gives the surface conductance of flat surfaces of different emissivities and orientations in contact with still air, the values given including the effects of both radiation and convection.

### HEAT LOSSES FROM BARE PIPES

Heat losses from horizontal bare steel pipes, based on tests at Mellon Institute and calculated from the fundamental radiation and convection equations (Chapter 5), are given in Table 1. Heat losses from horizontal copper tubes and pipes with tarnished surfaces, are given in Table 2.<sup>1</sup>

Heat losses from bare pipe of materials having lower emissivities may be calculated from data appearing in Chapter 5.

The area in square feet per linear foot of pipe is given in Table 3 for various standard pipe sizes, and Table 4 for copper tubing, while Table 5 gives the area in square feet of flanges and fittings for various standard pipe sizes. These tables can be used to advantage in estimating the amount of insulation required.

Very often, when pipes are insulated, flanges and fittings are left bare, so as to allow for easy access to the fittings in case of repairs. The fact that a pair of 8-in. standard flanges having an area of 2.41 sq ft would lose, at 100 lb steam pressure, an amount of heat equivalent to more than a ton of coal per year, shows the necessity for insulating such surfaces.

Examples 1 and 2 show how the annual heat loss from uncovered pipe and its dollar value may be computed from the data in Table 1.

**Example 1:** Compute the total annual heat loss from 165 ft of 2 in. bare pipe in service 4000 hr per year. The pipe is carrying steam at 10 lb pressure and is exposed to an average air temperature of 70 F.

**Solution:** The pipe temperature is taken as the steam temperature, which is 239.4 F, obtained by interpolation from Steam Tables. The temperature difference between the pipe and air = 239.4 - 70 = 169.4 F. By interpolation of Table 1 between temperature differences of 157.1 and 227.7 F, the heat loss from a 2-in. pipe at a

TABLE 1. HEAT LOSSES FROM HORIZONTAL BARE STEEL PIPES  
Expressed in Btu per (hour) (linear foot) (Fahrenheit degree difference between the pipe and surrounding still air at 70 F)

| NOMINAL PIPE SIZE<br>(INCHES) | HOT WATER                    |       |       |       | STEAM               |                      |                       |
|-------------------------------|------------------------------|-------|-------|-------|---------------------|----------------------|-----------------------|
|                               | 120 F                        | 150 F | 180 F | 210 F | 227.1 F<br>(5 psig) | 299.7 F<br>(50 psig) | 337.9 F<br>(100 psig) |
|                               | TEMPERATURE DIFFERENCE—F DEG |       |       |       |                     |                      |                       |
|                               | 50                           | 80    | 110   | 140   | 157.1               | 227.7                | 267.9                 |
| 1/4                           | 0.455                        | 0.495 | 0.546 | 0.584 | 0.612               | 0.706                | 0.760                 |
| 3/4                           | 0.555                        | 0.605 | 0.666 | 0.715 | 0.748               | 0.868                | 0.933                 |
| 1                             | 0.684                        | 0.743 | 0.819 | 0.877 | 0.919               | 1.065                | 1.147                 |
| 1 1/4                         | 0.847                        | 0.919 | 1.014 | 1.085 | 1.138               | 1.324                | 1.425                 |
| 1 1/2                         | 0.958                        | 1.041 | 1.148 | 1.230 | 1.288               | 1.492                | 1.633                 |
| 2                             | 1.180                        | 1.281 | 1.412 | 1.512 | 1.578               | 1.840                | 1.997                 |
| 2 1/2                         | 1.400                        | 1.532 | 1.683 | 1.795 | 1.883               | 2.190                | 2.363                 |
| 3                             | 1.680                        | 1.825 | 2.010 | 2.153 | 2.260               | 2.630                | 2.840                 |
| 3 1/2                         | 1.900                        | 2.064 | 2.221 | 2.433 | 2.552               | 2.974                | 3.215                 |
| 4                             | 2.118                        | 2.302 | 2.534 | 2.717 | 2.850               | 3.320                | 3.590                 |
| 5                             | 2.580                        | 2.804 | 3.084 | 3.303 | 3.470               | 4.050                | 4.385                 |
| 6                             | 3.036                        | 3.294 | 3.626 | 3.886 | 4.074               | 4.765                | 5.160                 |
| 8                             | 3.880                        | 4.215 | 4.638 | 4.960 | 5.210               | 6.100                | 6.610                 |
| 10                            | 4.760                        | 5.180 | 5.680 | 6.090 | 6.410               | 7.490                | 8.115                 |
| 12                            | 5.590                        | 6.070 | 6.670 | 7.145 | 7.500               | 8.800                | 9.530                 |

TABLE 2. HEAT LOSS FROM HORIZONTAL TARNISHED COPPER PIPE<sup>1</sup>  
Expressed in Btu per (hour) (linear foot) (Fahrenheit degree difference between the pipe and surrounding still air at 70 F)

| NOMINAL PIPE SIZE<br>(INCHES) | HOT WATER (Type K Copper Tube) |       |       |       | STEAM (Standard Pipe Size Pipe) |                      |                       |
|-------------------------------|--------------------------------|-------|-------|-------|---------------------------------|----------------------|-----------------------|
|                               | 120 F                          | 150 F | 180 F | 210 F | 227.1 F<br>(5 psig)             | 297.7 F<br>(50 psig) | 337.9 F<br>(100 psig) |
|                               | TEMPERATURE DIFFERENCE—F DEG   |       |       |       |                                 |                      |                       |
|                               | 50                             | 80    | 110   | 140   | 157.1                           | 227.7                | 267.9                 |
| 1/4                           | 0.280                          | 0.287 | 0.300 | 0.321 | 0.433                           | 0.500                | 0.530                 |
| 3/4                           | 0.340                          | 0.381 | 0.409 | 0.429 | 0.533                           | 0.543                | 0.654                 |
| 1                             | 0.440                          | 0.475 | 0.509 | 0.536 | 0.636                           | 0.746                | 0.803                 |
| 1 1/4                         | 0.500                          | 0.559 | 0.618 | 0.622 | 0.764                           | 0.878                | 0.934                 |
| 1 1/2                         | 0.580                          | 0.658 | 0.710 | 0.750 | 0.904                           | 1.053                | 1.120                 |
| 2                             | 0.730                          | 0.825 | 0.890 | 0.957 | 1.101                           | 1.273                | 1.364                 |
| 2 1/2                         | 0.880                          | 1.000 | 1.091 | 1.143 | 1.305                           | 1.490                | 1.605                 |
| 3                             | 1.040                          | 1.175 | 1.272 | 1.343 | 1.560                           | 1.800                | 1.940                 |
| 3 1/2                         | 1.180                          | 1.350 | 1.454 | 1.535 | 1.750                           | 2.020                | 2.170                 |
| 4                             | 1.460                          | 1.500 | 1.635 | 1.715 | 1.941                           | 2.240                | 2.430                 |
| 4 1/2                         |                                |       |       |       | 2.131                           | 2.465                | 2.650                 |
| 5                             | 1.600                          | 1.812 | 1.980 | 2.071 | 2.387                           | 2.770                | 2.990                 |
| 6                             | 1.840                          | 2.125 | 2.270 | 2.430 | 2.740                           | 3.210                | 3.440                 |
| 8                             | 2.400                          | 2.685 | 2.910 | 3.110 | 3.310                           | 4.050                | 4.370                 |

TABLE 3. EXTERNAL SURFACE PER LINEAR FOOT OF PIPE

| NOMINAL PIPE SIZE<br>(INCHES) | SURFACE AREA<br>(Sq Ft) | NOMINAL PIPE SIZE<br>(INCHES) | SURFACE AREA<br>(Sq Ft) | NOMINAL PIPE SIZE<br>(INCHES) | SURFACE AREA<br>(Sq Ft) |
|-------------------------------|-------------------------|-------------------------------|-------------------------|-------------------------------|-------------------------|
| 1/4                           | 0.22                    | 2                             | 0.622                   | 5                             | 1.456                   |
| 3/4                           | 0.275                   | 2 1/2                         | 0.753                   | 6                             | 1.734                   |
| 1                             | 0.344                   | 3                             | 0.917                   | 8                             | 2.257                   |
| 1 1/4                         | 0.435                   | 3 1/2                         | 1.047                   | 10                            | 2.817                   |
| 1 1/2                         | 0.498                   | 4                             | 1.178                   | 12                            | 3.338                   |

TABLE 4. EXTERNAL SURFACE PER LINEAR FOOT OF COPPER TUBING  
Outside diameter 1/8 in. greater than nominal size

| TUBE SIZE<br>(INCHES) | SURFACE AREA<br>(Sq Ft) | TUBE SIZE<br>(INCHES) | SURFACE AREA<br>(Sq Ft) | TUBE SIZE<br>(INCHES) | SURFACE AREA<br>(Sq Ft) |
|-----------------------|-------------------------|-----------------------|-------------------------|-----------------------|-------------------------|
| 1/4                   | 0.164                   | 2                     | 0.556                   | 5                     | 1.342                   |
| 3/4                   | 0.229                   | 2 1/2                 | 0.687                   | 6                     | 1.604                   |
| 1                     | 0.295                   | 3                     | 0.818                   | 8                     | 2.128                   |
| 1 1/4                 | 0.360                   | 3 1/2                 | 0.949                   |                       |                         |
| 1 1/2                 | 0.426                   | 4                     | 1.080                   |                       |                         |

perature difference of 169.4 F is found to be 1.624 Btu per (hr) (linear ft) (F deg). The total annual heat loss from the entire line =  $1.624 \times 169.4 \times 165$  (linear ft)  $\times 4000$  (hr) = 181,600 Mb. (Mb = 1000 Btu.)

**Example 2:** Coal costing \$11.50 per ton and having a calorific value of 13,000 Btu per pound is being burned in the furnace supplying steam to the pipe line given in the previous example. If the system is operating at an overall efficiency of 55 percent, determine the monetary value of the annual heat loss from the line.

**Solution:** The cost of heat per 1000 Mb supplied to the system =  $1,000,000 \times 11.5$  (dollars)  $\div [13,000$  (Btu)  $\times 2000$  (lb)  $\times 0.55$  (efficiency)] = \$0.804. The total cost of heat lost per year =  $0.804 \times 181.6$  (thousand Mb) = \$146.00.

## INDUSTRIAL AND PIPE INSULATIONS

Insulating materials are made of various substances and are supplied in a number of different forms. Preformed insulations are made in the form of blocks for flat surfaces, segmental pieces for small cylindrical vessels and large pipes, and sectional insulation for smaller pipes. Preformed pipe insulation is regularly supplied in sectional form up to about 12-inch pipe size. Certain types up to 20-inch pipe size are available in sectional form. Sections are either split in half longitudinally or cut through on one side and scored on the inner surface of the other to facilitate application to the pipe. Blanket insulations are used to insulate flat or curved surfaces or large pipes. Pipe fittings and bends are commonly insulated with portions of standard preformed insulations, or, when irregular in contour, with blankets or plastic insulating cements.

Insulation is secured to pipes, flat surfaces, and large vessels in a variety of ways depending on the contour of the surface and the form of the in-

TABLE 5. AREA OF FLANGED FITTINGS, SQUARE FEET<sup>a</sup>

| NOMINAL PIPE SIZE<br>(INCHES) | FLANGED COUPLING |             | 90 DEG ELL |             | LONG RADIUS ELL |             | TEE      |             | CROSS    |             |
|-------------------------------|------------------|-------------|------------|-------------|-----------------|-------------|----------|-------------|----------|-------------|
|                               | Standard         | Extra Heavy | Standard   | Extra Heavy | Standard        | Extra Heavy | Standard | Extra Heavy | Standard | Extra Heavy |
| 1                             | 0.320            | 0.438       | 0.795      | 1.015       | 0.892           | 1.083       | 1.235    | 1.575       | 1.622    | 2.07        |
| 1 1/4                         | 0.383            | 0.510       | 0.957      | 1.098       | 1.084           | 1.340       | 1.481    | 1.925       | 1.943    | 2.53        |
| 1 1/2                         | 0.477            | 0.727       | 1.174      | 1.332       | 1.337           | 1.874       | 1.815    | 2.68        | 2.38     | 3.54        |
| 2                             | 0.672            | 0.848       | 1.65       | 2.01        | 1.84            | 2.16        | 2.54     | 3.09        | 3.32     | 4.06        |
| 2 1/2                         | 0.841            | 1.107       | 2.09       | 2.57        | 2.32            | 2.76        | 3.21     | 4.05        | 4.19     | 5.17        |
| 3                             | 0.945            | 1.484       | 2.38       | 3.49        | 2.68            | 3.74        | 3.66     | 5.33        | 4.77     | 6.95        |
| 3 1/2                         | 1.122            | 1.644       | 2.98       | 3.96        | 3.28            | 4.28        | 4.48     | 6.04        | 5.83     | 7.89        |
| 4                             | 1.344            | 1.914       | 3.53       | 4.64        | 3.96            | 4.99        | 5.41     | 7.07        | 7.03     | 9.24        |
| 4 1/2                         | 1.474            | 2.04        | 3.95       | 5.02        | 4.43            | 5.46        | 6.07     | 7.72        | 7.87     | 10.07       |
| 5                             | 1.622            | 2.18        | 4.44       | 5.47        | 5.00            | 6.02        | 6.81     | 8.52        | 8.82     | 10.97       |
| 6                             | 1.82             | 2.78        | 5.13       | 6.99        | 5.99            | 7.76        | 7.84     | 10.64       | 10.08    | 13.75       |
| 8                             | 2.41             | 3.77        | 6.98       | 9.78        | 8.56            | 11.09       | 10.55    | 14.74       | 13.44    | 18.97       |
| 10                            | 3.43             | 5.20        | 10.18      | 13.58       | 12.35           | 15.60       | 15.41    | 20.41       | 19.58    | 26.26       |
| 12                            | 4.41             | 6.71        | 13.08      | 17.73       | 16.35           | 18.76       | 19.67    | 26.65       | 24.87    | 34.11       |

<sup>a</sup> Including areas of accompanying flanges bolted to the fitting.

sulation. The manufacturer's recommendations should be followed. Pipe insulation is usually fastened with staples across the joints between sections and with metal bands or wire rings to hold individual sections and keep all joints tight.

Surface finishes used over insulations depends upon the exposure, whether indoor or outdoor, the temperature of the insulated surface, and the appearance desired. The insulations over flat or large curved surfaces, operating at temperatures above the ambient, are usually coated with a finishing cement when exposed to indoor conditions and by a finishing cement plus a weatherproof finish when used outdoors. The insulation over pipes operating above ambient temperature is usually coated with a canvas cover for indoor exposure and an asphalt impregnated felt for outdoor exposure. Sectional pipe covering is available with a wide variety of surface finishes and jackets.

Insulation over surfaces operating at temperatures below the ambient must be protected from water vapor penetration, whether used indoors or outdoors.

The selection of an insulation for a particular service condition should be made with full consideration of a number of properties in addition to thermal conductivity. Factors which may, under certain circumstances, be of more importance than thermal conductivity are ease of application, fire resistance, heat stability, weathering stability, and resistance to damage by physical abuse. Other factors may apply to a particular installation. A complete evaluation of all insulations cannot be included here. Insulation manufacturers should be consulted with regard to the selection of insulation to meet specific requirements. In general, the use of skilled and experienced applicators will go a long way toward insuring a satisfactory installation.

Elbows and fittings should be covered with an insulation of equal thickness and material which is similar to the pipe covering. Pre-fabricated fittings are available for many types of insulation, such as cork and rock cork. Where asbestos cement or magnesia cement is used to build up the fittings, the material should be applied in layers not exceeding a thickness of  $\frac{3}{8}$  in. The final coat should be mixed with 10 percent Portland cement and troweled smooth. After the final coat has thoroughly dried, it is recommended that canvas of the same weight as that used on the pipe covering be pasted over the surface. This procedure will prevent the built-up portions of the covering from falling off due to a slight bump or other minor damage.

On permanent installations of high quality, it is recommended that all coverings and fittings be further encased in 8-oz. canvas, drawn tight over rosin-sized paper and sewed in place, using not less than four stitches per inch.

All pipe covering which has a high differential temperature between the pipe surface and the ambient air should be provided with metal pipe sleeves around the covering to support the pipe by means of hangers on the outside of the covering, thus preventing the conduction of heat through the hangers.

#### HEAT LOSSES FROM INSULATED PIPES

Table 6 lists a number of typical thermal conductivities for various insulating materials. These conductivities have been selected as average design values for engineering calculations and must not be confused with

TABLE 6. THERMAL CONDUCTIVITY ( $k$ ) OF INDUSTRIAL AND PIPE INSULATIONS  
(For Mean Temperatures Indicated)  
Expressed in Btu per (hour) (square foot) (Fahrenheit degree temperature difference per in.)

| FORM              | MATERIAL (COMPOSITION)                 | ACCEPTED<br>MAX.<br>TEMP.<br>FOR<br>USE* F | DEN-<br>SITY<br>Lb./Cu<br>Ft | TYPICAL CONDUCTIVITY $k$ AT<br>MEAN TEMP. FAHR. |      |      |      |      |      |      |      |
|-------------------|----------------------------------------|--------------------------------------------|------------------------------|-------------------------------------------------|------|------|------|------|------|------|------|
|                   |                                        |                                            |                              | 40                                              | 70   | 100  | 200  | 300  | 500  | 700  | 900  |
| BLANKETS          | MINERAL WOOL<br>(Rock, Slag, or Glass) |                                            |                              |                                                 |      |      |      |      |      |      |      |
|                   | Metal Reinforced                       | 1200                                       | 6-15                         |                                                 |      |      | 0.29 | 0.35 | 0.42 | 0.50 |      |
|                   | Felt-Flexible Type                     | 450                                        | 0.5-3                        | 0.23                                            | 0.25 | 0.26 | 0.34 | 0.45 |      |      |      |
|                   | Felt-Semi-Rigid Type                   | 450                                        | 2-8                          | 0.24                                            | 0.25 | 0.27 | 0.35 | 0.44 |      |      |      |
| BLOCKS AND BOARDS | VEGETABLE & ANIMAL FIBER               |                                            |                              |                                                 |      |      |      |      |      |      |      |
|                   | Hair Felt or Hair Felt plus Jute       | 180                                        | 10                           | 0.27                                            | 0.28 | 0.30 |      |      |      |      |      |
|                   | ASBESTOS                               |                                            |                              |                                                 |      |      |      |      |      |      |      |
|                   | Molded Amosite & Binder                | 1200                                       | 18                           |                                                 |      | 0.37 | 0.40 | 0.47 | 0.56 | 0.66 | 0.76 |
| PIPE INSULATION   | Laminated Asbestos Paper               | 700                                        | 30                           |                                                 |      | 0.40 | 0.45 | 0.50 | 0.60 |      |      |
|                   | Corrugated & Laminated Asbestos Paper  |                                            |                              |                                                 |      |      |      |      |      |      |      |
|                   | 4 ply                                  | 300                                        | 11-13                        |                                                 |      | 0.54 | 0.57 | 0.63 | 0.80 |      |      |
|                   | 6 ply                                  | 300                                        | 15-17                        |                                                 |      | 0.49 | 0.51 | 0.59 | 0.69 |      |      |
| INSULATING CEMENT | 8 ply                                  | 300                                        | 18-20                        |                                                 |      | 0.47 | 0.49 | 0.57 | 0.65 |      |      |
|                   | CALCIUM SILICATE                       | 1200                                       | 11                           |                                                 |      | 0.33 | 0.38 | 0.43 | 0.53 | 0.64 | 0.76 |
|                   | CELLULAR GLASS                         | 800                                        | 9                            | 0.37                                            | 0.39 | 0.41 | 0.48 | 0.55 |      |      |      |
|                   | CORKBOARD (Without Added Binder)       | 200                                        | 6.5-8                        | 0.26                                            | 0.27 | 0.28 |      |      |      |      |      |
| INSULATING CEMENT | DIATOMACEOUS SILICA                    | 1500                                       | 22                           |                                                 |      |      |      |      | 0.60 | 0.64 | 0.68 |
|                   | 85% MAGNESIA                           | 1900                                       | 25                           |                                                 |      |      |      |      | 0.70 | 0.75 | 0.80 |
|                   | Mag. Carb. & Asbestos                  |                                            |                              |                                                 |      |      |      |      |      |      |      |
|                   | MINERAL WOOL (Rock, Slag or Glass)     | 600                                        | 11-14                        |                                                 |      | 0.35 | 0.38 | 0.42 | 0.46 |      |      |
| INSULATING CEMENT | Low Temp. (Asphalt or Resin Bonded)    | 200                                        | 6-18                         | 0.28                                            | 0.29 | 0.31 |      |      |      |      |      |
|                   | High Temp. (Resin Bonded)              | 600                                        | 6-10                         |                                                 |      | 0.28 | 0.35 | 0.43 |      |      |      |
|                   | PLASTICS (Foamed)                      | 1600                                       | 16-24                        |                                                 |      | 0.34 | 0.39 | 0.44 | 0.54 | 0.64 |      |
|                   | RUBBER (Foamed)                        | 175                                        | 1.6                          | 0.26                                            | 0.28 | 0.30 |      |      |      |      |      |
| INSULATING CEMENT | VEGETABLE & ANIMAL FIBER               | 150                                        | 5                            | 0.23                                            | 0.24 | 0.25 |      |      |      |      |      |
|                   | Wool Felt                              |                                            |                              |                                                 |      |      |      |      |      |      |      |
|                   | Hair Felt or Hair Felt plus Jute       | 180                                        | 20                           | 0.29                                            | 0.31 | 0.33 |      |      |      |      |      |
|                   | 85% MAGNESIA                           | 180                                        | 10                           | 0.27                                            | 0.28 | 0.30 |      |      |      |      |      |
| INSULATING CEMENT | Mag. Carb. & Asbestos                  |                                            |                              |                                                 |      |      |      |      |      |      |      |
|                   | MINERAL WOOL (Rock, Slag or Glass)     | 600                                        | 18                           |                                                 |      | 0.46 | 0.52 | 0.58 |      |      |      |
|                   | With Colloidal Clay Binder             | 1800                                       | 24-30                        |                                                 |      | 0.49 | 0.61 | 0.73 | 0.85 |      |      |

\* These temperatures are generally accepted as maximum. When operating temperature approaches these limits the Manufacturer's recommendations should be followed.

actual test data. The conductivity of any particular insulation or pipe covering can only be obtained from unbiased tests, or from data guaranteed by the manufacturer.

The terms *standard* and *double standard* thickness of magnesia and diatomaceous silica pipe covering have been declared obsolete by the



*Magnesia Insulation Manufacturer's Association.* The new simplified nominal inch thicknesses for these insulations are 1, 1½, 2, 2½, 3, 3½, 4, 4½ and 5 for most pipe sizes ¼ to 33 in. Most of these new nominal thicknesses are slightly greater than the actual thickness. Revision of

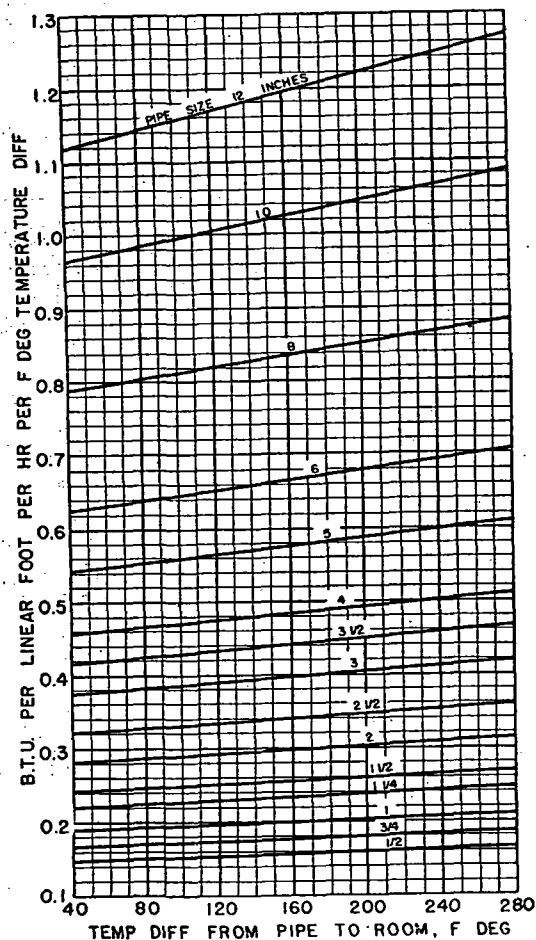


FIG. 1. HEAT LOSS THROUGH 1 IN. THICK 85 PERCENT MAGNESIA TYPE COVERING

the heat loss charts, Figs. 1, 2 and 3, will be made, but for the present these charts may be used with the factors given in Table 7 for all of the insulations shown in Table 6 without serious error.

Pipes operating at high temperatures are frequently insulated to the best advantage by combining a high temperature insulation near the pipe

with a moderate or low temperature insulation around it as an outer layer. By this method an efficient material may be used for each of the two temperature ranges encountered. In calculating the heat loss through such a combination the mean temperature of each layer must be determined along with the thickness of each. This is readily done in three or four calculations performed as a series of approximations, in which assumptions

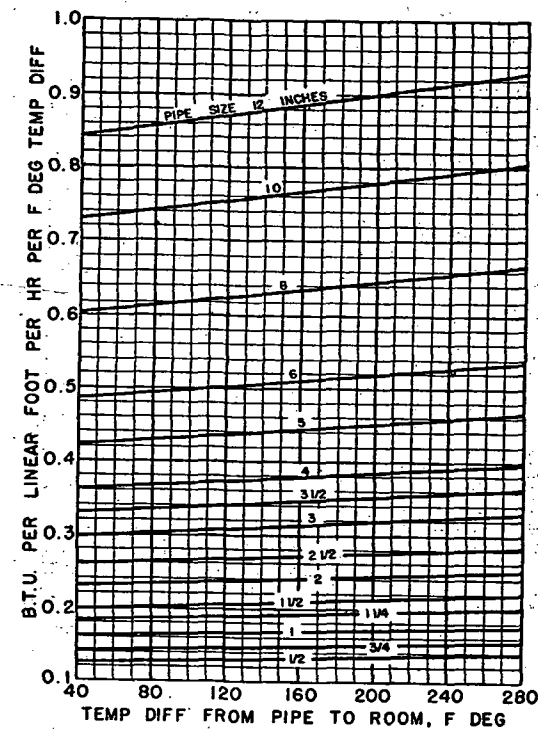


FIG. 2. HEAT LOSS THROUGH 1½ IN. THICK 85 PERCENT MAGNESIA TYPE COVERING

of thickness and mean temperature are adjusted as indicated in the discussion which follows.

In the case of a single thickness of pipe covering, the quantity of heat transferred per square foot of outer surface of the insulation is given by the equation:

$$q_o = \frac{k(l_1 - l_2)}{r_1 \log_e \frac{r_2}{r_1}} \quad (1)$$

where

$q_o$  = Btu per (hour) (square foot of outer surface of insulation).  
 $r_1$  = outer radius of pipe or inner radius of insulation, inches.

- $r_2$  = outer radius of insulation, inches.  
 $k$  = thermal conductivity of insulation, Btu per (hour) (square foot) (Fahrenheit degree per inch).  
 $t_1$  = temperature of inner surface of insulation, Fahrenheit degrees.  
 $t_2$  = temperature of outer surface of insulation, Fahrenheit degrees.

It is convenient to work from the outer surface of the insulation, since the loss through the covering must be determined from the outer surface loss by means of surface loss curves such as given in Fig. 4. The curves were plotted from tests conducted at the Mellon Institute.

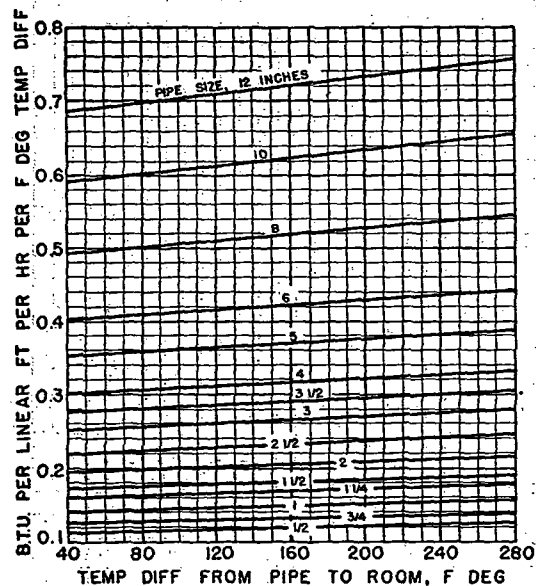


FIG. 3. HEAT LOSS THROUGH 2 IN. THICK 85 PERCENT MAGNESIA TYPE COVERING

After the true heat loss is obtained, the loss per square foot of pipe surface can be calculated from the relationship:

$$q_1 = q_o(r_2/r_1)$$

where

$q_1$  = Btu per (hour) (square foot outer surface of pipe).

The heat loss through two or more thicknesses of insulation applied to a pipe can be calculated by means of the equation:

$$q_o = \frac{t_1 - t_2}{\frac{r_2 \log_e \frac{r_2}{r_1}}{k_1} + \frac{r_3 \log_e \frac{r_3}{r_2}}{k_2} + \dots} \quad (2)$$

where

- $r_2$  = outer radius of second layer of insulation, inches.  
 $r_3$  = outer radius of last layer of insulation, inches.

The method of solving Equation 2, which is the most difficult of the two, is given in Example 3.

**Example 3:** Compute the heat loss per linear foot of pipe surface per hour from a 6-in. pipe, insulated with a 3-in. thickness of diatomaceous silica, 1900 F maximum type, and a 2-in. thickness of 85 percent magnesia. The pipe is operating at a temperature of 1200 F and is exposed to a room temperature of 80 F.

**Solution:** In figuring the heat loss from Equation 2, it is necessary to first make an assumption for the outer surface temperature  $t_2$  and the temperature between the diatomaceous silica and 85 percent magnesia insulation, so that the mean temperature of each material can be obtained and the thermal conductivity corresponding to the mean temperature of each material substituted in the formula. First assume an outer surface temperature of 140 F and a temperature of 570 F between the two materials corresponding to a mean temperature of  $(1200 + 570) \div 2$  or 885 F for the dia-

TABLE 7. PIPE COVERING FACTORS TO BE APPLIED TO FIGS. 1, 2 AND 3

| TYPE OF PIPE INSULATION                  | MEAN TEMPERATURE, FAHRENHEIT |      |      |      |      |      |      |      |
|------------------------------------------|------------------------------|------|------|------|------|------|------|------|
|                                          | 40                           | 70   | 100  | 200  | 300  | 500  | 700  | 900  |
| 85% MAGNESIA                             | 1.05                         | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | —    | —    |
| MOULDED AMOSITE AND BINDER               | —                            | —    | 0.89 | 0.95 | 1.01 | 1.09 | —    | —    |
| LAMINATED ASBESTOS PAPER (35-40 Per In.) | —                            | —    | 1.08 | 1.13 | 1.07 | 1.24 | —    | —    |
| CORRUGATED AND LAMINATED ASBESTOS PAPER  | —                            | —    | —    | —    | —    | —    | —    | —    |
| 4 Ply Per In.                            | —                            | 1.49 | 1.54 | 1.70 | 1.87 | —    | —    | —    |
| 6 Ply Per In.                            | —                            | 1.85 | 1.37 | 1.48 | 1.62 | —    | —    | —    |
| 8 Ply Per In.                            | —                            | 1.80 | 1.32 | 1.43 | 1.52 | —    | —    | —    |
| CALCIUM SILICATE                         | —                            | —    | 0.97 | 1.00 | 1.03 | 1.13 | —    | —    |
| CELLULAR GLASS                           | —                            | —    | —    | —    | —    | —    | —    | —    |
| DIATOMACEOUS SILICA (22 lb 1 cu ft)      | 1.05                         | 1.08 | 1.10 | 1.20 | 1.29 | —    | —    | —    |
| DIATOMACEOUS SILICA (25 lb 1 cu ft)      | —                            | —    | —    | —    | —    | 1.24 | 1.18 | 1.14 |
| MINERAL WOOL (Rock, Slag or Glass)       | —                            | —    | —    | —    | —    | 1.44 | 1.39 | 1.34 |
| Low Temp. (Asphalt or Resin Bonded)      | 0.80                         | 0.83 | 0.89 | 0.98 | —    | —    | —    | —    |
| High Temp. (Blanket, Metal Reinforced)   | 0.63                         | 0.64 | 0.65 | 0.68 | 0.73 | —    | —    | —    |
| PLASTICS (Foamed)                        | —                            | —    | 0.78 | 0.90 | 0.98 | 1.05 | —    | —    |
| RUBBER (Foamed)                          | 0.74                         | 0.78 | 0.84 | —    | —    | —    | —    | —    |
| WOOL FELT                                | 0.66                         | 0.72 | 0.68 | —    | —    | —    | —    | —    |
| HAIR FELT OR HAIR FELT PLUS JUTE:        | 0.53                         | 0.58 | 0.59 | —    | —    | —    | —    | —    |
|                                          | 0.77                         | 0.78 | 0.81 | —    | —    | —    | —    | —    |

tomaceous silica and  $(570 + 140) \div 2$  or 355 F for the 85 percent magnesia insulation. The conductivities of these two materials at mean temperatures of 885 and 355 F, interpolated from Table 6, are 0.796 and 0.467 Btu, respectively.

These values are substituted in Equation 2 and a trial calculation made. For a nominal 6-in. steel pipe:  $r_1 = 3.312$ ,  $r_2 = 6.312$ , and  $r_3 = 8.312$ . Then,

$$q_o = \frac{1200 - 140}{8.312 \log_e \frac{6.312}{3.312} + \frac{1060}{8.312 \log_e \frac{8.312}{6.312}}} = \frac{1060}{6.74 + 4.89} = 91.1 \text{ Btu.}$$

The temperature drop from the outer surface of the insulation to the surrounding air for a heat loss of 91.1 Btu is found from Fig. 4 to be 55 deg for a 16-in. O.D. cylindrical surface, or 55 + 80 F room temperature = 135 F surface temperature. Since a surface temperature of 140 F was assumed, it is evident that a temperature closer to 135 F, or, for instance, 136 F should be used for recalculation:

$$q_o = \frac{1200 - 136}{6.74 + 4.89} = 91.5 \text{ Btu.}$$

Since the temperature drop through each material is equal to the heat flow times the actual resistance of each material, the temperature drop through the diatomaceous silica is  $91.5 \times 6.74 = 617$  F, or the temperature between the two insulating materials is  $(1200 - 617) = 583$  F. Since a temperature of 570 F between the two materials was

assumed, it is obvious that a temperature closer to 583, or for instance 582 F may be selected. The mean temperatures of the two insulations corresponding to the new assumptions are  $(1200 + 582) \div 2 = 891$  and  $(582 + 136) \div 2 = 359$ , and the interpolated conductivities corresponding to the new mean temperatures are 0.798 and 0.468 for the diatomaceous silica and 85 percent magnesia, respectively. By substituting in Equation 2

$$q_o = \frac{1200 - 136}{\frac{5.36}{0.798} + \frac{2.29}{0.468}} = \frac{1064}{6.72 + 4.90} = 91.5 \text{ Btu.}$$

Again referring to Fig. 4, it is seen that the temperature drop from the outer surface of the insulation to the surrounding air for a heat loss of 91.5 Btu = 58 deg, which

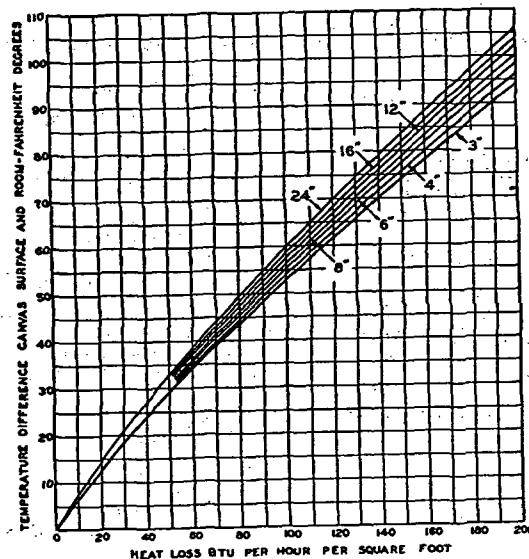


FIG. 4. HEAT LOSS FROM CANVAS-COVERED CYLINDRICAL SURFACES OF VARIOUS DIAMETERS

corresponds to the surface temperature of 136 F last assumed. The temperature drop through the diatomaceous silica is  $91.5 \times 6.72 = 615$  F, corresponding to a temperature of 585 F between the two materials, which checks very closely with the temperature of 582 F last assumed. The heat loss is therefore  $91.5 \times 8.312 \div 3.312$  or 230 Btu per sq ft of pipe surface. Since the surface area per linear foot of 6-in. pipe is 1.734 sq ft (Table 3), the heat loss per linear foot of pipe will be  $230 \times 1.734 = 399$  Btu per hr.

The rate of heat loss from a surface maintained at constant temperature is greatly increased by air circulation over the surface. In the case of well-insulated surfaces, the increases in losses due to air velocity are very small as compared with increases from bare surfaces, because of the fact that air flowing over the surface of the insulation can increase only the conductance of heat from surface to air, and cannot change the internal conductance of the insulation itself. The maximum increase in heat loss

due to air velocity ranges from about 15 percent in the case of 1-in. thick insulation, to about 5 percent in the case of 3-in. thick insulation, provided that the insulation is thoroughly sealed so that air can flow only over the surface. If the conditions are such that the air may circulate through cracks and crevices in the insulation, the increases may be far greater than those given. Therefore, it is essential that insulation be applied in such a manner that air circulation within it, or between it and the pipe, is avoided.

Piping which is covered with a water-mixed product or insulation which will absorb moisture, particularly in damp locations, should be coated with a corrosion resisting paint, such as black asphaltum. This precaution may prevent early failure due to external pipe corrosion.

The frequent practice of omitting insulation on that portion of a pipe which passes through a masonry wall, or which may be in contact with other metals, should be avoided. Physical contact between the pipe surface and other structural materials of high thermal conductivity will result in heat transfer much greater than that shown in Tables 1 and 2 for transfer from bare pipe to air.

The saving due to use of insulation on piping is illustrated in Example 4.

**Example 4:** If the steam pipe given in Examples 1 and 2 is covered with 1 in. thick 85 percent magnesia, determine the resulting total annual loss through the insulation. Also compute the monetary value of the annual saving and the percentage of saving over the heat loss from the bare pipe.

**Solution:** By referring to Fig. 1, the coefficient for 1 in. magnesia covering on a 2-in. pipe is found to be 0.300 Btu per (hr) (linear ft of pipe) (deg temperature difference) at a temperature difference of 169.4 F. Referring to Table 7 the correction factor to be applied is  $1.05 \times 0.300 = 0.315$ .

The total hourly loss per linear foot of pipe will then be  $0.315 \times 169.4 = 53.3$  Btu. The total annual loss through the insulation =  $53.3 \times 165$  (linear ft)  $\times 4000$  (hr) = 34,600 Mb. The annual bare pipe loss as determined in the solution of Example 1 was found to be 181,600 Mb. The saving due to insulation is then  $181,600 - 34,600 = 147,000$  Mb per year.

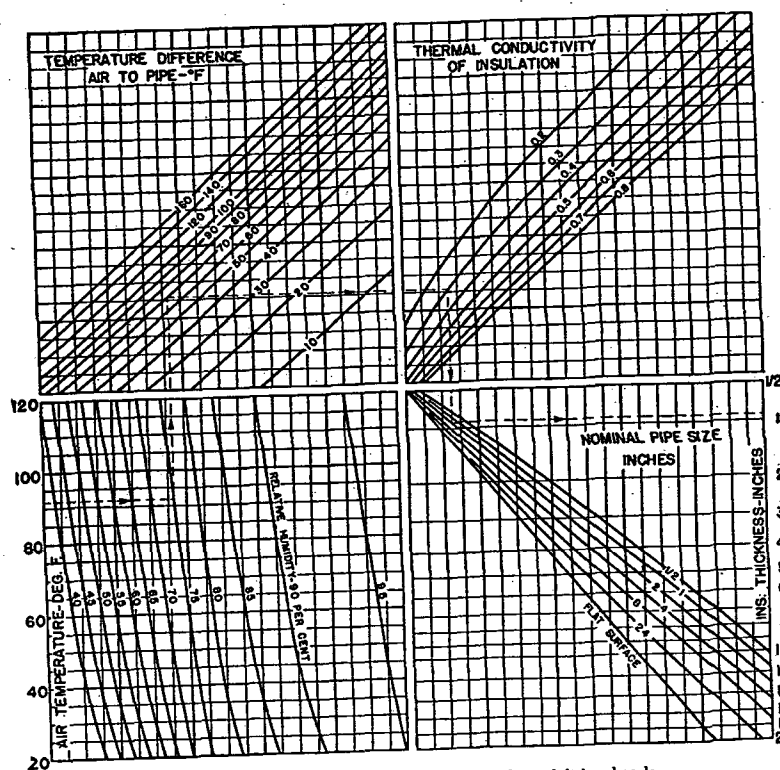
From the solution of Example 2, it was found that the heat supplied to the system cost \$0.804 per thousand Mb. Therefore, the monetary value of the saving =  $0.804$  (dollars)  $\times 147$  (thousand Mb) = \$118.00, or 81.0 percent of the cost when using uninsulated pipe.

### LOW TEMPERATURE PIPE INSULATION

Surfaces maintained at temperatures lower than the surrounding air are insulated to reduce the flow of heat and to prevent condensation. The insulating material should absorb a minimum amount of moisture, because the absorption of moisture substantially increases the conductivity of the material. This property is particularly important in the insulation of surfaces that are below the dew-point of the surrounding air. In such cases, due to vapor pressure difference, it is necessary to seal the surface of the insulating material against the penetration of water vapor which would condense within the material, causing a serious increase in heat flow, possible breakdown of the material, and corrosion of metal surfaces. An insulating material with a high degree of moisture absorption might pick up moisture before application and then, when the seal is in place and the temperature of the insulated surface reduced, release that moisture to the cold surface. There are a number of methods of producing vapor seals, some of which have been worked out by insulation

manufacturers to suit their products, and others by applicators and users. Unless time-proven methods are known, specifications of insulation manufacturers should be obtained and followed carefully.

Piping must be carefully protected against corrosion caused by condensation of water vapor. All metallic surfaces should be coated with a vapor-



\* Solve problems as indicated by dotted line, entering chart at lower left hand scale

FIG. 5. THICKNESS OF PIPE INSULATION TO PREVENT CONDENSATION ON OUTER SURFACE\*

impervious barrier (some types of which have an asphaltic or tar base) without any breaks or openings in order to prevent corrosion.

The thickness of insulation required to prevent condensation on the outer surface is that thickness which will raise the temperature of the outer surface of the insulation to a point slightly higher than the dew-point of the surrounding vapor. The dew-point for various humidities can be readily ascertained from a psychrometric chart. The external vapor barrier must be made as nearly perfect as possible in order to prevent leakage of vapor into the insulation.

The approximate required thickness of insulation to prevent condensa-

tion on pipes and flat metallic surfaces may be obtained from Fig. 5 in which a surface resistance of 0.606, corresponding to a film conductance of 1.65, was used in calculating the curves. This value provides a slight factor of safety and its use is known to give satisfactory field results. In using the chart it is advisable to specify the next thicker, rather than the next thinner, commercial insulation in cases where an intermediate thickness is indicated.

Heat gains for pipes insulated with a material having an installed conductivity of 0.30 Btu per (sq ft) (hr) (F deg per in.) are given in Table 8. This table may be used for any of the commercial insulations offered for this purpose since they have conductivities very near the 0.3 value used.

TABLE 8. HEAT GAINS FOR INSULATED COLD PIPES

Rates of heat transmission given in Btu per (hour) (Fahrenheit degree temperature difference between fluid in pipe and surrounding still air)

Based on materials having conductivity,  $k = 0.30$

| NOMINAL<br>PIPE SIZE<br>(INCHES) | ICE WATER THICKNESS                       |                           |                                     | BRINE THICKNESS                           |                           |                                     | HEAVY BRINE THICKNESS                     |                           |                                     |
|----------------------------------|-------------------------------------------|---------------------------|-------------------------------------|-------------------------------------------|---------------------------|-------------------------------------|-------------------------------------------|---------------------------|-------------------------------------|
|                                  | Thickness<br>of<br>Insulation<br>(Inches) | Btu Per<br>Linear<br>Foot | Btu Per<br>Sq Ft<br>Pipe<br>Surface | Thickness<br>of<br>Insulation<br>(Inches) | Btu Per<br>Linear<br>Foot | Btu Per<br>Sq Ft<br>Pipe<br>Surface | Thickness<br>of<br>Insulation<br>(Inches) | Btu Per<br>Linear<br>Foot | Btu Per<br>Sq Ft<br>Pipe<br>Surface |
| 1/4                              | 1.5                                       | 0.110                     | 0.502                               | 2.0                                       | 0.098                     | 0.446                               | 2.8                                       | 0.087                     | 0.394                               |
| 3/8                              | 1.6                                       | 0.119                     | 0.431                               | 2.0                                       | 0.111                     | 0.405                               | 2.9                                       | 0.094                     | 0.340                               |
| 1                                | 1.6                                       | 0.139                     | 0.403                               | 2.0                                       | 0.124                     | 0.352                               | 3.0                                       | 0.104                     | 0.294                               |
| 1 1/4                            | 1.6                                       | 0.155                     | 0.357                               | 2.4                                       | 0.131                     | 0.300                               | 3.1                                       | 0.113                     | 0.260                               |
| 1 1/2                            | 1.5                                       | 0.174                     | 0.351                               | 2.5                                       | 0.134                     | 0.270                               | 3.2                                       | 0.118                     | 0.238                               |
| 2                                | 1.5                                       | 0.200                     | 0.322                               | 2.5                                       | 0.151                     | 0.244                               | 3.3                                       | 0.134                     | 0.214                               |
| 2 1/4                            | 1.5                                       | 0.228                     | 0.303                               | 2.6                                       | 0.170                     | 0.226                               | 3.3                                       | 0.147                     | 0.197                               |
| 3                                | 1.5                                       | 0.269                     | 0.293                               | 2.7                                       | 0.186                     | 0.202                               | 3.4                                       | 0.162                     | 0.176                               |
| 3 1/2                            | 1.5                                       | 0.295                     | 0.282                               | 2.9                                       | 0.191                     | 0.183                               | 3.5                                       | 0.176                     | 0.167                               |
| 4                                | 1.7                                       | 0.294                     | 0.248                               | 2.9                                       | 0.209                     | 0.176                               | 3.7                                       | 0.182                     | 0.154                               |
| 5                                | 1.7                                       | 0.349                     | 0.239                               | 3.0                                       | 0.241                     | 0.165                               | 3.9                                       | 0.202                     | 0.138                               |
| 6                                | 1.7                                       | 0.404                     | 0.233                               | 3.0                                       | 0.259                     | 0.150                               | 4.0                                       | 0.228                     | 0.130                               |
| 8                                | 1.9                                       | 0.455                     | 0.201                               | 3.0                                       | 0.318                     | 0.140                               | 4.0                                       | 0.263                     | 0.116                               |
| 10                               | 1.9                                       | 0.559                     | 0.198                               | 3.0                                       | 0.383                     | 0.135                               | 4.0                                       | 0.309                     | 0.110                               |
| 12                               | 1.9                                       | 0.648                     | 0.194                               | 3.0                                       | 0.438                     | 0.131                               | 4.0                                       | 0.364                     | 0.108                               |

## INSULATION OF PIPES TO PREVENT FREEZING

If the surrounding air temperature remains sufficiently low for an ample period of time, insulation cannot prevent the freezing of still water, or of water flowing at such a velocity that the quantity of heat carried in the water is not sufficient to take care of the heat losses which will result and cause the temperature of the water to be lowered to the freezing point. Insulation can materially prolong the time required for the water to give up its heat, and if the velocity of the water flowing in the pipe is maintained at a sufficiently high rate, freezing may be prevented.

Table 9 may be used for making estimates of the thickness of insulation necessary to take care of still water in pipes at various water and surrounding air temperature conditions. Because of the damage and service interruptions which may result from frozen water in pipes, it is essential that an efficient insulation be utilized. This table is based on the use of a material having a conductivity of 0.30. The initial water tem-

perature is assumed to be 10 deg above, and the surrounding air temperature 50 deg below, the freezing point of water (temperature difference, 60 F).

The last column of Table 9 gives the minimum quantity of water at initial temperature of 42 F which should be supplied every hour for each linear foot of pipe, in order to prevent the temperature of the water from being lowered to the freezing point. The weights given in this column should be multiplied by the total length of the exposed pipe line expressed in feet. As an additional factor of safety, and in order to provide against temporary reductions in flow occasioned by reduced pressure, it is advisable to double the rates of flow listed in the table. It must be emphasized that the flow rates and periods of time designated apply only for the conditions stated. To estimate for other service conditions, the following method of procedure may be used.

If water enters the pipe at 52 F instead of 42 F, the time required to

TABLE 9. DATA FOR ESTIMATING REQUIREMENTS TO PREVENT FREEZING OF WATER IN PIPES WITH SURROUNDING AIR AT -18 F

| NOMINAL<br>PIPE<br>SIZE<br>(INCHES) | NUMBER OF HOURS TO COOL 42 F<br>WATER TO FREEZING POINT       |       |       | WATER FLOW REQUIRED AT 42 F TO<br>PREVENT FREEZING, POUNDS PER<br>LINEAR FOOT OF PIPE PER HOUR |      |      |
|-------------------------------------|---------------------------------------------------------------|-------|-------|------------------------------------------------------------------------------------------------|------|------|
|                                     | Thickness of Insulation in Inches (Conductivity, $k = 0.30$ ) |       |       |                                                                                                |      |      |
|                                     | 2                                                             | 3     | 4     | 2                                                                                              | 3    | 4    |
| 1/4                                 | 0.42                                                          | 0.50  | 0.57  | 0.54                                                                                           | 0.45 | 0.40 |
| 1/2                                 | 0.83                                                          | 1.02  | 1.16  | 0.68                                                                                           | 0.55 | 0.48 |
| 3/4                                 | 1.40                                                          | 1.74  | 2.02  | 0.84                                                                                           | 0.68 | 0.58 |
| 1                                   | 1.94                                                          | 2.48  | 2.90  | 0.95                                                                                           | 0.75 | 0.64 |
| 1 1/4                               | 3.25                                                          | 4.27  | 5.08  | 1.24                                                                                           | 0.94 | 0.79 |
| 2                                   | 4.55                                                          | 6.02  | 7.20  | 1.47                                                                                           | 1.11 | 0.93 |
| 3                                   | 5.92                                                          | 7.96  | 9.69  | 1.73                                                                                           | 1.29 | 1.06 |
| 4                                   | 7.35                                                          | 9.58  | 12.20 | 1.98                                                                                           | 1.46 | 1.19 |
| 6                                   | 10.05                                                         | 13.90 | 17.25 | 2.46                                                                                           | 1.78 | 1.43 |
| 8                                   | 13.00                                                         | 18.10 | 22.70 | 2.96                                                                                           | 2.12 | 1.70 |
| 10                                  | 15.80                                                         | 22.20 | 28.10 | 3.43                                                                                           | 2.45 | 1.93 |
| 12                                  |                                                               |       |       |                                                                                                |      |      |

cool it to the freezing point will be prolonged to twice that given in the table, or the rate of flow of water may be reduced so that the quantity required will be one-half that shown in the last column of Table 9. However, if the water enters the pipe at 34 F, it will be cooled to 32 F in one-fifth of the time given in the table. It will then be necessary to increase the rate of flow so that five times the specified quantity of water will have to be supplied in order to prevent freezing.

If the minimum air temperature is -38 F (temperature difference 80 F) instead of -18 F, the time required to cool the water to the freezing point will be 60/80 of the time given in the table, or the necessary quantity of water to be supplied will be 80/60 of that given.

In making calculations to arrive at the values given in Table 9, the loss of heat stored in the insulation, the effect of a varying temperature difference due to the cooling of pipe and water, and the resistance of the outer surface of the insulation to the transfer of heat to the air, have all been neglected. When these factors enter into the computations it is necessary to enlarge the factor of safety. Also as stated, the time shown in the table is that required to lower the water to the freezing point. A

longer period would be required to freeze the water, but the danger point is reached when freezing starts. The flow of water will stop and the entire line will be in danger as soon as the water freezes across the section of the pipe at any point.

When water must remain stationary longer than the times designated in Table 9, the only safe way to insure against freezing is to install a steam or hot water pipe parallel to the cold water pipe or to place an electric resistance heater along the side of the exposed water pipe. The heating system and the water pipe are then insulated so that the heat losses from the heating system are not excessive, and the heating effect is concentrated against the water pipe where it is needed. For this form of protection 2 in. of an efficient insulation may be applied.

### ECONOMICAL THICKNESS OF PIPE INSULATION

The thicknesses of insulation which ordinarily are used for various temperature conditions are given in Table 10. Where a thorough analysis

TABLE 10. THICKNESS OF PIPE INSULATION ORDINARILY USED INDOORS\*

| STEAM PRESSURE<br>PSIG<br>OR CONDITION | STEAM TEMPERATURE<br>FAHRENHEIT<br>DEGREES | THICKNESS OF INSULATION    |                            |                                |
|----------------------------------------|--------------------------------------------|----------------------------|----------------------------|--------------------------------|
|                                        |                                            | Pipes Larger<br>Than 4 in. | Pipes<br>2 in. to<br>4 in. | Pipes<br>1 1/2 in.<br>to 1 in. |
| 0 to 25                                | 212 to 267                                 | 1 in.                      | 1 in.                      | 1 in.                          |
| 25 to 100                              | 267 to 338                                 | 1 1/2 in.                  | 1 in.                      | 1 in.                          |
| 100 to 200                             | 338 to 388                                 | 2 in.                      | 1 1/2 in.                  | 1 in.                          |
| Low Superheat                          | 388 to 600                                 | 2 1/2 in.                  | 2 in.                      | 1 1/2 in.                      |
| Medium Superheat                       | 600 to 600                                 | 3 in.                      | 2 1/2 in.                  | 2 in.                          |
| High Superheat                         | 600 to 700                                 | 3 1/2 in.                  | 3 in.                      | 2 in.                          |

\* All piping located outdoors or exposed to weather is ordinarily insulated to a thickness 1/2 in. greater than shown in this table, and covered with a waterproof jacket.

of economic thickness is desired, this may be accomplished through the use of the chart, Fig. 6.

The dotted line on the chart illustrates its use in solving a typical example. In using the chart, start with the scale at the left bottom margin representing the given number of hours of operation per year; then proceed vertically to the line representing the given value of heat; thence horizontally to the right, to the line representing the given temperature difference; thence vertically to the line representing the conductivity of the given material; thence horizontally to the left, to the line representing the given discount on that material; thence vertically to the curve representing the required percent return on the investment; thence horizontally to the right, to the curve representing the given pipe size; thence vertically to the scale at the top right margin where the economical thickness may be read off directly.

A rapid method for determining the economical thickness of insulation by use of tables has been published.<sup>2</sup>

### UNDERGROUND PIPE INSULATION

Underground steam distribution pipes may be installed in protective structures of various types, sizes and shapes (see (Chapter 29). Detailed

data on commonly used forms of tunnels and conduit systems, have been published by the *National District Heating Association*.<sup>3</sup>

Another form of underground insulation consists of the direct burial of the pipe in a trench with a complete covering of about 4 in. of a granular bitumen which, upon heating, forms a semiplastic, waterproof covering having a very good insulating value. The pipe must be supported on a solid insulating substance such as insulating blocks or asbestos cement pipe sections filled with an insulating cement. The expansion of steam and hot water pipes, using loop expansion joints, offers no difficulty as the plastic nature of the warm material allows free movement of the pipes. Care must be exercised in installing this material in accordance with the manufacturer's recommendations.

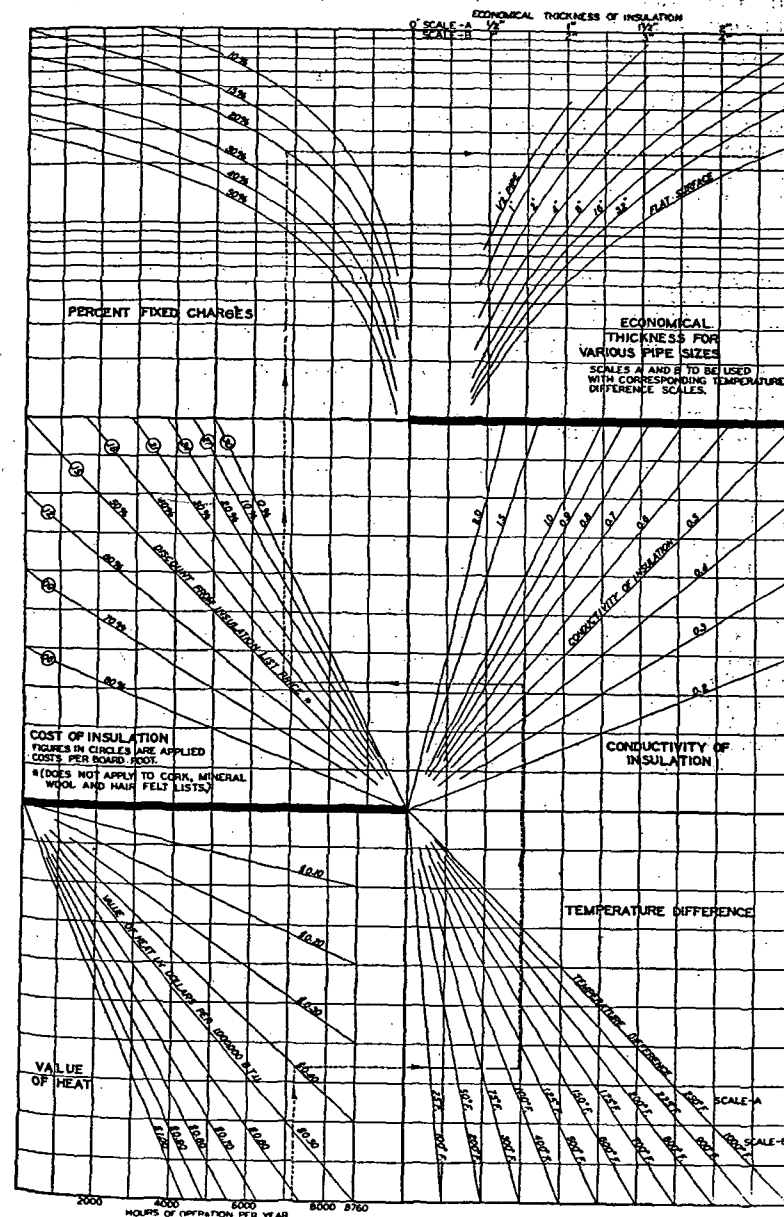
Pipes in tunnels are covered with sectional insulation to provide maximum thermal efficiency, and are also finished with good mechanical protection in the form of metal or waterproofing membrane outer jackets.

TABLE 11. THICKNESS OF LOOSE INSULATION FOR USE AS FILL IN UNDERGROUND CONDUIT SYSTEMS

| STEAM<br>PRESSURE<br>PSIG<br>OR CONDITION | STEAM<br>TEMPERATURE<br>FAHRENHEIT<br>DEGREES | MINIMUM THICKNESS OF INSULATION IN INCHES |                          |                             |                          |                           | MINIMUM<br>DISTANCE<br>BETWEEN<br>STEAM<br>AND<br>RETURN |
|-------------------------------------------|-----------------------------------------------|-------------------------------------------|--------------------------|-----------------------------|--------------------------|---------------------------|----------------------------------------------------------|
|                                           |                                               | STEAM LINES                               |                          |                             | RETURN LINES             |                           |                                                          |
|                                           |                                               | Pipes Less<br>than 4 in.                  | Pipes 4 in.<br>to 10 in. | Pipes Larger<br>than 12 in. | Pipes Less<br>than 4 in. | Pipes 4 in.<br>and Larger |                                                          |
| Hot Water,<br>or 0 to 25                  | 212 to 267                                    | 1½                                        | 2                        | 2½                          | 1¼                       | 1½                        | 1                                                        |
| 25 to 125                                 | 267 to 352                                    | 2                                         | 2½                       | 3                           | 1¼                       | 1½                        | 1¼                                                       |
| Above 125, or<br>superheat                | 352 to 500                                    | 2½                                        | 3                        | 3½                          | 1¼                       | 1½                        | 1½                                                       |

In some instances, where actual submersion of hot lines may occur, it has been found good practice to fasten the covering securely with corrosion resistant wire, and then sew on a wire-inserted asbestos fabric jacket with wire. This jacket is porous. The principle of withstanding submersion is that water may enter as water, then actually boil at the pipe surfaces and escape as steam without rupturing the insulation or jacket. Conduit systems are in more general use than tunnels. Pipes carried in conduits may be insulated with sectional insulation; however, the more usual practice is to fill the entire section of the conduit around the pipes with high quality, loose insulating material. The insulation must be kept dry at all times, and for this purpose effective waterproofing membranes enclose the insulation. A drainage system is also provided to divert water which may tend to enter the conduit.

The economical thickness of insulation for underground work is difficult to determine accurately due to the many variables which have to be considered. As a result of theories<sup>4</sup> previously developed, together with other experimental data which have been presented, the usual endeavor is to secure not less than 90 percent efficiency for underground piping. Table 11 can be used as a guide in arriving at the minimum thickness of loose insulation fills to use for laying out conduit systems. Other factors such as the number of pipes and their combination of sizes, as well as the



(L. B. McMillan, *Proc. National District Heating Association*, Vol. 18, p. 138).

FIG. 6. CHART FOR DETERMINING ECONOMICAL THICKNESS OF PIPE INSULATION

standard conduit sizes, are primary controlling factors in the amount and thickness of insulation for use.

When sectional insulation is applied to pipes in tunnels or conduits, usual practice is to apply the most efficient materials  $\frac{1}{2}$  in. less in thickness than that determined by the use of Fig. 6. The data in Fig. 6 are based on conditions of insulation exposed to the air, whereas normal ground temperature is substituted for air temperature in determining the temperature difference for use with the chart when applying it for underground pipe system estimates.

### REFERENCES

- <sup>1</sup> Heat Loss from Copper Piping, by R. H. Heilman (*Heating, Piping and Air Conditioning*, September 1933, p. 458).
- <sup>2</sup> Rapid Method of Determining the Economical Thickness of Pipe Insulation, by Utley W. Smith (A.S.H.V.E. JOURNAL SECTION, *Heating, Piping and Air Conditioning*, October 1947, p. 118).
- <sup>3</sup> *District Heating Handbook* of the National District Heating Association, Third Edition, 1951.
- <sup>4</sup> Theory of Heat Losses from Pipes Buried in the Ground, by J. R. Allen (A.S.H.V.E. TRANSACTIONS, Vol. 26, 1920, p. 335).

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## CHAPTER 29.

### DISTRICT HEATING

Steam Requirements, Distribution Pressures, Boiler Plants, Distribution Piping, Pipe Sizes, Conduits for Piping, Accessory Equipment, Insulation, Return of Condensate, Pipe Tunnels, Building Piping and Equipment, Zoning and Operation, Metering

THE term *district heating* refers to the supplying of heat from a central plant to a group of buildings in a city, institution, housing development, or factory area. The heat may be used for space heating, air conditioning, processing, or other purposes. It is usually preferable that groups of industrial or institutional buildings be supplied from a central plant rather than by individual plants in order to permit use of less expensive fuel, improve efficiency of combustion, reduce the labor required, assure use of competent operators, and often decrease the investment for heating purpose.

Those phases of district heating which frequently fall within the province of the heating engineer are outlined here, and information is given for solving incidental problems in connection with institutions, housing developments, and factories. Some data are included with reference to special requirements for district heating steam piping. Design of a complete district heating installation to provide utility service in a city should not be attempted unless a thorough study of the entire problem has been made by competent men having experience in district heating.

### STEAM REQUIREMENTS

The first step in the design of a district heating system is to determine the maximum hourly and the annual steam requirements of each of the buildings to be supplied. Methods of determining the maximum *hourly* requirements, or heat load, will be found for space heating in Chapter 12, for building service-water heating in Chapter 49, and for various process applications in Table 1. Measured demands of several types of buildings are given in Table 10, Chapter 18.

Methods of estimating *annual* steam requirements for heating various types of buildings are also given in Chapter 18. Table 7 in Chapter 18 lists average annual steam consumption per degree day for buildings located in all sections of the United States. Annual steam requirements for building service-water heating are given in Table 2. Table 1 may be used to estimate annual consumptions for process applications if the hourly requirements are multiplied by the hours per year the equipment will be in use.

Additional data on steam requirements of various types of buildings in a number of cities may be found in the *District Heating Handbook*, Third Edition.

### STEAM DISTRIBUTION PRESSURES

The pressure at which the steam is to be distributed will depend upon that available at the plant and pressure requirements of apparatus to be served.

The advantages of low-pressure distribution (2 to 50 psig) compared



TABLE 1. UNIT STEAM CONSUMPTION OF PROCESS EQUIPMENT<sup>a</sup>

| KITCHEN APPLIANCES (EXCLUSIVE OF WATER HEATING)         | CONSUMPTION, <sup>b</sup><br>LB PER HR | PRESSURE,<br>PSIG |
|---------------------------------------------------------|----------------------------------------|-------------------|
| Stock and vegetable kettles (per 5 gal)                 | 20.0                                   | 7-20              |
| Vegetable steamers (per compartment)                    | 40.0                                   | 7-20              |
| Steam tables (per sq ft)                                | 1.7                                    | 7-20              |
| Bain-Maries (per sq ft)                                 | 3.4                                    | 7-20              |
| Coffee urns (per gal)                                   | 3.4                                    | 7-20              |
| Water urns (per gal)                                    | 5.0                                    | 7-20              |
| Soup warmers (30 X 30 X 28 in.)                         | 100.0                                  | 7-20              |
| Egg boilers (3 compartments)                            | 18.0                                   | 7-20              |
| Clam, lobster, and potato steamers (per compartment)    | 40.0                                   | 7-20              |
| Oyster pots                                             | 18.0                                   | 7-20              |
| Plate and cup warmers (per 20 cu ft)                    | 35.0                                   | 7-20              |
| Food-warming ovens (per 20 cu ft)                       | 35.0                                   | 7-20              |
| Silver burnisher and washers                            | 69.0                                   | 7-20              |
| Dishwashers (per tray)                                  | 60.0                                   | 7-20              |
| LAUNDRY EQUIPMENT                                       |                                        |                   |
| Tumblers                                                |                                        |                   |
| 40 X 94 in.                                             | 360                                    | 100               |
| 30 X 36 in.                                             | 225                                    | 100               |
| Washers, (per gal water heated)                         | 1                                      | 15-100            |
| Flatwork ironers,                                       |                                        |                   |
| 100 to 120 in. chest type (per roll)                    | 60                                     | 100               |
| 60 to 100 in. cylinder type (per machine)               | 60-120                                 | 100               |
| Standard presses                                        | 105                                    | 100               |
| Large shirt body presses                                | 190                                    | 100               |
| Cuff and neckband presses                               | 15                                     | 100               |
| Sleevers                                                | 12                                     | 100               |
| Steam-electric irons                                    | 8                                      | 100               |
| Woolen pressing machines                                |                                        |                   |
| Large—electric vacuum                                   | 25                                     | 65                |
| Small—electric vacuum                                   | 12                                     | 65                |
| Large—steam vacuum                                      | 35                                     | 65                |
| Small—steam vacuum                                      | 20                                     | 65                |
| Feather cleaning and sterilizing<br>15 pillows per hr   | 175                                    | 100               |
| HOSPITAL EQUIPMENT                                      |                                        |                   |
| Sterilizers, for bottles or pasteurization (per bottle) | 1                                      | 40                |
| Sterilizers, for water, (per gal)                       | 12                                     | 40                |
| Sterilizers, for instruments and utensils,              |                                        |                   |
| 8 X 9 X 18 in., water depth 3 1/4 in.                   | 27                                     | 40                |
| 9 X 10 X 20 in., water depth 3 1/4 in.                  | 30                                     | 40                |
| 10 X 12 X 22 in., water depth 4 in.                     | 39                                     | 40                |
| 12 X 16 X 24 in., water depth 4 in.                     | 60                                     | 40                |
| 10 X 12 X 36 in., water depth 4 in.                     | 66                                     | 40                |
| 16 X 15 X 20 in., water depth 10 in.                    | 92                                     | 40                |
| 20 X 20 X 24 in., water depth 24 in.                    | 144                                    | 40                |
| Sterilizers, for instruments @ 240-250 F,               |                                        |                   |
| 12 X 20 in.                                             | 48                                     | 40                |
| 14 X 22 in.                                             | 60                                     | 40                |
| 16 X 24 in.                                             | 72                                     | 40                |

TABLE 1. UNIT STEAM CONSUMPTION OF PROCESS EQUIPMENT (CONCLUDED).

| HOSPITAL EQUIPMENT (CONTINUED)       | CONSUMPTION,<br>LB PER HR | PRESSURE,<br>PSIG |
|--------------------------------------|---------------------------|-------------------|
| Sterilizers, for surgical supplies   |                           |                   |
| 10 X 20 in.                          | 10                        | 40                |
| 12 X 20 in.                          | 22                        | 40                |
| 14 X 22 in.                          | 28                        | 40                |
| 16 X 24 in.                          | 38                        | 40                |
| 16 X 36 in.                          | 54                        | 40                |
| 20 X 28 in.                          | 60                        | 40                |
| 20 X 36 in.                          | 78                        | 40                |
| 20 X 48 in.                          | 98                        | 40                |
| 20 X 60 in.                          | 124                       | 40                |
| Sterilizers, (autoclave) (240-250 F) |                           |                   |
| 15.5 X 24 in.                        | 24                        | 40                |
| 17.5 X 26 in.                        | 32                        | 40                |
| 21.5 X 30 in.                        | 40                        | 40                |
| 24 X 36 in.                          | 42                        | 40                |
| Disinfectant, mattress               |                           |                   |
| 30 X 42 X 84 in.                     | 42                        | 35-60             |
| 60 X 66 X 108 in.                    | 318                       | 35-60             |
| Blanket warmers                      |                           |                   |
| 18 X 24 X 72 in.                     | 4                         | 35-60             |

<sup>a</sup> From District Heating Handbook (National District Heating Association, Third Edition, 1951).  
<sup>b</sup> These values represent approximate requirements after warm-up period.

with high pressure are: (1) lower heat loss per square foot of pipe surface; (2) less trouble with traps and valves; (3) simpler problems in pressure reduction at the buildings; and (4) general reduction in maintenance costs. With distribution pressures not exceeding 50 psig, there is less danger if the full distribution pressure should build up in the radiators or heaters through the faulty operation of pressure-regulating valves. With pressures higher than 50 psig, a second pressure-reducing valve or some form of emergency relief is required to prevent excessive pressures in the radiators or other heaters.<sup>1</sup>

The advantages of high-pressure distribution are: (1) smaller pipe sizes; (2) availability of the steam for various other operations requiring higher pressures than the building heating system; and (3) wider flexibility in allowance for maximum pressure drop. Where distribution pressures

TABLE 2. ANNUAL STEAM CONSUMPTION FOR WATER HEATING FOR VARIOUS TYPES OF BUILDINGS, PER CU FT OF VOLUME<sup>a</sup>

| TYPE OF BUILDING | CONSUMPTION,<br>LB/(Yr)(Cu Ft) | CONSUMPTION LB/(Yr)<br>(Cu Ft)(100 F DEG<br>TEMP. RISE OF WATER) |
|------------------|--------------------------------|------------------------------------------------------------------|
| Hotel            | 3.20                           | 2.66                                                             |
| Residence Club   | 2.56                           | 2.11                                                             |
| Apartment House  | 2.41                           | 1.99                                                             |
| Department Store | 0.95                           | 0.79                                                             |
| Office           | 0.85                           | 0.71                                                             |
| Theatre          | 0.57                           | 0.48                                                             |
| Parking Garage   | 0.46                           | 0.38                                                             |

<sup>a</sup> Based on analysis by fourteen district heating companies from metered consumptions. Building volume is approximate gross volume.  
<sup>b</sup> From District Heating Handbook (National District Heating Association, Third Edition, 1951, p. 347).

are not as high as desired, higher pressures can be obtained by use of a steam compressor.<sup>2</sup>

It is sometimes desirable to install a separate high-pressure line from the boiler plant for steam supply to laundries or other high-pressure equipment rather than to operate the entire distribution system at higher pressures.

### BOILER PLANTS

In the design of a plant for district heating, consideration should be given to the following factors:

1. *Annual load factor.* The ratio of the average hourly plant send-out (defined as rate of flow to the distribution system) to the maximum hourly send-out, which is a direct measure of the extent to which investment in facilities is used. This factor is often employed to determine savings by equipment offering higher efficiency. The load factor for space heating is usually between 10 and 30 percent. For space heating

TABLE 3. LOAD DURATION FOR TYPICAL DISTRICT-HEATING SYSTEM  
(Cumulative Hours of Plant Send-out per Year at Various Loads Expressed in Percent of Peak Hourly Load\*)

| LOAD % OF PEAK | HOURS PER YEAR | LOAD % OF PEAK | HOURS PER YEAR | LOAD % OF PEAK | HOURS PER YEAR |
|----------------|----------------|----------------|----------------|----------------|----------------|
| 100            | 5              | 70             | 750            | 30             | 4100           |
| 95             | 40             | 65             | 1050           | 20             | 5150           |
| 90             | 90             | 60             | 1400           | 15             | 5700           |
| 85             | 150            | 55             | 1800           | 10             | 6400           |
| 80             | 300            | 50             | 2200           | 6              | 8760           |
| 75             | 500            | 40             | 3100           |                |                |

\* Based on curve on page 89, *District Heating Handbook*, Third Edition, 1951.  
Note: A plant having a peak send-out of 100,000 lb per hr will send out 80,000 (80 percent of 100,000) lb per hr or more for 300 hr per yr.

plus additional steam requirements such as water heating, cooking, or laundry, it is between 15 and 40 percent. Load factors for various types of buildings are given in Table 10, Chapter 18.

2. *Duration of load.* The cumulative number of hours for the various plant send-outs, is used to determine the number and sizes of boilers in order to effect most efficient loading of individual units and of the plant as a whole. The cumulative number of hours a typical district heating plant will send out steam at various loads, with loads expressed in percentage of maximum hourly rate, is given in Table 3. It will be noted that the duration of load for the higher send-outs is very low.

3. *Feed-water treatment.* This is desirable in plants to prevent corrosion and scale formation.

4. *Smoke abatement.* This is a modern requirement. The installation of suitable fuel-burning and dust-collecting equipment to limit the emission of smoke and fly ash is usually necessary.

5. *Plant location.* A boiler plant should be situated where fuel deliveries, water supply, and other utility services are convenient and should be as near as possible to the distribution center in order to simplify and shorten the distribution piping.

### STEAM DISTRIBUTION PIPING

The methods used in district heating work for the distribution of steam are applicable to any problem involving the supply of steam to a group of buildings. The first step is to establish the route of the pipes which is influenced by local conditions and investment.

Important points in laying out distribution piping are:

1. The depth of the conduit should be kept at a minimum. Excavation costs are a

large factor in the total cost. On the other hand, institutional lawns will be damaged if steam conduit is too close to the surface.

2. The use of basement or sub-sidewalk space for the distribution piping where feasible may reduce the cost of installation and maintenance.

3. In some industrial and institutional applications, the distribution piping may be installed, entirely or in part, above ground. This method of construction has the advantage of requiring no excavation and permits easy maintenance but it may introduce freeze-up problems. Thin corrugated aluminum sheets are available for covering the insulation on lines exposed to the weather.

4. Piping routed in loops with suitable valves to provide alternate feeds for major loads, allows service to be maintained despite trouble in any one feeder.

### PIPE SIZES

After establishing the route of the pipes, the next step is to determine the pipe sizes. In district heating work it is common practice to design the piping system on the basis of pressure drop. The initial pressure and the minimum permissible terminal pressure are specified, and the pipe sizes are so chosen that the required amount of steam, with suitable allowances for future increases, will be transmitted without exceeding this pressure drop. The steam velocity is therefore almost disregarded and may be very high. Velocities of 35,000 fpm are not considered high. By the use of high velocities the pipe sizes are kept to a minimum with consequent savings in investment. Some lines in a loop system may need to be increased in size in order to handle reverse-direction flow in emergencies.

The steam flowing through any section of the piping can be computed from a study of the hourly steam requirements of the several buildings served. Steam requirements for ventilation-air heating, water heating, laundering, cooking, or processing, should be individually calculated and added to the heating load. Unusual features, such as large heaters for swimming pools, should not be overlooked.

When the lengths of pipe, steam quantities, and initial and terminal pressures have been chosen, the pipe sizes can be calculated by means of Babcock's pressure drop formula given in Table 2 of Chapter 21. The district-heating industry uses *Unwin's* formula for determining pipe sizes because pressure drops can be determined simply and directly from a chart. This formula has been checked by tests, and found correct within ranges of velocity used in district heating. A convenient chart developed from this formula is available from the *National District Heating Association*,<sup>3</sup> and provides a simple yet accurate means for determining pipe sizes.

### CONDUITS FOR PIPING

Conduits for underground steam pipes should be reasonably waterproof and able to withstand earth and traffic loads.

Since it is difficult to make a concrete or masonry conduit absolutely watertight, provision should be made for some seepage. The pipe should be protected by a waterproof jacket over the insulation, unless subject to actual submersion, and the seepage should be drained from the inside of the conduit. Underdrainage of the conduit is generally obtained by means of a tile drain laid in gravel underneath the conduit. The tile underdrain should discharge to a sewer or some other drainage point. Manholes are required at intervals for access to valves, traps, and some types of expansion joints.

There are many types of conduits, some of which are prefabricated prod-

ucts and some of which are built in the field. The more common forms are illustrated in Fig. 1.

Conduits B and C are prefabricated. In conduit C the pipe is insulated and then placed concentrically within the metal jacket. The intervening space between jacket and insulation is filled with high-melting-point asphalt which becomes the protective medium for the insulation. Conduit B has spirally corrugated galvanized ingot iron surrounding the insulation and high-melting-point asphalt is applied to the outside of the conduit. The pipe is supported by precast rings to maintain alignment and to prevent pressure on the insulation.

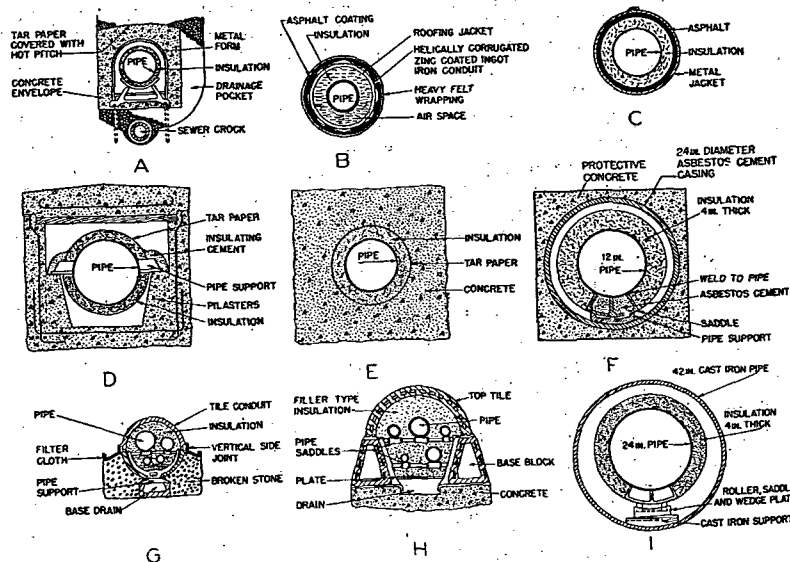


FIG. 1. CONSTRUCTION DETAILS OF CONDUITS\*

\* From District Heating Handbook, Third Edition.

Conduits A and D are of concrete-box construction and are typical of conduits built of common materials.

Conduit E is of solid-pour construction wherein concrete is poured around an insulated steam pipe. If insulation is of a rigid type it can support the pipe; otherwise, the pipe should be supported independently. A space may be left around the pipe by using insulation larger than the outside diameter of the pipe, the space helping to avoid crushing of insulation if the pipe tends to rise when steam is admitted to a cold line.

Conduit F is made of asbestos-cement pipe joined together with special couplings and enclosed in a protective concrete envelope. The steam pipe is supported within the conduit on specially-designed slip-type supports with saddles welded to the line.

Conduits G and H are constructed of specially-shaped, vitrified bell and spigot tile. Conduit G is also available in cast iron. This construction

is intended for the support of excessive loads and to withstand shocks, such as are found beneath railroad tracks.

Conduit I is of cast-iron construction with lead-caulked joints. It is watertight and intended for special applications.

There are, in addition to those mentioned, several conduits which use an insulating concrete as pipe insulation. The insulating effect of the concrete is obtained through air cells formed by a special process or by a mixture of an insulating material with cement. An insulating hydrocarbon in granular form is available for trench fill around underground lines. This material fuses to the lines with application of heat, forming a semi-plastic, waterproof zone next to the pipe.

### ACCESSORY EQUIPMENT

Provision should be made to take care of expansion and contraction of the piping in order to prevent stress in the pipe or fittings. Anchors can be special fittings or U-shaped steel straps which partially encircle the pipes, and are firmly bolted to a short length of cast or stainless steel set in concrete.

An expansion joint, offset, or bend should be placed at or between each two anchors. *Advantage should be taken of the flexibility of piping to absorb expansion wherever feasible.* Information on provisions for expansion will be found in Chapter 27. The section on Pipe Tunnels in this chapter contains further comment on expansion joints and anchors. Manholes for expansion joints should be kept free of water by proper drainage and should be of adequate size. Small manholes discourage proper maintenance.

Pipe lines should be of welded steel construction, flanges being used only to permit removal of equipment in accessible places. Piping should be properly supported and equipped with guides to prevent pipe deviation from a straight line between expansion devices.

A proper hydrostatic test should be made on the assembled line before the pipe welds and other joints are insulated. The hydrostatic test pressure should be at least one and one-half times the maximum service pressure, and it should be held for a period of at least two hours without evidence of leakage.

### INSULATION

Insulating materials constitute a primary element of district steam distribution structures and must be suitable for underground service. Insulation should be noncombustible, vermin-proof, moisture-resistant, durable, non corrosive to steel pipe when wet, and able to retain its position in relation to the pipe line without service maintenance. It should be relatively unaffected by such chemicals as are usually found in ground or other contaminated waters. It should have the lowest practical heat conductivity consistent with the given requirements. Underground insulation can be applied directly to the pipe or poured as a monolithic structure in a suitable duct. Insulation is discussed further in Chapter 28.

### RETURN OF CONDENSATE

If the condensate can be returned to the plant to be used for boiler feed water at an overall cost less than that required to process raw water, the installation of return lines parallel to the steam supply lines should be given consideration.

Where steam and return piping are installed in the same conduit, the

return piping usually follows the same grade as the steam piping. Return of condensate by gravity is desirable, but usually, the condensate is pumped back under pressure.

In a heating system the pipes carrying condensate are more subject to corrosion than other parts of the system. Care must be taken to give proper pitch to the pipes and to provide proper venting of noncondensable gases. (See Chapter 43, Corrosion.)

### PIPE TUNNELS

Because of their relatively high first cost as compared with smaller conduits, *walking tunnels* are usually not provided for steam mains in the district-heating industry unless they are required to accommodate miscellaneous other services or to provide underground passage between buildings. However, in institutions a different approach may be justified. Many institutional buildings are expected to last several times longer than the life of underground conduit.

Adequate maintenance programs are frequently harder to initiate and keep up in institutions than in industry. As an underground steam line approaches the end of its reasonable life, traps, threaded connections, valve bonnets, gaskets, and expansion joints may require nearly continuous maintenance. Without walking tunnels it might be impossible to maintain steam service. When institutional appropriations for steam-main replacement are involved, some institutions try to postpone construction of new buildings until sufficient funds for walking tunnel extensions are available.

Tunnels are usually built of reinforced concrete or brick and are waterproofed on the outside. Provision for drainage is essential. Repair work along main lines may be seriously hampered if tunnels are less than 4 ft wide by 6 ft high. Tunnels with sidewalks running over the top are effective in melting snow. Special precautions to reduce corrosion from ceiling condensation is in order where ceilings are close to grade.

Tunnel piping is generally supported on racks at the side or sides of the tunnel or by ceiling hangers. Roller frames and insulation saddles may be used, or the lines may be placed directly on horizontal pipe supports. The latter construction may cause appreciable heat loss, due to bare pipe at the supports. Special attention should be paid to the corrosive effect of moisture in tunnels. Steel pipe supports and anchors in contact with the floor are especially vulnerable. Pipe supports made of steel pipe may be welded (using proper welding rods) to short lengths of cast-iron pipe embedded in the tunnel floor. Dipping the lower portion of supports in a protective coating before installation is helpful. Concrete mounds around the pipe supports at the floor help to divert water from the support. Pockets for supports should not extend through floors, walls, or ceilings, as entry of ground water will reduce the life of the support.

Fewer expansion loops and more expansion joints are expected in tunnels. Possibility of superheat as well as the steam pressure must be considered in providing for pipe expansion. Extraction steam from a turbine may be supplemented at night by steam direct from high-pressure boilers, and consequently the steam may be superheated as it passes through reducing valves at the power plant. Unanticipated superheat may cause excessive expansion which may damage anchors and the distribution piping system. Desuperheaters may be required ahead of the distribution piping. Thermometers at critical points will be helpful.

Spare expansion capacity in expansion joints may be desirable due to the following:

1. Workmen may allow unexpected tolerances in cutting and welding of lines.
2. Due to seasonal conditions, the temperature of the line at time of welding may not be at the lower design temperature or the temperature of the line may not be uniform at time of welding.
3. Partial failure of reducing valves may cause line pressures to exceed the design pressure.

Pipe anchors should be designed for line thrusts occurring with valves both open and closed. Liberal factors of safety for corrosion are desirable in sizing anchors. The tendency of anchors to slip along a pipe may be reduced by welding steel lugs to the pipe on either side of the anchor. The lugs will bear against the anchor in case slippage of U-straps or U-bolts occurs.

Branch lines will exert side thrusts on mains and produce distortion of the main and misalignment of expansion joints near the branch. Good design can be achieved by locating anchors exactly at tees and at Y-branches. Unless anchor designs are specifically detailed, workmen tend to install anchors on one side of branch tees, thereby causing distortions that the anchor was supposed to avoid. Where branches do not coincide conveniently with fixed anchors, sliding anchors may be used to prevent distortion of the main and yet allow movement of the branch with movement of the main. Special pipe guides may be necessary to prevent distortion of expansion joints. Expansion joints with both an anchor base and a branch service connection can be effectively used to eliminate troubles caused by branch line thrusts.

Where excessive tunnel temperatures will reduce efficiency of maintenance personnel, extra thick insulation may be desirable. For the same reason return lines in tunnels are insulated. For further comments on insulation in tunnels see Chapter 28.

Electric conduit for tunnel lighting may not last beyond the early life of the tunnel whether exposed or embedded in the concrete. Knob and tube wiring and bare lamps may be more satisfactory. Extensive tunnel systems effectively use 220 volt lamps to offset line loss.

Tunnel heat and high humidity may make tunnels uninhabitable for workmen when steam leaks must be serviced. Portable fans to blow air into one manhole and to pull it out of another may be essential. In addition, general ventilation obtained by a permanent fan, continuously operating, may be necessary. Perforated manhole covers located at ends of runs allow air to enter and sweep the tunnels. Doors across tunnels may be opened or closed to force extra ventilation air through that portion of a tunnel system where repair work is being done.

### BUILDING PIPING AND EQUIPMENT

There are certain fundamental principles that should be followed in the design of a building heating system which is to be supplied from district steam mains. Although some of these apply to any building, they have been demonstrated to be particularly important when district steam is used.

Most district heating companies enforce certain regulations regarding the consumer's installation, partly to safeguard their own interests, but principally to insure satisfactory and economical service to the consumer. When an installation is designed, local regulations should be observed.

Typical service connections are shown in Fig. 2 for low-pressure service and Fig. 3 for high-pressure service. The district-heating industry refers to valves according to their functional use. The pressure-reducing valve reduces pressure to a safe point, and the pressure-regulating valve regulates pressures to that required by equipment served. Fig. 2 illustrates the use of a pressure-regulating valve with a bypass such as generally provided for larger installations. This bypass permits the operation of the system in case of failure in the pressure-regulating valve. In the smaller sizes, the bypass is usually omitted. When servicing is required, the pressure-regulating valve can be removed, a filler installed, and the gate valves (part 7 in Fig. 2) used to throttle the flow of steam until repairs are made.

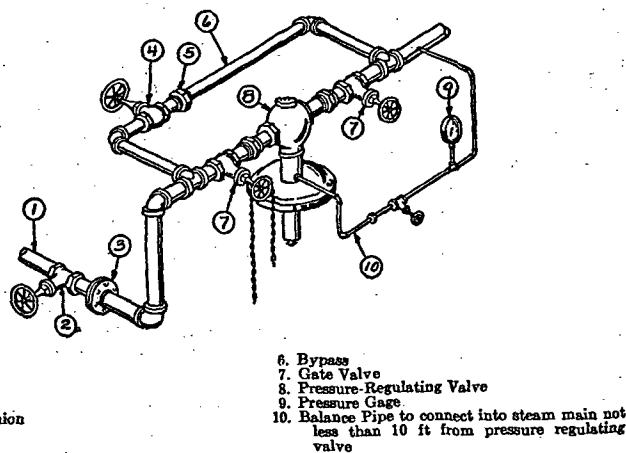


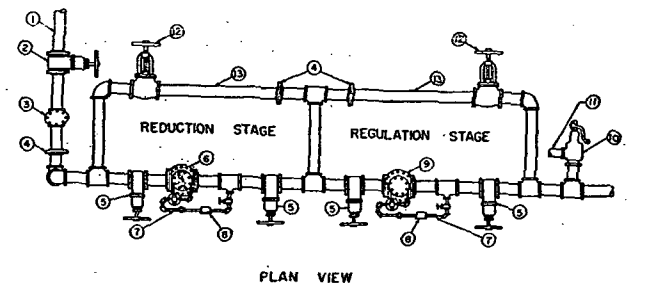
FIG. 2. PRESSURE-REGULATING VALVE WITH BYPASS\*

\* From District Heating Handbook, Third Edition.

Fig. 3 shows a typical installation where the pressure in the district-steam main exceeds 50 psig, which pressure is usually higher than can safely be applied to building heating systems, as much heating equipment is not intended to withstand more than 15 psig.<sup>1</sup> The first or pressure-reducing valve effects the initial pressure reduction. The pressure-regulating valve controls the steam at the desired pressure.

It is often advisable to install a separate pressure-regulating valve for each steam use in the building such as for water heating, building heating, cooking, so that each system may operate at the optimum pressure.

Pressure-reducing valves are more fully described in Chapter 21. For use with district heating, dead-end type valves of the pilot-operated or spring-loaded type are generally preferred where applicable. Pressure-regulating valves should be sized to supply adequately the maximum steam requirements of the heating system or equipment. This is especially important with temperature control systems using intermittent flow of steam



1. Service Pipe
2. Service Valve
3. Strainer
4. Flanged Union
5. Gate Valve
6. Pilot-Operated Pressure-Reducing Valve
7. Balance Line

PLAN VIEW

8. Pressure Gage
9. Pilot-Operated Pressure-Reducing Valve
10. Pressure Relief Valve (optional)
11. Vent
12. Globe Valve
13. Bypass Line

Note: All fittings should be American Standard Class 250 cast iron.

FIG. 3. TWO-STAGE PRESSURE-REDUCING AND PRESSURE-REGULATING EQUIPMENT\*

(Used Where High-Pressure Steam is Supplied for Low-Pressure Requirements).

\* From District Heating Handbook, Third Edition.

to heat the building. Pressure-regulating valve capacity recommended for use with various types of temperature control are shown in Table 4.

### ZONING AND OPERATION

**Zoning.** Where the hours of occupancy or heating loads differ in various sections of the building, it is good practice to install separate supply lines to the different sections. For example, in an office building with stores or restaurants on the first floor which are open in the evening, a separate main supplying the first floor will permit the steam to be shut off from the remainder of the building in the late afternoon. The division of the building into zones, each with a separately-controlled heat supply, is sometimes desirable, as it permits the heat to be adjusted according to variations in sunshine and wind.

Fig. 4 shows a typical service installation with a separate line to the

TABLE 4. SUGGESTED CAPACITY OF PRESSURE-REGULATING VALVES AND TRAPS

| TYPE OF CONTROL                                                                        | PRESSURE-REGULATING VALVE CAPACITY, LB/(HR) (SQ FT OF RADIATION) <sup>a</sup> | TRAP CAPACITY, LB/(HR) (SQ FT OF PIPE AND RADIATION) <sup>b</sup> |
|----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------|
| Continuous or modulating operation, intermittent with on periods over 3 hr in duration | 1/2                                                                           | 1/2                                                               |
| Intermittent operation with on periods of 1/2 to 3 hr in duration                      | 1/2                                                                           | 1/2                                                               |
| Intermittent operation with on periods of 1/4 hr or less                               |                                                                               | 1/4 <sup>b</sup>                                                  |

<sup>a</sup> Square Feet EDR.

<sup>b</sup> Except for drip traps on mains which should be 1 lb per sq ft EDR.

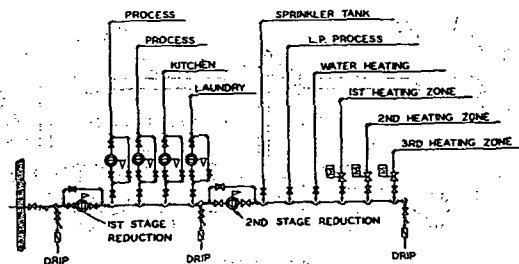


FIG. 4. STEAM SUPPLY INSTALLATION WITH HEADER FOR PROCESS AND ZONE CONNECTIONS

various heating zones and process equipment. If initial pressure is below 50 psi the first stage pressure-reducing valve may be omitted.

Heat supply should be graduated according to variations in the outside temperature. The maximum in economical operation and satisfactory heating can only be obtained by the use of automatic temperature control (see Chapter 39).

Rapid draining and venting of the heating system should be obtained by means of suitable traps and air vents in order to obtain rapid circulation and quick heating. This is particularly important with intermittent-type temperature-control equipment. The selection of traps is discussed in Chapter 21. Suggested trap capacities are given in Table 4.

Provision should be made for conveniently shutting off the steam supply at night and at other times when heat is not needed. A considerable amount of heat can be saved by shutting off steam at night and other times when optimum building temperatures are not required. It is necessary, however, to have an ample amount of heating surface in order that the building may be quickly warmed after such turn-off periods.

Residual heat in the condensate should be salvaged. This heat may be salvaged by means of an air-cooling coil, or as is more frequently done, by a

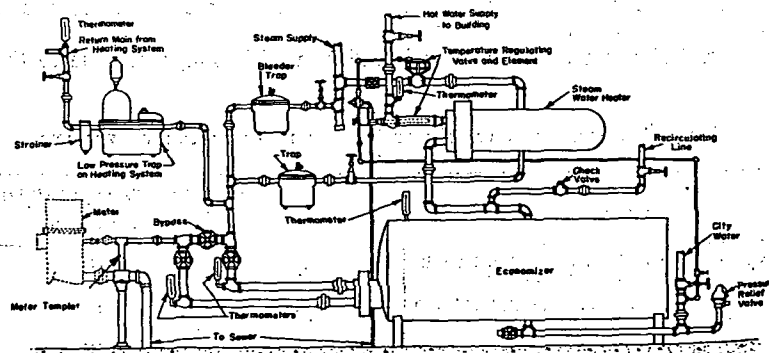
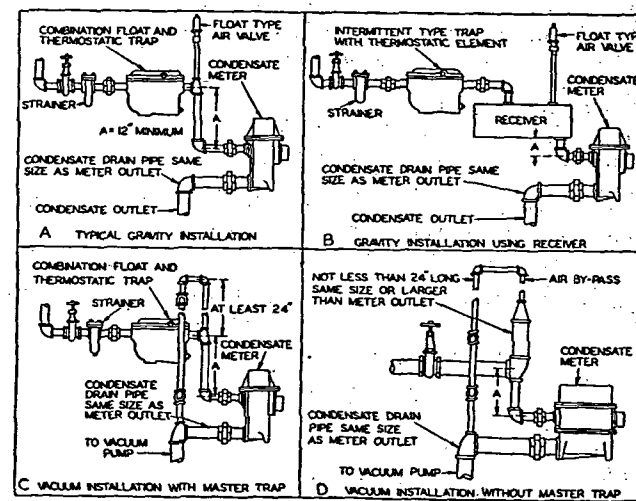


FIG. 5. METHOD OF INSTALLING A WATER HEATER AND ECONOMIZER IN A GRAVITY HEATING SYSTEM

water-heating economizer, shown in Fig. 5, which preheats the hot water supply to the building.

The condensate from the heating system, after leaving the traps, passes through the economizer. The water supply to the heater passes through the economizer, absorbing heat from the condensate. If the hot-water system in the building is of the recirculating type, the recirculating line should be connected between the economizer and the water heater proper,



| METER CAPACITY<br>LB PER HR | 250                | 500 | 750 | 1500 | 3000 | 6500 | 12000 |
|-----------------------------|--------------------|-----|-----|------|------|------|-------|
|                             | DIMENSION A—INCHES |     |     |      |      |      |       |
| Diagram B.....              | 4                  | 4   | 8   | 8    | 8    | 12   | 12    |
| Diagram C.....              | 12                 | 12  | 15  | 15   | 15   | 18   | 18    |
| Diagram D.....              | 12                 | 12  | 15  | 15   | 15   | 18   | 18    |

FIG. 6. CONDENSATE METER INSTALLATION DETAILS

not at the economizer inlet, because the recirculated hot water is itself at a high temperature.

Since the heating-system load and the hot-water demand are not coincident a greater amount of heat can be extracted from the condensate if storage capacity is provided for the preheated water. Frequently, therefore, the economizer coils are submerged in the storage tank.

### METERING

Meters are classified into two groups: *Condensate Meters* and *Flow Meters*.

The *Condensate Meter* is a popular type for use where all the condensate can be brought to a common point for metering purposes. Its simplicity

of design, ease in testing, accuracy at all loads, low cost, and adaptability to low pressure distribution have made it standard equipment with many heating companies.

Condensate meters should not be operated under pressure; they are made for either gravity or vacuum installations. Typical meter installations are shown in Fig. 6. In diagram A a continuous-flow type trap is shown installed ahead of the meter, while in diagram B an intermittent type trap is used. In the latter case, a receiving tank must be placed between the trap and meter to prevent intermittent overloading of the meter. When measuring the discharge from a vacuum pump, a vented receiver should always be installed ahead of the meter.

Installations of meters in a vacuum return line are shown in diagrams C and D. In diagram C a master, float-type, continuous-flow trap is installed immediately ahead of the meter to prevent steam from entering it in case of leaking radiator or fixture traps. Where individual traps are reliable, connections may be made as shown in diagram D.

*Flow Meters* used for district heating work are of three types: *Area Meters*, *Head Meters* and *Velocity Meters*. Meters are described in Chapter 4, *Fluid Flow*. Flow meters are generally used for measuring send-out from plants, high-pressure requirements in buildings, and in installations where all of the condensate cannot be returned to a central point. Further information on flow meters is available in the *District Heating Handbook* and from publications of the Fluid Meter committee of the *American Society of Mechanical Engineers*.

#### REFERENCES

<sup>1</sup> American Standard Code for Pressure Piping, ASA B31.1-1955 (*American Standards Association*).

<sup>2</sup> *District Heating Handbook*, Third Edition, 1951, p. 329 (*National District Heating Association*).

<sup>3</sup> Graphical Solution of Unwin's Formula (a chart published by *National District Heating Association*).

#### CHAPTER 30

### CENTRAL SYSTEMS FOR AIR CONDITIONING

Features of Systems, Zoning, Humidity Control, Cooling Load, Heating Load, Air Quantity and Temperature Differential, Unitary-Central Systems, Low- and High-Pressure Induction Convectors, Dual-Duct Systems, Fan and Coil Units, Evaporative Cooling, Precooling, Sensible Cooling with Un-wetted Coils, Selection of Type of System, Location of Apparatus

THE term, central, applied to an air conditioning system implies that the equipment such as fans, coils, filters and their encasement are designed for assembly in the field rather than in a factory as a unit. As a central system usually serves several different rooms, or spaces individual controls are required for each room.

#### FEATURES OF CENTRAL SYSTEMS

One advantage of a central air supply system is that one apparatus serving many rooms may involve a lower investment cost than that for a number of self-contained plants, each serving a single room. A central system may occupy basement or attic space that is relatively unimportant, whereas individual factory-assembled apparatus placed in each room may occupy otherwise valuable space. Another advantage of a central system is accessibility for servicing, since it is possible to provide doors in the encasement for cleaning and inspecting all of the component parts in a manner usually superior to that practicable with compact factory-assembled equipment. In addition service is concentrated in one or just a few places.

Central air conditioning systems usually are connected by ducts with the various rooms served, and preferably have exhaust fans that may effect complete removal and disposal of any desired proportion of the air. The return-air fan may return air to the supply system for recirculation, as a measure of economy of fuel or refrigeration.

Central air conditioning systems are served by heating and refrigerating equipment which may be located at some distance from the air supply apparatus, and which may serve one or more central air supply systems.

Fig. 1 is a sketch of a typical year-round central system. Outdoor air enters from an intake preferably on that side of the building least exposed to solar heat, and not close to the ground or to a sun-heated or dust-gathering roof. The outdoor-air damper is split into two sections, minimum outdoor-air and maximum outdoor-air, with the maximum outdoor-air damper interlocked with the return-air damper in such a manner that as the outdoor-air volume increases the return-air volume decreases. The return air duct or connection could come from a return-air fan. All the air passes through filters which must have ample room on both sides of the filters for servicing. The filters may be of a mechanically-cleaned type, a replaceable cell type, or may be electronic as described in Chapter 34.

The cleaned air passes to the equipment that changes its temperature



and humidity. Except in very warm climates, heating or tempering coils are required to warm the entering outdoor air to a temperature above freezing, the heat being supplied by means of hot water or steam. Cooling coils provide the necessary sensible cooling and dehumidification. The coils may be chilled by direct expansion of an approved refrigerant within the tubes, or by a pump-circulated liquid such as water or brine. A water-tight drainage tank must be installed under the cooling coil and should extend for a distance toward the fan.

Reheater coils utilizing steam or hot water reheat the air in warm weather for control purposes or bring the air to its final temperature in cold weather. For humidification in dry weather, water sprays are used either separately

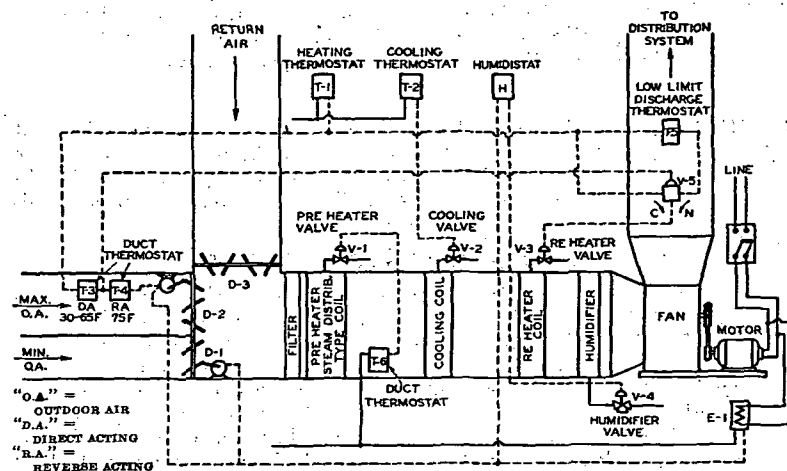


FIG. 1. TYPICAL YEAR-ROUND CENTRAL SYSTEM

as shown or combined with the cooling coils having the spray nozzles directed against the coil surfaces. The spray water may be circulated by a small pump from the water tank under the spray chamber.

The general requirements for the control of the various components of the central station apparatus are covered in Chapter 39. The functioning of a typical set of controls as illustrated in Fig. 1 is as follows:

Whenever the fan is started, solenoid air valve or relay E-1, actuated by the fan motor starter, opens minimum outdoor-air damper D-1, places humidistat H in service, and allows duct thermostats T-3 and T-4 to control the maximum outdoor-air damper D-2 and the return-air damper D-3.

When the fans stop, E-1 is de-energized to close the outdoor-air dampers and also to close humidifier valve V-4.

Thermostat T-1 positions steam valve V-3, on the reheater coil, to maintain a constant space temperature. As the space temperature rises, T-1 positions reheater valve V-3 to a closed or to a minimum open position, as determined by low limit discharge thermostat T-5. Duct thermostat T-6, in the preheater discharge, positions preheater coil valve V-1 to maintain a constant preheater discharge temperature.

On rising outdoor temperature, between 30 F and 65 F, duct thermostat T-3 located in the outdoor-air intake, moves maximum outdoor-air damper D-2 toward the open position provided that T-1 is satisfied. At 65 F outdoor, D-2 will be fully open and return-air damper D-3 will be fully closed.

As the outdoor-air temperature rises above 65 F, duct thermostat T-3 positions V-5 in such a way as to by-pass low limit thermostat T-5, so that reheater coil valve

V-3 is operated directly from thermostat T-1. As outdoor-air temperature rises from 65 F to 75 F, duct thermostat T-4 gradually closes maximum outdoor-air damper D-2 and opens return-air damper D-3.

Cooling thermostat T-2 positions cooling coil valve V-2 to admit more chilled water as the space temperature rises.

Humidistat H positions humidifier valve V-4 to maintain the desired humidity in the conditioned space.

### ZONING AND ZONE CONTROL

It is apparent that while an apparatus like that of Fig. 1 would be very desirable for any single room, since in that case the air could be delivered at optimum conditions, the cost of a complete individual system for each room and the space required for the equipment generally would be prohibitive. Economy is favored if the varying requirements of numerous rooms or zones can be simultaneously satisfied by air from a single central supply system.

Various methods are practicable for controlling the temperature, humidity and air movement in various rooms or zones. A measure of control is attainable merely by proportioning the flow of air to each room, though usually such control by throttling dampers is difficult to maintain and should be avoided when possible.

Another scheme is to install a properly proportioned coil in the branch air supply duct serving each room or zone to warm the air to suit the occupants. For example, the air leaving the fan that serves several zones may be cooled, before entering the fan, to the condition favorable for one zone, and the air for each other zone may be reheated by the branch duct coil to the required temperature. It is also possible to circulate a heat absorbing medium in the branch duct coils to reduce the temperature of the air passing to rooms that would be overheated if they received air at the condition leaving the central air supply system. When heat transfer devices are placed in branch ducts for improved temperature control, mechanically circulated water gives excellent results as a heat carrier. The water usually is warmer than the air but it is possible to use water colder than the air.

It is practicable also to use single central air conditioning equipment similar to that shown in Fig. 1, in conjunction with several fans, one for each room or zone. In such cases there may be a separate reheater on the suction side of each relatively small supply fan.

The designer must remember that the various supply fans will compete with each other for air, against the resistance interposed by the filters, coils, etc., that are used in common under such circumstances, and consequently, unless the fans are of backward-curved blade, non-overloading type, they may alternate in carrying more than their share of the air, and thereby cause the air distribution to be chaotic and unsatisfactory.

Another method of controlling temperature in various rooms served by a central air supply system is shown in the sectional elevation, Fig. 2. The supply fan is placed immediately after the humidifier. When cooling the air in hot weather, the humidifier is not operated. The fan will deliver the air through the heating coil and through the cooling coil to the two air pressure chambers A and B at the right of these coils. From these chambers many separate ducts, one of which is shown, each with a double-blade mixing damper, may convey the air to the various rooms. The mixing dampers, one of which is shown, are interlocked so that as the upper one closes, the lower one opens; selecting between them, air in the required quantity from either the warmer chamber A or the cooler one B:

In cold weather no refrigerant is required in the cooling coil, and in hot weather no heating medium is circulated in the heating coil. With this scheme, the control of relative humidity in warm weather is not always sufficiently precise to meet requirements, since the untreated air delivered through the upper coil may be so high in relative humidity that it cannot sufficiently compensate for the nearly saturated air leaving the lower coil. A reheater could be placed if desired, to the right of the lower coil to bring the air in the lower chamber to the desired relative humidity. The simple arrangement of Fig. 2 is admirable in winter and, except where close control of relative humidity is important, may be acceptable in summer.

Another method of attaining temperature control in individual rooms with a year-round central air supply system, is to install a booster fan between the main air supply duct and the air delivery opening to each zone or room, as shown in Fig. 3. Air can then be delivered from the

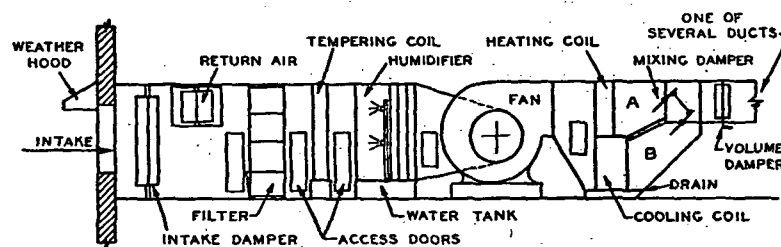


FIG. 2. ALTERNATE ARRANGEMENT OF EQUIPMENT FOR CONTROLLING AIR CONDITION IN CENTRAL AIR SUPPLY SYSTEM

central supply fan through the main duct at some desired condition, for instance, 60 F, 45 percent relative humidity. A double mixing damper near the intake opening of the booster fan, controlled by a thermostat in the room or zone that is served by the fan, is interlocked with an outlet exhaust damper in the spent air opening, so that as more of the room air is recirculated, and as less new air from the main air supply duct is delivered into the room, the spent air outlet is throttled in proportion. In many large installations this principle is applied successfully for zoning different stories in multi-story office buildings, the main supply fan being on the roof, and each booster fan used for supplying the rooms of one orientation of each story. In other cases the booster fans serve only single offices, and therefore are small enough to be concealed above ceilings alongside the main supply duct.

There may be installations in which the use of recirculated air for mixing with new refrigerated and nearly saturated air to control temperature and relative humidity is objectionable. In such cases the general recirculation arrangements of Fig. 1 may be omitted, and heat transfer coils located in the ducts may be used. In some cases where general recirculation is not acceptable, as for all the rooms in an entire building, use of the local circulation of Fig. 3 may solve the problem.

#### HUMIDITY CONTROL

In winter, room relative humidities in excess of 30 percent are seldom required in a system designed for comfort conditioning only, and a low saturating efficiency may be desirable, or even necessary, especially if the

same volume of air is handled as in summer. With a spray type dehumidifier the main sprays may be shut off and only the eliminators need be flooded; which may give sufficient moisture. In other cases, such as those in which cooling coils are sprayed, the spray water supply may be throttled. If the saturation efficiency of the sprays is too low, the spray water may be heated. The amount of heat put into the spray water by open or closed water heaters will be equal to that required to bring the dew-point temperature of the air entering the sprays up to that required before entering the preheater. It is possible, where clean steam is available, to introduce steam directly into the air stream to produce the desired dew-point temperature of supply air. However, the steam must be exceptionally clean, or objectionable odors will result.

It should be noted that the quantity of outdoor air to be introduced is affected by infiltration and leakage. Infiltration will reduce the quantity

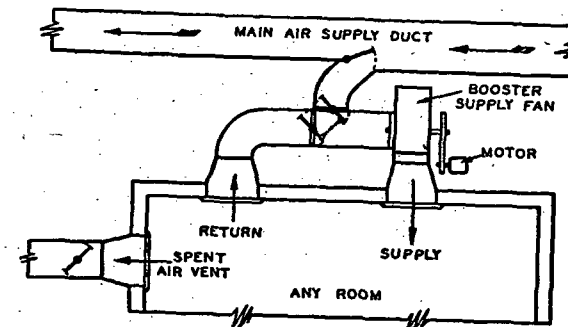


FIG. 3. ARRANGEMENT FOR INDIVIDUAL ROOM TEMPERATURE CONTROL WITH CENTRAL AIR SUPPLY SYSTEM

to be introduced by the system, while leakage may have to be offset by an increase in the quantity of outdoor air.

#### COOLING LOAD

The method of determining the cooling load for a conditioned space or spaces is outlined in Chapter 13. As pointed out therein, many of the items of heat gain are variable and do not reach their maximum values simultaneously. Proper consideration of these peaks and the avoidance of pyramiding these peaks in the cooling load calculations are stressed. Maximum solar heat gain on an east exposure is seldom coincident with the maximum outdoor wet-bulb temperature.

A large difference in the time-incidence of the peaks between various spaces or parts of the same space indicates the necessity for zoning. In a building having an east and west exposure, where solar heat gains forms a fair share of the cooling load, the times of individual zone peaks are apt to be some hours apart, and the peak load of one plus the off-peak load of the other will be substantially less than their combined peak loads. Proper zoning will permit operation to take full advantage of this condition or of similar conditions of non-simultaneous peaks, and will result in a lower total load and in savings in equipment.

A factor similar in effect and closely related to the non-simultaneous occurrence of peak loads, is diversity. Typical of this is the case of a

large department store where the air handling equipment serving a certain space must be sufficient to handle the load created by the throngs of people attending sales in that space. Under such a condition the number of people in other spaces is usually normal or below. While this means that the air handling equipment for certain departments must be large enough to cope with the situation, the refrigeration equipment need be only large enough to handle the average maximum. If a system employing zone recirculating fans and a single central fan and dehumidifier were used, the saving would be reflected in the capacity of the central fan and dehumidifier. Another example of this diversity is found in an office building having restaurants and stores of certain types in the first story and basement. At noon, when the restaurants and stores are crowded, the offices are below normal occupancy.

Heat lag should be carefully considered in the cooling load calculations. In certain types of buildings the effect of solar radiation is still apparent several hours after the sun has shifted from that exposure. In other types having a much lighter construction, the heat gain due to solar radiation decreases markedly with the passing of the sun. Some walls warmed by the sun, may radiate heat long after the passing of the sun, thus requiring lower inside temperatures to offset the radiant energy.

Buildings have considerable heat storage capacity which can often be utilized to great advantage, and which has more than once provided an unexpected safety factor. If a space is kept below the design inside temperature for some time, the interior walls, floors, furniture and fixtures begin to assume the temperature of the space. Where the time is sufficient the entire mass, rather than merely its surface, may reach the room temperature. Thus, when a space has been precooled below the design maximum temperature for a period of time prior to the advent of the peak load, and the heat gain begins to increase to peak conditions, some of the increase is used in raising the temperature of the furniture, fixtures, etc., to the design conditions and the cooling load can be reduced accordingly. However, unless very accurate data with regard to the mass, surface, specific heat, etc., of the items within the space are available, due caution must be used in discounting the cooling load for this storage effect. In the absence of reliable data this allowance is often a matter of experience rather than calculation.

Where air conditioning supply and return ducts pass through unconditioned spaces, there will be a transfer of heat from these spaces to the air in the ducts, even though these ducts are well insulated. An allowance should be made for this heat gain and included in the heat estimate so that air can be supplied at a temperature low enough to offset the rise caused by this heat gain (see Chapter 32). There will also be some heat gain to the air in ducts passing through conditioned spaces, but since a cooling effect is produced in the space through which the duct passes, this is not a loss and usually can be compensated for by adjustment of air quantities between the various spaces.

#### HEATING LOAD

Methods of calculating the heating load are shown in Chapter 12. Many of the factors outlined previously under Cooling Load, such as zoning, non-simultaneous peaks, and diversity, apply in the reverse manner due to the heating requirements instead of the cooling requirements. However, these factors affect the heating load from the standpoint of control of inside conditions, overall performance, and economy of opera-

tion more than from a capacity of equipment standpoint. It is not only necessary to heat a building or space to its design conditions when there is but the merest fraction of normal occupancy, and when there are practically no lights, internal heat, or solar radiation, but it is also necessary to provide capacity to heat the building quickly when sudden cold follows relatively warm weather, as may occur after a week-end or holiday shutdown. However, in normal operation during week-ends and holidays, buildings are usually kept at a holding temperature to prevent the freezing of services. In many cases, less fuel is required to operate the heating plant at a near-normal rate and maintain the building or space at a temperature of 50 to 65 F at such times, than to shut the system down and then bring the temperature back to normal through forced operation of the heat-generating equipment with a consequent loss in efficiency.

#### AIR QUANTITY AND TEMPERATURE DIFFERENTIAL

The difference between the room-air temperature and the supply-air temperature at the outlet to the room is known as the temperature differential. In the theoretical case of a dehumidifier having 100 percent saturating efficiency, and where this air is delivered directly to the room without temperature increases due to heat gain, then the temperature differential is the difference between room temperature and apparatus dew-point temperature. If duct heat gains are considered a part of the room load, this still holds true. The apparatus dew point, as outlined previously, is fixed by the latent and sensible loads of the space, but in many cases, it is desirable to deliver more air to the spaces than is indicated by the difference between the room temperature and the apparatus dew point.

It has been indicated that where a percentage of air is passed through the dehumidifier without being treated, the relationship is modified in direct proportion, and that if room air is passed through untreated, no effect on the heat balance results. Similarly, if room air is passed around the dehumidifier and mixed with the treated air, the heat balance is not adversely affected. Therefore, if the quantity of air passed through the dehumidifier is determined by the usual methods, room air can be passed around the dehumidifier and mixed with the dehumidified air, increasing the supply air quantity and temperature and decreasing the temperature differential. Thus if the difference between the room temperature and the apparatus dew point indicates that 10,000 cfm at 30 deg below room temperature will be required to hold conditions, that quantity can be passed through the dehumidifier and cooled to 30 deg below the room temperature, then mixed with 10,000 cfm of room air, resulting in a supply-air quantity of 20,000 cfm and a temperature differential of 15 deg instead of 30 deg. Air supply outlets and grilles having a high induction ratio are available, and through their induction effect cause a large amount of room air to be mixed with the supply air within a short distance of the grille. A proper selection of outlets may make it possible to introduce air at low temperatures and high velocities without causing objectionable drafts or cold spots, but care must be used to see that too little air motion is not a result. Low temperature differentials may be required for this reason. While the use of a high temperature differential results in a saving in initial cost of fans and ducts, and in the operating cost of fans, this differential should be carefully considered. If the sensible heat load of a space is subjected to substantial variations, low temperature differentials should be considered, since systems employing low temperature differentials require less precision in controls.

Reduction of air quantity by slowing down the fans for the winter season,

and increasing the temperature differential, often is feasible. A saving in fan power can thus be effected, provided the air distribution remains adequate.

Extremes should be avoided in all cases. For summer air conditioning, low supply-air temperatures result in larger heat gains to the air passing through the ducts, as well as in poor control. Too high a supply-air temperature may result in excessive initial and operating costs. Suggested limits for the temperature differential are from 12 to 25 deg, the actual selection being based on the requirements of the particular case. For winter air conditioning, too high supply-air temperatures result in excessive heat losses from the ducts and stratification within the room unless thorough mixing is assured, while too low supply-air temperatures may cause drafts, high operating costs, etc. Suggested limits are from 15 to 35 deg. There can be no set rule, and each case should be judged according to its particular requirements of the installation.

Reference may be made to Chapter 31 for further discussion of the most satisfactory design difference between the entering air temperature and volume in relation to the desired room condition.

### UNITARY-CENTRAL SYSTEMS

Many different types of units have been developed for use in central systems where a high degree of zoning or individual room control is required, such as in hotels, hospitals and office buildings. These types of buildings are further characterized as usually having a larger perimeter relative to the floor area. The units usually are installed beneath the windows. Where the spaces to be conditioned extend a considerable distance from the outer wall into the interior of the building, such as might be found in office buildings, a separate system or zone for the conditioning of the interior portions may be required. In these cases the interior system handles the relatively small and steady loads, due to such items as lights and people; whereas the exterior system must cope with the relatively large and variable loads imposed by sunshine and temperature difference through walls and glass. Descriptions of four common unitary-central systems follow.

#### Induction Convectors—Low Pressure Type

Induction convectors located in the room that is to be served, utilize a jet of primary conditioned air to mix with a stream of secondary room air as shown in Fig. 4. The mixture is discharged into the room through a grille at the top of the convector. Heating coils are located in the secondary air stream. The output is controlled either by manually or automatically throttling the air jet. Heat may be supplied to the coil in summer as well as in winter. These induction convectors present several advantages. Since the secondary air stream is thoroughly mixed with the high velocity low temperature air stream before leaving the discharge outlet of the device, the resultant temperature of the mixture is satisfactory even though the primary air is introduced at a temperature too low for ordinary methods of distribution. One of these devices usually is provided under each window in place of the customary direct radiator, and combines the air distribution system with the heating system. An air conditioning system without induction convectors may require installation of direct radiation for maintenance of minimum temperatures during air conditioning shut-down periods, but when induction convectors are used they may be selected with heating coils of sufficient capacity to maintain, by thermal circulation, a reasonable temperature when the pri-

### Central Systems for Air Conditioning

mary-air supply system is shut off. The use of low temperature, dehumidified air which has not been reheated or mixed with room air before delivery to the room, may permit a reduction in fan capacity and the use of smaller ducts. In some cases a bypass may be desirable in order to maintain the primary air volume and to provide additional control. This system can provide a degree of zoning that is usually difficult with conventional design since the air delivered by each unit can be controlled individually. Selection of induction convectors should be made with due regard to noise level. The inductive capacity of the device increases with the jet velocity, but high jet velocities may result in objectionable noise.

The units are supplied with primary air from one or more central stations with the primary air providing all ventilation and handling the entire cooling load. The central apparatus is arranged in general conformity to

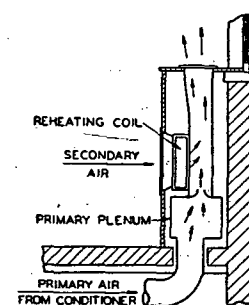


FIG. 4. INDUCTION UNIT  
(LOW PRESSURE TYPE)

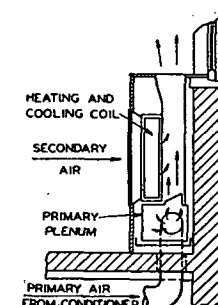


FIG. 5. INDUCTION UNIT  
(HIGH PRESSURE TYPE)

Fig. 1 except that the central reheater is omitted since each unit has its own reheater. The controls are arranged to maintain a substantially constant supply air temperature equal to that required for maximum cooling. Final control is obtained by means of a room thermostat, or remote bulb thermostat in the unit having its measuring element in the recirculated air stream. The controlling thermostat operates the coil supply valve and a damper operator on the primary air damper in sequence. At maximum heating load the valve is wide open and the primary air quantity is at a minimum. As the space temperature tends to rise, the valve is first gradually closed, then the primary-air quantity is gradually increased from minimum to maximum. Alternately the primary-air quantity can be kept constant and all final control achieved by the individual heating coils. If variable air quantities are to be handled by the primary-air fan, some form of fan-capacity control is necessary.

#### Induction Convectors—High Pressure Type

Another type of induction convector, Fig. 5, employs nozzles which produce a high velocity air jet without objectionable noise. The term, high pressure, is to some extent inaccurate, since the air pressure at the nozzles, while several times that used with a low pressure induction convector, is still less than the total resistance pressure of a conventional central system. The high velocity jet of primary air induces a flow of air from the room through coils located in the secondary air stream and

supplied with chilled water in summer and with hot water in winter. The chilled water removes a large portion of the sensible heat in summer and the hot water supplies the sensible heat loss in winter. The primary air is delivered at a sufficiently low dew point to compensate for the latent heat gain in summer. In winter the primary air is supplied at a sufficiently high dew point to take care of latent heat losses. Control of temperature is obtained by throttling the water quantity supplied to the secondary coil. The required flow of primary air is greatly reduced due to the fact that a portion of the sensible heat load is carried by the secondary air stream. Since the primary quantity is small, very high velocities can be maintained in the supply ducts without requiring fan power in excess of that for a conventional system. Therefore, the supply ducts or pipes can be very small and can be run in chases, or furred in at columns

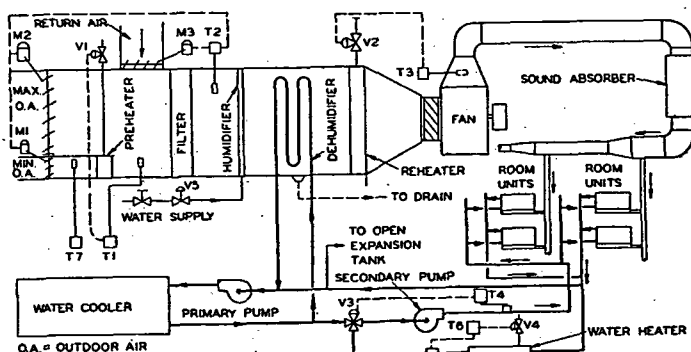


FIG. 6. TYPICAL INDUCTION UNIT SYSTEM

along with the water pipes. The primary air is treated in the usual manner to reach the required dew point and a surface or spray dehumidifier or a dehydrator may be used. The primary-air quantity is sufficient for ventilation purposes and frequently consists entirely of outdoor air.

Fig. 6 shows the general arrangement and control of the system. The operation of the controls is as follows:

The final temperatures in the spaces are controlled by individual valves, either automatic or manual, which throttle the flow of secondary water to the unit coils. Where automatic valves are used, the thermostats are of the heating-cooling type so that a rise in room temperature opens the valve when cold water is circulated and closes the valve when hot water is being supplied. Thermostat T1 controls the preheater steam valve V1 to maintain a temperature of about 45 F leaving the preheater. Thermostat T2 controls the maximum outdoor-air and return-air dampers so that the air entering the dehumidifier is maintained at 50 F whenever outdoor air conditions permit.

During the heating cycle, thermostat T3 and valve V2 are inoperative so that cool primary air is supplied to the units but at the same time thermostat T6 operates valve V4 so that the secondary water is heated. Thus the combination of cool primary air and hot secondary water can provide heating or cooling as required. The primary pump and water cooler are inoperative.

When the outdoor air is no longer suitable to provide sufficient cooling through the primary air system (typically about 50 F) the system is changed from heating to cooling operation. The primary pump is started and supplies chilled water to the dehumidifier. Thermostat T4 controls mixing valve V3 so as to maintain the secondary water at temperatures in the range of 50 to 55 F. At outdoor temperatures

below 80 F thermostat T3 regulates reheater valve V2 so that warm primary air is supplied at the same time that cold secondary water is fed to the units. The changeover from heating to cooling is usually manual and the exact time is not too important because both heating and cooling are available in either case. During the cooling cycle, thermostat T7 acting through thermostat T3 readjusts the primary air temperature downward as the outdoor air temperature increases from the changeover point to about 80 F so that above this temperature the primary air is equal to the apparatus dew point.

In some buildings the primary air system and water circuits are zoned according to exposure, but because both heating and cooling are available at the units whenever either is needed, such zoning is not always used.

### Dual-Duct System

The dual-duct system conditions all the air in a central apparatus and distributes it to the conditioned areas through two parallel mains or dual

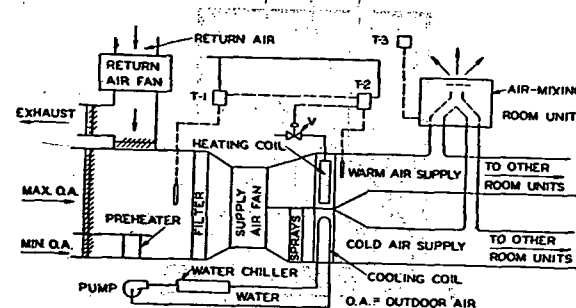


FIG. 7. SCHEMATIC ARRANGEMENT OF DUAL DUCT SYSTEM

ducts. The air supply fan, return-air fan, filters, heating and cooling means, outdoor-air equipment, dampers, and controls are located in the apparatus space. One air distribution main carries cold air while the other carries warm air at approximately room temperature in summer and at a higher temperature in winter.

The general arrangement of a typical dual-duct system is shown in Fig. 7. In some arrangements, two supply-air fans are used with one fan supplying the cold-air duct and the other the hot-air duct. The warm-air fan handles only recirculated air so that operating economy is slightly improved.

The maximum outdoor-air damper and the preheater are controlled as in Fig. 1 so that when the temperature of the outdoor air is favorable it is used increasingly instead of return air.

The warm-air supply-duct temperature is controlled by a thermostat, T2, Fig. 7, in the air leaving the heating coil. Thermostat T2 is reset by thermostat T1 in accordance with variations in outdoor-air temperature. Whenever outdoor-air temperature is not low enough to accomplish the required cooling, the cold-air supply-duct temperature is regulated by the cooling coil. The final temperature in the conditioned areas is controlled by the individual air-mixing units.

Air-mixing room units under control of the room thermostat draw warm and cold air from the ducts in accordance with the room requirements, affording individual room control without zoning. Fig. 8 shows schematically one type of room unit designed for dual-duct systems. The warm and cold air pass through the three-way mixing damper which delivers air at

the temperature required by the room. Some units are placed under windows, while others are mounted in the ceilings from which air may be delivered to the room through ceiling, wall, or window outlets. Some units are also provided with volume regulators to maintain a steady flow condition.

This system is best suited for multi-room or multi-zone installations, and may be of either high- or low-velocity and high- or low-pressure type with substantially the same control methods. It is often applied to high-velocity systems with long distribution mains, and consequently high-static fan pressures; although extremely high static pressures are seldom justified. With two supply mains, the system static pressures vary as a result of changing demands for heating or cooling. Thus volume regulation often becomes necessary. Extreme variations of flow to different

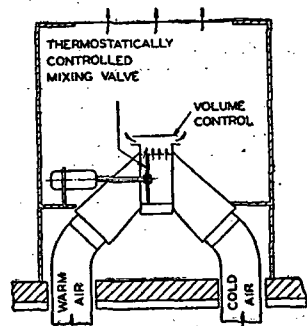


FIG. 8. ROOM AIR-MIXING UNIT FOR DUAL DUCT SYSTEM

rooms may be somewhat limited by static-pressure regulators and volume dampers at selected points along the mains. There are some installations where volume control at each room supply is desirable to maintain close control regardless of static-pressure changes in the ducts, and incidentally to facilitate balancing of the distribution system.

Air-capacity requirements are generally governed by summer cooling loads, and general practice is to supply the cold air to the cold-air duct at 25 to 30 deg below the established room temperature, this being satisfactory with suitably designed room outlets.

#### Fan and Coil Units

Another type of room convector used in connection with central cooling and heating plants is known as the *Fan and Coil Unit* (see Fig. 5, Chapter 26).

These units, like induction units, are located around the periphery of a building, usually under windows, and are equipped with fans and a water-type heating-cooling coil. They normally take air for ventilation directly from outdoors, and have a manual damper for adjusting the quantity of outdoor air within certain limits. Positive closing of this damper when the fan stops, can be obtained by adding a damper operator actuated by the fan-motor switch. Hot water supplied during the heating season frequently is varied in accordance with outdoor temperature. Cold water for use during the cooling season should be supplied at a fixed temperature low enough to provide the proper amount of dehumidification.

These units sometimes are used with a primary-air system which supplies the outdoor ventilation air and handles the latent load. In such cases the primary air unit is controlled as explained under the section Unitary-Central Systems, and may be of either the low- or high-pressure type.

The combined heating-cooling coil of each unit may be controlled by a valve in the water supply line to each unit, actuated by a thermostat in the room or recirculated air of the unit. The thermostat is of the heating-cooling type.

#### EVAPORATIVE COOLING

In climates where, on the hottest days, the outdoor wet-bulb depression is relatively great, it may be possible to replace mechanical refrigeration, or other cooling sources, and use the evaporative cooling effect. A well-designed air washer using recirculating sprays will reduce the entering dry-bulb temperature to within a degree or two of the entering wet-bulb condition. Thus, it may be possible that, with air entering at 100 F dry-bulb, 60 F wet-bulb, a leaving condition of 62 F dry-bulb, nearly saturated, can be obtained. Under some conditions of latent and sensible heat load, this evaporative cooling may be adequate.

At times when the outdoor wet-bulb temperature is not low enough to permit the use of straight evaporative cooling, it is still possible to use pre-cooling convectors with refrigeration, well water, or a cooling tower, as the basic source of sensible heat removal to reduce the wet-bulb temperature of the air before it enters the spray chamber. Where internal heat loads are high, this scheme may be more economical than one using return air. Where the required supply air dew point is too low to permit straight evaporative cooling, and where the sensible heat load is not too great, intentional partial saturation may be employed. That is, the low dew point of the outdoor air is utilized by permitting some of this air to pass through the humidifying sprays untreated, or to bypass the humidifier. All of these remarks with regard to evaporative cooling are based on the assumption that all of the supply air will be taken from outside. Provision should be made in most cases for the return of some air from the conditioned spaces for control purposes, as well as for economy of fuel in winter.

#### PRECOOLING

Where sufficiently cold water from wells or streams is available, a saving in refrigeration may be obtained by the use, in location ahead of the dehumidifier, of precooling coils through which the cold water is circulated. The resultant cooling of the air decreases the load to be carried by the dehumidifier and refrigeration plant. In normal practice the water, after passing through the precooling coils, may be further utilized in the refrigeration plant condenser. The economic advantages of this scheme are apparent, and it is frequently used.

#### SENSIBLE COOLING WITH UNWETTED COILS

Under favorable atmospheric conditions where a large wet-bulb depression exists and the dew point of the outdoor air is sufficiently low at all times, acceptable cooling may be obtained by removing only the sensible heat from the outdoor air delivered to the rooms. Under this condition of a great wet-bulb depression, a temperature-reducing coil may be located in the air stream and supplied with water from a cooling tower. When humidity control is desired, sprays to saturate or partially saturate the air may be used down stream from the unwetted coil. Saturation or partial



saturation after the coil will reduce further the dry-bulb temperature and the air quantity required. This system has very definite application in hot dry climates.

### SELECTION OF TYPE OF SYSTEM

If the perimeter of the building is large with regard to the area, and if there are many rooms, induction convectors of either the low- or high-pressure type may be employed. Occasionally a dual-duct system, one duct carrying air at a warmer temperature than the other, may be considered.

Low buildings with large floor areas may be divided into sections or zones with separate central air-supply systems to facilitate temperature control. In the case of large department stores it may be possible to provide a single conditioner, with a fan delivering the conditioned air to local mixing fans which supply the various departments or spaces. This application is limited by the practicability of running the large conditioned air ducts to the various recirculating fans. Each vertical section of the building also may be supplied by a separate fan delivering conditioned air to local mixing fans. In many cases the most economical and satisfactory scheme may be to employ a hot-water or steam reheater in each branch duct. Where vertical sectionalizing is not indicated, the building may be divided into horizontal groups, each handled by a central system and adequately zoned. In some large buildings, apparatus rooms for the systems may be located in the basement and attic and on intermediate floors.

In high buildings the necessity for horizontal sectionalizing may be suggested by the size of air supply and return risers, and by the extent to which they encroach upon usable space. Each story should be cut off by doors from other stories, as otherwise the cool air tends to collect in the lower story and the warm air is forced to the upper story.

Balconies and large lobbies in theatres and similar high rooms frequently justify the use of separate zoning fans, to counteract the tendency of the heavier, cooler air to collect at the lower levels of these spaces.

Fans operate at full capacity continuously in many systems, and therefore should be selected for good efficiencies. In winter when higher temperature differentials are used, it is sometimes practicable to deliver smaller air quantities than when cooling.

In climates where winter temperatures fall below freezing, the tempering coils should be of the steam-distributing type; or if they are heated by a liquid, this liquid should contain some anti-freezing substance such as ethylene glycol. If hot water is used in cold climates, the control of air temperature should be obtained by means of face and bypass dampers rather than by throttling the valves, to prevent damage due to freezing.

If zone reheaters placed in supply-duct branches are employed, they should be of such type as to be heated over the entire surface so that no temperature-stratification can occur in the delivered air. Steam-distributing-tube coils or mechanically-circulated water coils are satisfactory in such cases, and throttling valves may be used.

Refrigeration equipment must be carefully selected to satisfy the particular requirements of each installation. For some small plants the evaporator may be placed in the air stream, when type of refrigerant and nature of occupancy permit. In many cases, chilled water coils are required by considerations of safety. Where low temperature and relative humidity are necessary, brine, often of calcium chloride, may be indicated.

Condensing requirements must have economic analysis. Wells, public water service, cooling towers and evaporative condensers present possibi-

ties for consideration. Condenser water may have a secondary use for roof sprays in hot weather, and is usually suitable for lawn sprinkling. Most health department rules in cities prohibit any connection from refrigerant condensers that might permit the water to be used for drinking or lavatory purposes.

Practically without exception, air cleaners should be provided for both outside and recirculated air.

Control of temperature and of relative humidity by automatic means is vital, if comfort and economical operation of air conditioning equipment are to be attained.

The insulation of ductwork may be necessary to prevent condensation of moisture either inside or outside of ducts, housings and fan encasements or to prevent a change of temperature in ducts passing through hot or cold spaces.

In general, the apparatus should be arranged to have a straight-line air flow. Each change in direction increases air resistance and, in addition, elbows and offsets may cause eddy currents resulting in stratification. The usual order of equipment location, beginning at the outdoor-air intake, is: weather hood or louvers, outdoor-air dampers, return-air connection, filters, tempering coils, cooling coils or sprays, bypass connection with or without reheaters, reheaters, fan and distributing ducts.

Screens at the intake prevent the entry of large foreign matter, birds, etc. A hood or louver at the outdoor-air intake prevents the entry of rain and snow. Since in most climates there are many days during which use of 100 percent outdoor air unheated or uncooled may be economical, the areas of all air-passing and treating apparatus should be large enough for such a volume, and the exhaust or spent-air equipment should be capable of discharging out of doors, all of the air admitted.

The bypass connection normally connects the return-air duct system with the apparatus casing between the conditioner and the supply fan. Usually the bypass opening is sized to handle about 50 percent of the fan capacity where a variable bypass is used though extreme load variations may require a larger size. It is at times good design to locate a reheating coil in the bypass connection to permit using some bypass air when heating is required. Since the relatively high resistance of the cooling coil or spray is to be balanced by the heating coil and bypass connection, enough heating surface can be provided to raise the temperature of the bypass air to the point where the mixture of bypassed air and conditioned air will have the required temperature. When a variable bypass is used, a damper working in opposition to the bypass damper should be placed across the face of the dehumidifier, for unless the resistances of the two are carefully balanced at all operating points, the proper mixtures of air will not be obtained. Outdoor air that has not been dehumidified should not be bypassed around a cooling coil or spray dehumidifier if accurate control of the delivered relative humidity is desired. Where the bypass is made a part of the dehumidifier or conditioner and is located on the top or side of it, the return-air connection should be arranged so that stratification of return air is insured, baffles being provided to accomplish this purpose if necessary. When return-air and bypass air connections are taken off a return duct system, it may be necessary to install a back-draft damper between the return-air connection and the bypass connection. When the bypass damper is at maximum opening it may be much easier for outside air to pass through the return damper, into the return duct connection and through the bypass, than for return air to pass through the bypass con-



nection into the fan. Air tends to take the path of least resistance and, if the dehumidifier resistance is high, and if the return duct resistances are low, this situation is apt to occur. A recirculating air fan, instead of a back-draft damper, may be required for this case, if the failure of return air to reach the dehumidifier or conditioner is a serious matter under reduced load conditions.

### LOCATION OF APPARATUS

In general, the outdoor-air intake, preheaters, and return air connections precede the conditioner, while the bypass, reheaters and fan follow it. In the case of a blow-through system, where the fan is located ahead of the conditioner, the leakage of air at the conditioner is outward, instead of inward, and may be accompanied by water leakage.

The location of the complete apparatus assembly, including the dehumidifier, will be dependent on the type of building, spaces available, structural characteristics, etc. The type of conditioner used may limit the location under certain conditions. Where cooling coils employing chilled water or brine as the cooling agent are used, there are few limitations with regard to location other than those of pumping power, working pressures, piping costs, etc. Where spray dehumidifiers are used, very definite limitations present themselves, and these may require certain extraneous equipment to make the system workable. If several spray-type dehumidifiers are located on different levels, thus involving different water pressures, a surge or storage tank, to which the return water from each dehumidifier can be taken, is required. Should the water level in the pan of the dehumidifiers be low in relation to that of the surge tank, return water pumps will be required, and these pumps will have to be operated until the water supply lines are drained in order to prevent flooding of the lower dehumidifiers. Where spray dehumidifiers are on the same level, equalizing lines between the pans may be required if a storage tank is not provided. It is exceedingly important that water-tight drained floors be provided under all overhead cooling systems, since water condensed out of the air generally will be present and may damage the interior finish of the rooms below the apparatus.

All of the various pieces of equipment from the outdoor air intake through the fan usually are connected together by sheet metal casings. Frequently, the building structure or specially constructed walls or partitions may be used to form a portion of the casing. In any case the casing or connection must be sufficiently sturdy for the required duty. Sheet metal work must be well braced not only to prevent vibration under pulsations in air flow, but also to withstand the abuse of normal usage. Casings should be braced wherever access doors are installed, and all large panels should be adequately reinforced by structural steel.

### Accessibility for Service

Each apparatus layout should be made with accessibility in mind. Where cooling convectors are used, space for removing and repairing or replacing them should be provided. Adequate space should be provided for the servicing and replacement of eliminators. Filters must be so located that the proper cleaning, replacement or routine servicing can be accomplished without difficulty. Free access to the bearings of all moving machinery is a necessity. Provision should be made for the replacement of any parts that are subject to wear, deterioration or damage, such as filters, fanwheels, motors, pump impellers, or heat transfer surface.

## CHAPTER 31

### AIR DISTRIBUTION

Definitions, Standards for Satisfactory Conditions, Principles of Air Distribution, Ventilating Jets in Air Distribution, Outlet Performance, Outlet Types, Outlet Location and Selection, Direction and Volume Control, Return and Exhaust Intakes, Specific Applications.

**C**ORRECT air distribution is essential in warm air heating, ventilating, and air conditioning systems. Even though a system delivers the required quantity of conditioned air to a room, unsatisfactory conditions result if the air is poorly distributed.

This chapter deals with room air distribution only; the transmission of air through ducts is treated in Chapter 32, Air Duct Design. The objectives of this chapter are to:

1. Describe the present state of air distribution problems by discussing ventilating jets in room air distribution.
2. Present general information on practical air distribution problems by discussing outlet performance, outlet types, and also location, selection, and control of outlets.
3. Illustrate the use of the basic concepts and of the practical experience gained in air distribution by discussing specific applications.

Further pertinent information on air distribution will be found in Chapter 6, Physiological Principles; Chapter 12, Heating Load; Chapter 13, Cooling Load; Chapter 19, Gravity Warm Air Systems; Chapter 20, Forced Warm Air Systems; Chapter 25, Unit Heaters and Unit Ventilators; Chapter 26, Unit Air Conditioners and Unit Air Coolers; Chapter 30, Central Systems for Air Conditioning; Chapter 41, Sound Control; Chapter 48, Transportation Air Conditioning; Chapter 52, Instruments and Measurements.

### DEFINITIONS

The following definitions referring to air distribution equipment have gained general acceptance.

1. *Supply Opening or Outlet*: Any opening through which air is delivered into a space which is being heated, or cooled, or humidified, or dehumidified, or ventilated.
2. *Exhaust Opening or Return*: Any opening through which air is removed from a space which is being heated, or cooled, or humidified, or dehumidified, or ventilated.
3. *Outside Air Opening*: Any opening used as an entry for air from outdoors.
4. *Damper*: A device used to vary the volume of air passing through a confined cross-section by varying the cross-sectional area.
5. *Grille*: A covering for any opening and through which air passes.
6. *Register*: A grille equipped with a damper or control valve.
7. *Free Area*: The total minimum area of the openings in the air outlet or inlet through which air can pass.
8. *Core Area*: The total plane area of that portion of a grille, included within lines tangent to the outer edges of the outer openings through which air can pass.
9. *Free Area Ratio*: The ratio of the free area to the core area.
10. *Coefficient of Discharge*: Ratio of area at vena contracta to area of opening.
11. *Aspect Ratio*: The ratio of length to width of an opening or core of a grille.

12. *Vane Ratio*: The ratio of depth of vane to minimum width between two adjacent vanes.
13. *Plaque*: A ceiling outlet in which the supply air impinges against a plate or series of parallel plates, and is deflected horizontally in all directions.
14. *Diffuser*: An outlet discharging supply air in various directions and planes.
15. *Primary Air*: The air delivered to the outlet by the supply duct.
16. *Induction*: The induction of room air drawn into an outlet by the primary air stream (commonly called *aspiration*).
17. *Entrainment*: The entrainment of room air by the air stream discharged from the outlet (commonly called *secondary air motion*).
18. *Total Air*: The mixture of discharged air and entrained air.
19. *Entrainment Ratio*: The total air divided by the discharged air.
20. *Throw (Blow)*: The horizontal or vertical axial distance an air stream travels on leaving the outlet (grille) before the maximum velocity is reduced to 50 fpm.
21. *Drop*: The vertical distance, the lower edge of a horizontally projected air stream drops between the outlet and the end of its throw.
22. *Rise*: The converse of drop.
23. *Envelope*: The outer boundary of an air stream moving at a perceptible velocity.
24. *Spread*: The divergence of the air stream in a horizontal or vertical plane after it leaves the outlet.
25. *Diffusion*: Distribution of air within a space by an outlet discharging supply air in various directions and planes.
26. *Radius of Diffusion*: The horizontal distance from the diffuser outlet to the perimeter of the space, within which air motion in the occupied zone is reduced to 50 fpm maximum.
27. *Outlet Velocity*: The average velocity of air emerging from the outlet, measured in the plane of the opening.
28. *Terminal Velocity*: The average air stream velocity at the end of the throw.
29. *Temperature Differential*: Temperature difference between primary and room air.
30. *Temperature Variation*: Temperature difference between points of the same space.

### STANDARDS FOR SATISFACTORY CONDITIONS

The object of air distribution in warm air heating, ventilating and air conditioning systems is to create in the occupied zone of the conditioned room (floor to 6 ft above floor level) the proper combination of temperature, humidity and air motion. To obtain comfort conditions within this zone, standard limits have been established as acceptable *effective temperatures*. This term comprises air temperature, motion, humidity, and their physiological effect on the surface of the human body. Any variation from accepted standards of one of these elements may result in discomfort to the occupants. The same effect may be caused by lack of uniformity of conditions within the space or by excessive fluctuation of conditions in the same part of the space. Such discomfort may arise due to excessive room air temperature variations (horizontally, vertically, or both), excessive air motion (draft), failure to deliver or distribute the air according to the load requirements at the different locations, or too rapid fluctuation of room temperature or air motion (gusts).

With reference to permissible room air motion it is not possible to establish a specific standard covering the entire complex problem of air distribution. Velocities less than 15 fpm generally cause a feeling of air stagnation, whereas velocities higher than 65 fpm may result in a sensation of draft. Air velocities of 25 to 35 fpm in the occupied zone are most satisfactory, but air motion of 20 to 50 fpm will usually be acceptable, with the lower values used in cooling applications, and the higher values on heating

jobs. The permissible air motion depends to some degree on the geographic location of the air conditioning installation. In addition the noise level created by the introduction of supply air should be kept within acceptable limits, and streaking or smudging of walls or ceilings should be prevented.

Reference should be made to Chapter 6, Physiological Principles, for information on effective temperature and comfort lines, and to Chapter 41, Sound Control, for acceptable room noise levels and noise generated by air outlets. Material in Chapter 45, Industrial Air Conditioning, covers temperature and humidity requirements for products and manufacturing processes, and for health, safety and efficiency of workers.

### PRINCIPLES OF AIR DISTRIBUTION

Conditioned air is supplied to air outlets at temperatures and velocities which differ greatly from those in the occupied zone of the room. Proper air distribution, therefore, calls for (1) entrainment of room air by the primary air stream outside of the zone of occupancy in order that air motion and temperature differences will be reduced to acceptable limits before the air enters the occupied zone, and (2) counteraction of the natural convection and radiation effects within the room.

Practical room air distribution is predominantly an art depending upon clear recognition of physical principles, good judgment, and the cumulative benefits of extensive experience. The characteristics and performances of air outlets are evaluated by experiment, and full-scale models are employed in order to develop satisfactory installation recommendations for specific applications. Frequently the performance of the air distribution system is checked in the field before the installation is turned over to the customer. Adjustments may be necessary before all requirements are met. Manufacturers' literature is available to provide data for the performance and application of various outlets which are usually based upon observations in full-scale test rooms.

The complexity of practical room air distribution is due to innumerable variations in building construction, system design, and operating requirements, and makes the exploration of the basic character of air distribution imperative. Research at the A.S.H.A.E. RESEARCH LABORATORY<sup>1</sup> and co-operative programs at Case Institute of Technology<sup>2</sup> since 1937 have advanced considerably the fundamental knowledge in air distribution.

A comprehensive survey of the literature relevant to air distribution problems was made at the A.S.H.A.E. RESEARCH LABORATORY in connection with the experimental investigation of ventilation jets.<sup>1(b)</sup> This survey deals with fundamentals of turbulence, jet behavior, and miscellaneous problems, and is sufficiently complete to permit the study of these problems without requiring recourse to the original papers. Therefore, the survey is an indispensable and timesaving tool for every researcher in air distribution.

### VENTILATING JETS IN AIR DISTRIBUTION

The theory concerning the distribution of conditioned air within an enclosure is still far from complete but a considerable fund of knowledge supported by experimental guidance is available for free jets, and particularly for axial-flow type free jets, both singly and in combination.<sup>3</sup> For many conditions of jet discharge, therefore, it is possible to analyze jet performance, and to determine (1) the angle of divergence of the jet boundary, (2) the velocity patterns along the jet axis, (3) the velocity profile at any cross section in the zone of maximum engineering importance, and (4) the entrainment ratios in the same zone. In other words, it is possi-

ble to answer the following questions about a jet discharged from any air supply outlet:

1. What is the shape of the jet (spread or coverage)?
2. How can the velocity at any selected point within the jet be determined?
3. How far does the jet travel or what is its throw?

A *free jet* is a straight-flow jet, free from pulsations or helical flow, which is discharged into a large open room in which no surfaces, objects, or convection currents interfere with the formation of the natural flow pattern.

Most of the available data refer to isothermal jets. Information given herein refers to this type unless otherwise noted.

### Types of Outlets

Two general classes of outlets have been the subject of experimental study:

*Class 1.* Straight-flow devices, such as ducts, nozzles, orifices, slots, straight-flow grilles and multiple openings located close together, perforated panels being an extreme example.

*Class 2.* Annular outlets including ceiling plaques, but not including diffusers.

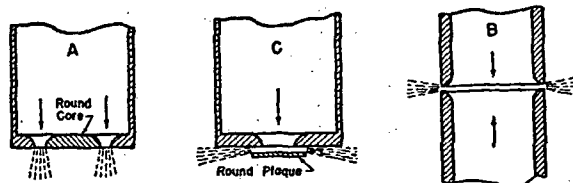


FIG. 1. CROSS-SECTIONS OF ROUND DUCTS WITH THREE BASIC TYPES OF ANNULAR OUTLETS

Fig. 1 shows three basic types of annular outlets. Outlet A is a circular slot in a wall or ceiling, and produces a jet similar to straight-flow jets. Outlet B discharges the jet radially from the axis of the approach duct, and also produces a jet quite similar to straight-flow jets. Outlet C, usually called a ceiling plaque, is a radial outlet with a plane boundary extending from one edge, but it cannot readily be correlated with outlet B.

### Shape of Axial Jets

A surprising similarity between the shape of the jets exists at a short distance from the outlet face, whether the outlet is round, rectangular, grille-like, or a perforated panel. Even in the case of wide-angle grilles or annular outlets, the similarities are such as to permit the same analysis of performance.

The jet discharged from a round opening forms an expanding cone; whereas jets from rectangular outlets rapidly pass from rectangular to elliptical cross-sectional shape at a short distance from the outlet face, and then to a circular shape, at a rate depending primarily on the aspect ratio.

The angle of divergence is very definite close to the outlet face, but the boundary contours are somewhat billowy and are easily affected by external influences. Here, as in air distribution generally, room air movement is replete with local eddies, vortices, and surges, which are manifestations

of unbalance in the forces acting within the air stream. These internal forces govern the air motion, yet they are extremely delicate.

Measured angles of divergence (spread) for discharge into large open spaces have usually ranged from 20 to 24 deg with an average of 22 deg. Coalescing jets for closely spaced multiple outlets expand at somewhat smaller angles, averaging 18 deg, and jets discharging into relatively small spaces show even smaller angles of expansion.<sup>3</sup> Tests indicate that in cases where the outlet area itself is small compared to the dimensions of the space normal to the jet, the jet may be considered free as long as

$$X \leq 1.5\sqrt{A_R}$$

where

$X$  = distance from face of outlet, feet.

$A_R$  = cross-sectional area of the confined space, square feet.

### Four Zones in Jet Expansion

In analyzing the performance of jets, four major zones can be distinguished. They may be roughly defined in terms of the maximum or centerline velocity existing at the cross section being considered:

*Zone 1:* A short zone, extending about 4 diameters or widths from the outlet face (or vena contracta for orifice discharge), in which the maximum velocity of the air stream remains practically unchanged.

*Zone 2:* A transition zone, extending to about 8 diameters for round outlets, or for rectangular outlets of small aspect ratio, over most of which maximum velocities vary inversely as the square root of the distance from the outlet. For rectangular outlets of large aspect ratio, this zone is elongated and extends from about 4 widths to a distance approximately equal to the width multiplied by four times the aspect ratio.

*Zone 3:* A long zone, of major engineering importance, in which the maximum velocity varies inversely as the distance from the outlet. This zone is often called the zone of fully established turbulent flow and may be 25 to 100 diameters long (or equivalent diameters of equal areas), depending on the shape and area of the outlet, the initial velocity, and the dimensions of the space into which the outlet discharges.

*Zone 4:* A terminal zone in which, in the case of confined spaces, the maximum velocity decreases at an increasing rate, or, in the case of large spaces free from wall effects, the maximum velocity decreases rapidly in a few diameters to the velocity range below 50 fpm which is usually regarded as still air.

### Centerline Velocity in Zone 3

Research has shown that maximum or centerline velocities in Zone 3 of straight flow isothermal jets can be determined with good engineering accuracy from

$$\frac{V_z}{V_0} = \frac{KD_0}{X} = \frac{K'\sqrt{A_0}}{X} \quad (1)$$

$$V_z = \frac{K'V_0\sqrt{A_0}}{X} = \frac{K'Q}{X\sqrt{A_0}} \quad (2)$$

$$= \frac{K'Q}{X\sqrt{A_0} \times C_d \times R_{t_1}} \quad (2a)$$

where

$V_z$  = centerline velocity, feet per minute.

$V_0 = \frac{V_0}{C_d \times R_{t_1}}$  = average initial velocity at discharge from open-end duct or across contracted stream at vena contracta of orifice or multiple-opening outlet, feet per minute.

$V_o$  = nominal velocity of discharge based on the core area, feet per minute.

$C_d$  = coefficient of discharge (usually between 0.65 and 0.90).

$R_{fa}$  = ratio of free area to gross (core) area.

$X$  = distance from face of outlet, feet.

$K$  and  $K'$  = proportionality constants, with  $K' = 1.13 K$ .

$D_o$  = effective or equivalent diameter of stream at discharge from open-end duct or at a contracted section, feet.

$A_o = A_c \times C_d \times R_{fa}$  = effective area of stream at discharge from an open-end duct or at a contracted section, square feet.

$A_c$  = measured gross (core) area of outlet, square feet.

$Q$  = discharge from outlet, cubic feet per minute.

Equation 1 is nondimensional and requires only that consistent units be used, as in the above nomenclature. Values of  $K$  and  $K'$  are listed in Table 1.<sup>2, 4</sup>

TABLE 1. RECOMMENDED VALUES OF THE CENTERLINE VELOCITY CONSTANT  $K$  OR  $K'$  (See Equation 1)

| TYPE OF OUTLET                             | $K$                    |                           | $K'$                   |                           |
|--------------------------------------------|------------------------|---------------------------|------------------------|---------------------------|
|                                            | $V_o =$<br>500 to 1000 | $V_o =$<br>2000 to 10,000 | $V_o =$<br>500 to 1000 | $V_o =$<br>2000 to 10,000 |
| Free Openings                              |                        |                           |                        |                           |
| Round or Square                            | 5.0                    | 6.2                       | 5.7                    | 7.0                       |
| Rectangular, large aspect ratio (<40)      | 4.3                    | 5.3                       | 4.9                    | 6.0                       |
| Annular slots axial or radial <sup>a</sup> | —                      | —                         | 3.9                    | 4.8                       |
| Grilles and Grids                          |                        |                           |                        |                           |
| Free area 40% or more                      | 4.1                    | 5.0                       | 4.7                    | 5.7                       |
| Perforated Panels                          |                        |                           |                        |                           |
| Free area 3 to 5%                          | 2.7                    | 3.3                       | 3.0                    | 3.7                       |
| Free area 10 to 20%                        | 3.5                    | 4.3                       | 4.0                    | 4.9                       |

<sup>a</sup> For radial slots use  $X/H$  instead of  $X/(A)^{1/2}$ .  $H$  is the height or width of the slot.

Note:  $K$  and  $K'$  are indexes of loss in axial kinetic energy. Interpolate as required. Departures from maximum value indicate losses in first and second zones when compared with the jet from a rounded-entrance, circular nozzle.

Low velocity test results, in the range  $V_x < 150$  fpm, indicate that the normal values of  $K$  and  $K'$  should be reduced about 20 percent for  $V_o = 50$  fpm, as used in later Equation 4b for throw. Fig. 2 gives the effective diameter  $D_o$  in inches for single openings and includes the coefficient of discharge.<sup>5</sup> Similar values for grilles are available in the literature or can be experimentally determined. Values of  $C_d$  and  $R_{fa}$  are required for determining  $V_o$ ,  $D_o$  and  $A_o$  for orifice-type and multiple-opening outlets, and should, therefore, be included in catalog data of these outlets.

In the case of multiple-opening outlets and annular-ring outlets (see diagram A of Fig. 1), the streams coalesce into a solid jet before actual jet expansion takes place. This coalescence affects the experimentally determined proportionality constants  $K$  or  $K'$  and accounts for some of the divergence in reported values for similar outlets.

#### Centerline Velocities in Zones 1 and 2

Experimental evidence indicates that in Zone 2

$$\frac{V_x}{V_o} = \sqrt{\frac{K'H_o}{X}} \quad (3)$$

where

$H_o$  = width of jet at outlet or at vena contracta.

Approximately the same values of  $K'$  apply as for Zone 3 expansion from axial outlets.

In Zone 1, the ratio  $V_x/V_o$  is constant and equal to the ratio of the cen-

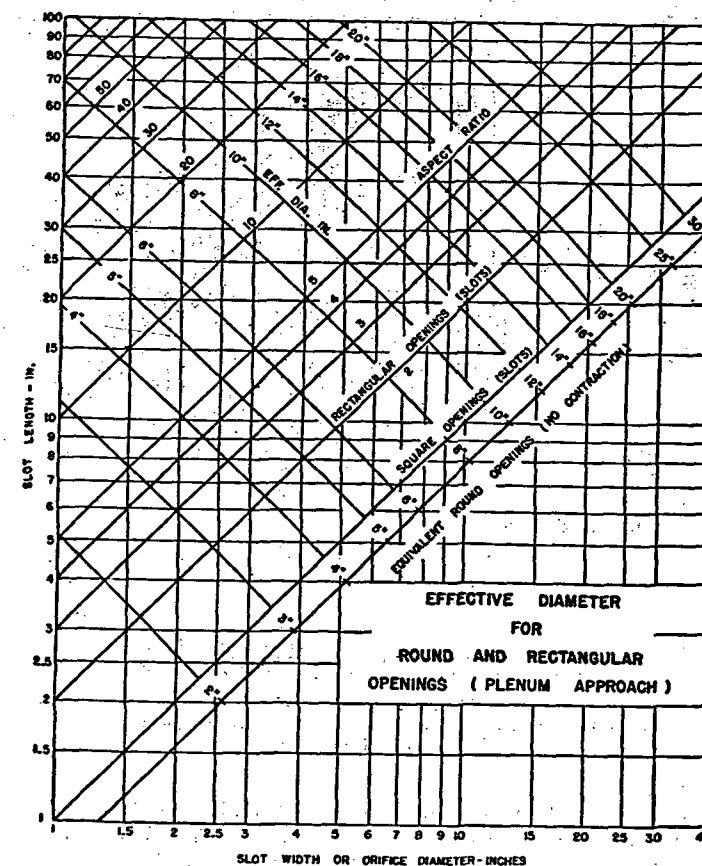


FIG. 2. EFFECTIVE DIAMETERS FOR ROUND AND RECTANGULAR OPENINGS (PLENUM APPROACH)

ter velocity of the jet at start of expansion to the average velocity, ranging from approximately 1.0 for rounded-entrance nozzles to about 1.2 for straight pipe discharge, but with much higher values for diverging-discharge outlets.

#### Determining Centerline Velocities

To permit correlation of data from all four zones, centerline velocity ratios are plotted against distance from outlet in Fig. 3 in accordance with

the basic relation of Equation 2, and a nomogram for calculating the parameters

$$\frac{X}{A_o} \quad \text{and} \quad \frac{V_x}{V_o} \quad \text{from} \quad \frac{X}{\sqrt{A_o}} \quad \text{and} \quad \frac{V_x}{V_o}$$

through  $R_{ts}$  and  $C_d$  is given in the same illustration.

The variation of the centerline velocity ratio with distance from outlet, or more properly, from start of jet expansion, is also shown on Fig. 3 for

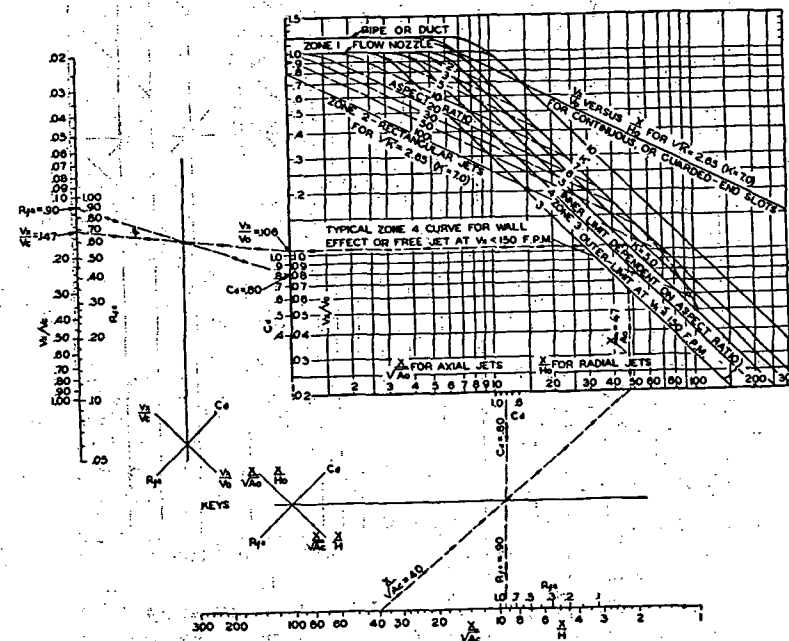


FIG. 3. CHART FOR DETERMINING CENTERLINE VELOCITIES OF AXIAL AND RADIAL JETS

Zones 1 and 2.  $V_x/V_o$  is plotted against  $X/H_o$  and, for a range of aspect ratios, against  $X/\sqrt{A_o}$  for the single value of  $K' = 7.0$ . Values of  $V_x/V_o$  for other values of  $K'$  may be obtained by direct proportioning of  $\sqrt{K'}$  to  $\sqrt{7.0}$ .

The following *Example 1* which is solved on Fig. 3 will illustrate the use of the chart.

*Example 1:* A grille has a core area 12 in. x 18.75 in.,  $R_{ts} = 0.90$ ,  $C_d = 0.80$ , and  $K' = 5.0$ . Find  $V_o$  (velocity through core area) when  $V_x$  is 50 fpm for throw of 50 feet. ( $X = 50$ ).

*Solution:*

$$A_o = \frac{12 \times 18.75}{144} = 1.56 \text{ sq ft}$$

$$\frac{X}{\sqrt{A_o}} = \frac{50}{1.25} = 40$$

$$A_o = 1.56 \times 0.80 \times 0.90 = 1.123$$

$$\frac{X}{\sqrt{A_o}} = \frac{50}{1.06} = 47.2$$

$$\frac{V_x}{V_o} = \frac{K' \sqrt{A_o}}{X} = \frac{5 \sqrt{1.123}}{50} = 0.106$$

$$\frac{V_x}{V_o} = \frac{V_x}{V_o(C_d R_{ts})} = \frac{0.106}{0.80 \times 0.90} = 0.147$$

For  $V_x = 50$ ,

$$V_o = \frac{50}{0.147} = 340 \text{ fpm.}$$

The quantity of air discharged is then,

$$Q = V_o A_o = 340 \times 1.56 = 530 \text{ cfm.}$$

#### Throw

Equation 2a can be used to determine the *throw*  $X$  of an outlet, if the discharge volume and the center velocity are known.

$$X = \frac{K'}{V_x} \cdot \frac{Q}{\sqrt{A_o} \times C_d \times R_{ts}} \quad (4)$$

or, if

$$Z = \sqrt{C_d \times R_{ts}}$$

$$X = \frac{K'}{V_x} \cdot \frac{Q}{Z \sqrt{A_o}} \quad (4a)$$

The maximum throw  $L$  is usually defined as the distance from the outlet face where the centerline velocity is 50 fpm. Therefore, for  $V_x = 50$  fpm,

$$L = X = \frac{K'}{50} \cdot \frac{Q}{Z \sqrt{A_o}} \quad (4b)$$

#### Velocity Profiles of Jets

In Zone 3 of both axial and radial jets, the velocity distribution may be expressed by a single curve (Fig. 4) in terms of dimensionless coordinates, and this same curve can be used as a good approximation for adjacent portions of Zones 2 and 4. Experiments have shown that temperature and density differences have but a small effect on cross-sectional velocity profiles.

Velocity distribution in Zone 3 can be expressed by the Gauss error-function or probability curve which is approximated by a simple equation using common logarithms

$$\left(\frac{r}{r_{0.5}}\right)^2 = 3.3 \log \frac{V_x}{V} \quad (5)$$

where

$r$  = the radial distance of the point under consideration from the centerline of the jet.

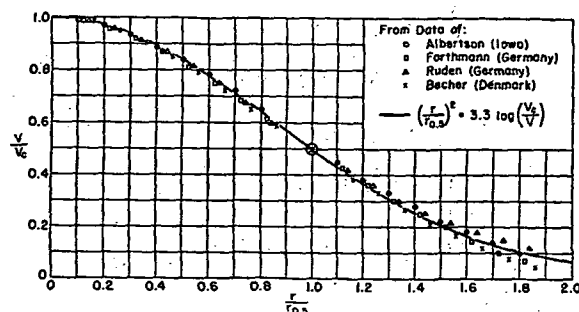


FIG. 4. CROSS-SECTIONAL VELOCITY PROFILES FOR STRAIGHTFLOW TURBULENT JETS

$r_{0.5}$  = the radial distance in the same cross-sectional plane from the axis to the point where the velocity is half the centerline velocity: ( $V = 0.5 V_x$ ).

$V_x$  = the centerline velocity in the same cross-sectional plane, feet per minute.

$V$  = the actual velocity at the point being considered, feet per minute.

Experiments show that the conical angle for  $0.5 V_x$  and  $r_{0.5}$  is approximately one-half of the total angle of divergence of a jet. The velocity profile curve for one-half of a straight-flow turbulent jet (the other half being a symmetrical duplicate) is shown in Fig. 4. For multiple-opening outlets, such as grilles, or perforated panels, the velocity profiles are similar, but the angles of divergence are smaller.

### Radial Jets

In the radial jet (diagram B in Fig. 1) the cross-sectional area at any distance from the outlet varies as the square of this distance, the same as for an axial jet. Experiments have shown that the centerline velocity gradients and the cross-sectional velocity profiles are similar to those of Zone 3 of axial jets and that the angles of divergence are about the same. In using Fig. 3,  $X/H$  should be used as abscissa instead of  $X/\sqrt{A}$ .

Jets from ceiling plaques (diagram C in Fig. 1) have the same form as one-half of a free radial jet. The jet is wider and longer than a free jet, with the maximum velocity close to the wall. This is demonstrated in Fig. 5 which also indicates that under the conditions shown the width of the slot

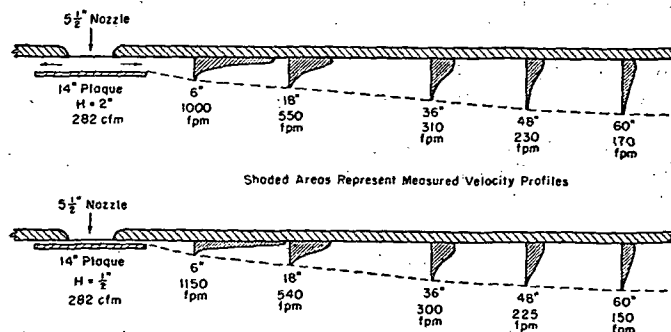


FIG. 5. AIR JETS FROM A 14-IN. CEILING PLAQUE FOR TWO SLOT WIDTHS WITH SAME RATE OF FLOW

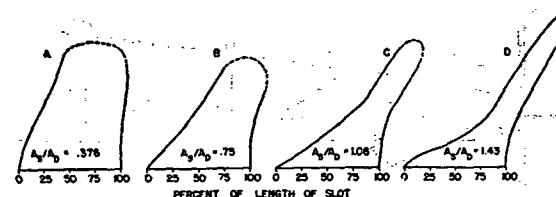


FIG. 6. SHAPE OF AIR-STREAM ENVELOPES AS SLOT AREA IS INCREASED

between ceiling and plaque has little effect on the jet pattern or velocities at some distance from the plaque.<sup>2</sup>

### Discharge from a Long Slot

When a long slot receives its air supply from one end only, the important design factor is the ratio of the area of the slot to the area of the supply duct, and both the air stream profiles and the duct pressure requirements are determined by this ratio.<sup>6</sup> Fig. 6 shows the changing profile as the slot area is increased for a rounded entrance slot ( $C_d = 0.93$ ) with constant duct cross section.

The air discharge from a slot in a tapered duct will be uniform (Fig. 7) for a relationship between discharge angle and slot-duct dimensions<sup>7</sup>

$$\cot \theta = \frac{A_s C_d}{A_d} \quad (6)$$

where

$\theta$  = discharge angle, degrees.

$A_s$  = slot area, square feet.

$A_d$  = duct cross-sectional area at upstream end, square feet.

$C_d$  = coefficient of discharge.

### Perforated Panels

When air is discharged from perforated panels of relatively large sizes, the constant velocity core formed by the coalescence of the individual jets extends a considerable distance from the panel face. In this Zone 1 region the proportionality constants  $K$  and  $K'$  do not apply. Therefore, the proportionality constants given in Table 1 should be used only when the ratio (Distance from panel/ $\sqrt{\text{Panel area}}$ ) is larger than 5. When the ratio is less than 5, the equation

$$V_x = V_0 \cdot 1.2 \sqrt{C_d \times R_{1s}} \quad (7)$$

should be used for estimating centerline velocities.<sup>8</sup>

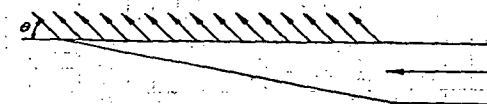


FIG. 7. UNIFORM AIR FLOW FROM A SLOT SUPPLIED BY A TAPERED DUCT

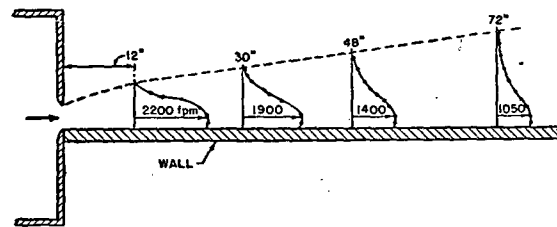


FIG. 8. JET VELOCITY PATTERNS FOR A SQUARE OUTLET DISCHARGING ALONG WALL OR CEILING  
( $V_0 = 2260$ ,  $A = 0.10$ ,  $C_d = 0.78$ )

### Effect of Walls and Ceilings

Jets discharging parallel to a wall with one edge of the outlet coinciding with the wall, take the form of one-half of an axial jet discharging from an outlet twice as large, similar to radial jets from ceiling plaques. Entrainment takes place practically only along the surface of a half cone and the maximum velocity remains close to the wall.<sup>2</sup> (See Fig 8). Values of  $K$  and  $K'$  are approximately those for a free jet multiplied by  $\sqrt{2}$ , that is to say, the normal maximum of 7.0 for  $K'$  for free jets becomes 9.9 for a similar jet adjacent to, and discharged parallel to, a wall, and in Fig. 3,  $\frac{X}{\sqrt{2A_0}}$

should be used in place of  $\frac{X}{\sqrt{A_0}}$

When a jet is discharged parallel to, but at some distance from a wall, its expansion in the direction of the wall is reduced and entrained air must be obtained by recirculation from the jet itself instead of from ambient air.<sup>3, 9</sup> The jet expands normally to within a short distance from the wall, which nearer to the outlet only affects velocity distribution in the outer shell of the jet, but further on also affects centerline velocities. This happens at some distance from a plane where the jet outline becomes parallel to the wall, and where the jet enters its fourth or terminal zone. Few engineering data are available on this important phase of jet expansion.<sup>3</sup>

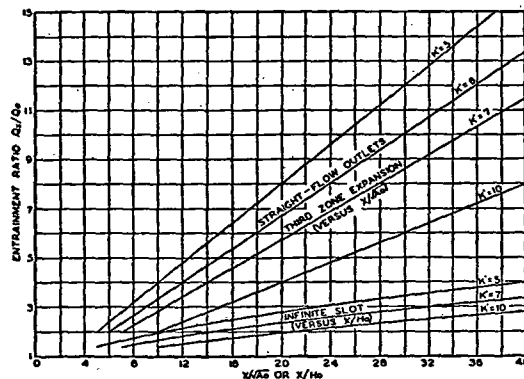


FIG. 9. ENTRAINMENT RATIOS FOR STRAIGHT-FLOW OUTLETS

### Effect of Resistance on Return Path of Jet Air

Laboratory experiments on jets usually involve recirculated air with negligible resistance to flow on the return path of the jet air. Experience and experiments in tunnels of small cross-sectional area in mines, where considerable resistance is offered to the return flow of jet air to outlets, show that the expansion of the jet terminates abruptly at a distance that is independent of velocity of discharge and but slightly affected by size of outlet. Such distances are determined primarily by size and length of return path. In a long 5 ft x 6 ft tunnel, a jet may not travel more than 25 ft

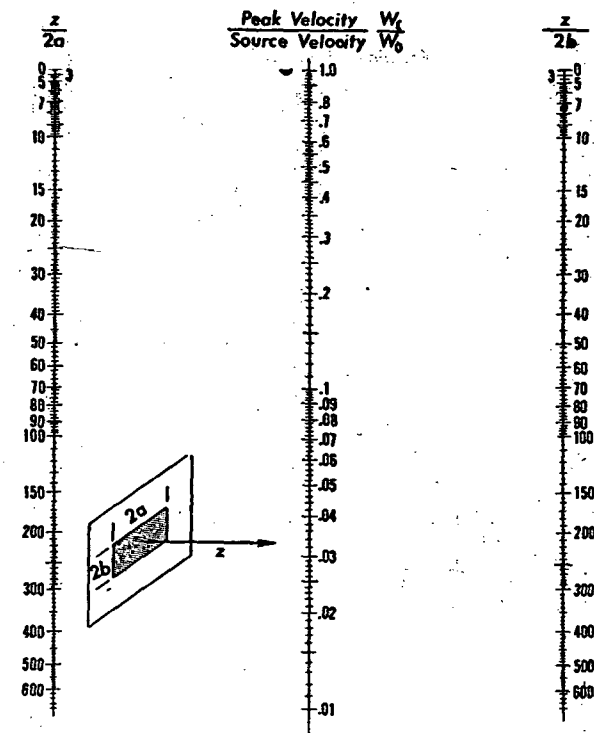


FIG. 10. NOMOGRAM FOR CENTER, OR PEAK, VELOCITIES FOR ROUNDED, RECTANGULAR JET SOURCES

whereas in a relatively short opening, 25 by 60 ft, it may travel more than 250 ft. Few engineering data are available on this phase of jet expansion but it can be of great practical importance.<sup>3</sup>

### Entrainment Ratios

Equations for the entrainment of circular jets and of jets from long slots have been mathematically derived.<sup>10</sup> They are:

For third zone expansion of circular jets,

$$\frac{Q_2}{Q_0} = \frac{2}{K'} \cdot \frac{X}{\sqrt{A_0}} \quad (8)$$



For a long slot

$$\frac{Q_x}{Q_0} = \sqrt{\frac{2}{K'}} \cdot \sqrt{\frac{X}{H_0}} \quad (8a)$$

where

$Q_x$  = total volume flow rate at distance  $X$  from face of outlet, cubic feet per minute.

$Q_0$  = discharge from outlet, cubic feet per minute.

$X$  = distance from face of outlet, feet.

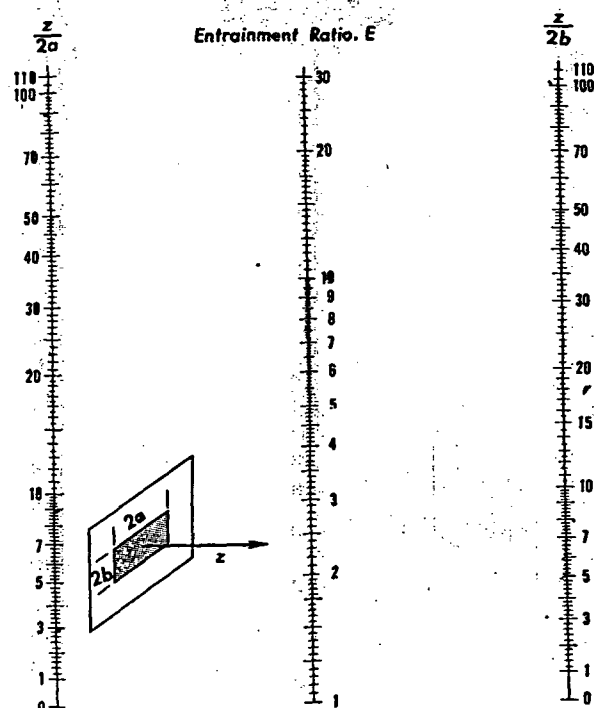


FIG. 11. NOMOGRAM FOR ENTRAINMENT RATIOS OF ROUNDED, RECTANGULAR JET SOURCES

$K'$  = proportionality constant.

$A_0$  = effective area of stream at discharge from an open-end duct or at a contracted section, square feet.

$H_0$  = width of slot, feet.

Equations 8 and 8a have been used in plotting Fig. 9 for entrainment ratios.

The nomograms (Figs. 10 and 11) for center velocities and entrainment ratios for jets emitted from circular sources, and from rectangular sources of all aspect ratios, are based upon recently developed theory.<sup>11</sup>

## OUTLET PERFORMANCE

The results of the studies undertaken in room air distribution which have been presented in the foregoing section can be used as a basis for engineering design of supply outlets if the following is kept in mind:

1. The method for finding jet velocities is based upon several approximations and the two recommended equations must be used with caution for extreme axial and radial distances.
2. The characteristics of the low-velocity regions of ventilating jets are not yet well understood, and for both axial and radial jets the effect of the Reynolds number is not fully known.
3. The quantitative treatment of the forces which govern room air distribution phenomena has been limited, and non-isothermal conditions involving buoyant forces have not yet been fully explored.
4. All investigations have been concerned with *free* jets, whereas air streams in practical room air distribution are not free streams but are influenced by walls, ceilings, floors and obstructions.
5. The science of air distribution has not yet reached its final stage where a basic theorem permits the exact mathematical solution of all problems, and velocity patterns in closed rooms, and of a great variety of outlets, such as radial and slotted outlets, diffusers and perforated panels, must be further studied before their performance can be predicted with confidence.

However, the air distribution research sponsored by the AMERICAN SOCIETY OF HEATING AND AIR-CONDITIONING ENGINEERS has proved that the phenomena of room distribution are amenable to scientific research and rational interpretation, and the ventilation jet problem has reached a stage where a definite technique of experimentation in combination with semi-empirical theories can be of great help in the design of air outlets.

6. In the design of air outlets, the days of unguided and unrelated experimentation should be over. Practical room air distribution, however, is still predominantly an art, where decisions depend on isolated tests and judgments must be based on the accumulated experience of the behavior of outlets in the laboratory and in the field. In designing a satisfactory air distribution system, the engineer must make use of such tests and draw on this experience; and weigh the different factors of the outlet performance which place considerable limitations on his proceedings. A short discussion follows regarding some of these factors which are: (1) jet pattern, (2) capacity, (3) temperature differential, (4) permissible room air motion, (5) permissible noise level, and (6) smudging.

### Jet Pattern

Refer to section Ventilating Jets in Air Distribution for a general discussion of the jet pattern. In selecting the *throw* and *drop* of outlets the following considerations are important: (1) throw, (2) effect of vanes, (3) effect of type of outlet, and (4) drop.

1. *Throw*. The throw of a wall outlet must be sufficient to produce satisfactory conditions over the area to be conditioned. Underblowing may cause heated air to rise too rapidly above the occupied zone and thus create excessive vertical temperature variation (stratification); in cooling operation it may cause cold air to drop into the occupied zone before supply and room air are mixed sufficiently, and thereby create a condition of acute discomfort (draft). On the other hand, overblowing will result in objectionable downdrafts from any surface the primary air stream may strike.

On the average, it is considered most practicable to select a throw which is three-fourths of the distance toward an exposed wall or window, as shown in diagram A of Fig. 12. However, structural characteristics, mounting height of outlet, temperature differential, and resultant drop or rise, or location of greatest heating or cooling loads strongly affect the selection of the optimum throw. In spaces with beamed ceilings, the outlets should be located below the bottom of the lowest beam level, and preferably low enough so that an upward or arched blow may be employed. The blow should be aimed sufficiently to miss the beams and, at the same time, in such a manner as to prevent the primary or induced air stream from striking furniture and obstacles, and producing objectionable drafts.

2. *Effect of Vanes*. Vanes affect grille performance if their depth corresponds at



let velocity. In addition, however, noise may be caused by excessive restriction of the free outlet area due to outlet design, by unnecessary turbulence due to one-sided air flow through the outlet, or by the impingement of high velocity air on sharp edges.

The origin of excessive noise may be spotted by removing the outlet without stopping the air supply. If noise is still evident, other elements of the air conditioning system or entirely different sources are at fault. High-pitched, rushing noise indicates that the duct system or excessive velocities in the duct are the cause, low-pitched rumbling noise points to the mechanical equipment of the air conditioning plant.

When very high duct velocities are used, sound absorbing lining or special acoustical filters (sound traps) must be provided. High pressure or high velocity outlets for multi-room and other buildings are equipped with a special pressure reduction and sound attenuation box. (Refer to section Types of Air Outlets).

For a general discussion of permissible room noise levels and air supply outlet noises, refer to Chapter 41, Sound Control.

### Smudging

All air outlets have their particular *smudging* problems which have been studied by various investigators but cannot yet be considered solved. Smudging is due to dirt in the room air and in the air discharged by the outlets. Although the primary air may be carefully filtered, small particles of dirt and dust will not be captured by mechanical filters, and may finally be deposited on the walls or ceiling. With ceiling outlets, dirt streaking may be minimized by carefully controlling the discharge of the outlets, or by the use of special deflecting plates or anti-smudge rings. With wall outlets, dirt streaking may be minimized by preventing direct impingement of the air on any ceiling or room surface. Floor outlets may offer objection as dirt collectors.

### TYPES OF AIR OUTLETS

Air supply outlets for commercial, industrial and residential applications are either side wall or ceiling type outlets. In homes, baseboard and floor type outlets are also used. (Refer to Chapter 19, Gravity Warm Air Systems, and Chapter 20, Forced Warm Air Systems). As a great variety of outlets of various design are available in these four types, the final selection of a supply air outlet depends to a large degree upon the specific problems of the air distribution system to be used.

In addition to the comments which follow on use and application of outlets, reference should also be made to sections Outlet Location and Selection and Specific Applications of this chapter.

#### Wall Outlets

Side wall outlets in general use are (1) perforated grilles, (2) fixed and adjustable bar and vane grilles, (3) registers, (4) wall diffusers, (5) slotted wall outlets, and (6) high pressure or high velocity wall outlets.

1. *Perforated Grilles.* These grilles have a small vane ratio and are not adjustable. They are useful primarily where directional air flow is unnecessary, and for applications where the grille size can be increased in order to provide the required free area.

2. *Fixed and Adjustable Bar and Vane Grilles.* Grilles with fixed bars or vanes are used for wall, floor or baseboard applications when the performance is not critical or can be adequately predicted. Adjustable grilles are equipped with either vertical or horizontal adjustable bars or vanes or both, and are used where proper control of air motion is essential. Vanes should be designed for quiet operation.

### Air Distribution

3. *Registers.* Grilles equipped with dampers or adjustable valves for controlling volume distribution of the supply air are called registers.

4. *Wall Diffusers.* These outlets incorporate design features originally developed for ceiling outlets, and therefore make use of semi-conical or semi-pyramidal guide vanes instead of the straight vanes of the conventional side wall outlet. In warm air perimeter systems they are used to blanket the outside wall with the warm supply air.

5. *Slotted Outlets.* These outlets are available in a great variety of designs, consisting either of elongated outlets with perforations, or flat outlets with a number of long narrow slots or a single narrow slot, or straight long outlets with one long slot or diffusing vanes. Due to their high aspect ratio, slotted outlets have higher entrainment than comparable round or square vane outlets of equal area and consequently, the throw is reduced. (Refer to Discharge From a Long Slot in section Ventilating Jets in Air Distribution).

Slotted outlets are particularly useful in connection with the linear design motif in architecture, for applications where it is desired to merge air outlets unobtrusively with the room decoration. They may be used for either ceiling or wall air distribution, including the so-called under-the-window application. In all applications, capacity limitations, proper duct approaches and correct balancing of slotted outlets must be carefully considered, as correction after installation is difficult.

6. *High-Pressure or High-Velocity Outlets.* Ejector nozzles operate at high static pressure and convert this pressure into velocity pressure with resulting high induction of room air. They are mainly used for industrial process installations, particularly drying. Another type of ejector nozzle is sometimes referred to as a *lower nozzle* and has a 45 to 90 deg elbow, which can be rotated similarly to a universal joint about an axis perpendicular to the surface to which it is fastened. These outlets give a considerable degree of adjustability and are, therefore, useful for spotcooling in confined spaces.

High-pressure or high-velocity air conditioning systems installed in multi-room and other buildings, use very high velocity and pressure so that the size of the ducts can be reduced. This in turn requires the use of *high-pressure or high-velocity air outlets* which reduce the velocity and pressure and attenuate the sound to predetermined values at the point where the air is discharged. It is also possible, of course, to use high velocity only in part of the system, for example in the main trunk ducts, and conventional velocities in the branch ducts. Special high-pressure control units are then installed at the end of the main duct, and the air is discharged through conventional air outlets in the various spaces of the building.

Various high-pressure or high-velocity outlets of different design, but usually consisting of a pressure reduction and sound attenuation box and a grille or diffuser, have been developed for high-velocity systems and are described in the literature of the manufacturers. These outlets may be used in the ceiling or in the wall of the air conditioned space, including under-the-window installation, or in the ceilings of corridors.

Refer to Induction Convectors for multi-room buildings in Chapter 30, Central Systems for Air Conditioning.

#### Ceiling Outlets

Ceiling outlets in general use are (1) ceiling plaques, (2) ceiling diffusers, (3) high pressure or high velocity ceiling outlets, and (4) perforated ceilings and panels.

1. *Ceiling Plaques.* (Diagram C of Fig. 1). Plaques are of simple design. The air from the supply opening impinges on a plate and is discharged horizontally. Plaques are inexpensive, but as the air is not always uniformly discharged in all directions, proper control is difficult.

2. *Ceiling Diffusers.* Ceiling diffusers are round, square, rectangular or slotted outlets of various designs installed on, or parallel to, the ceiling. Performance of the different designs varies according to the principle employed. Some have no internal induction, but hasten external induction by supplying air in multiple layers. Others have internal induction and distribute air over an entire hemisphere. The induction effect is greatest in the direction of the axis of the outlet, and least in the plane perpendicular to the axis and located at the ceiling level. Thus the induction is greatest in the vertical direction where the least throw can be tolerated, and least in the horizontal plane at the ceiling where the greatest throw is desired.

Refer to section Slotted Outlets under Wall Outlets.

3. *High-Pressure or High-Velocity Outlets.* Refer to text in section Wall Outlets.

4. *Perforated Ceilings and Perforated Panels.* These devices discharge air through perforations in the ceiling or part of the ceiling, and share with slotted outlets the advantage of unobtrusive appearance. In addition, sound absorbing materials may be used for the panels, or the panels may provide a luminous ceiling.

Outlet air velocities may be kept low by using large outlet areas, particularly in spaces with high room loads, high ventilating requirements or low ceilings. Some perforated panels have a control plate frame which is inserted in the conventional ceiling duct. Supply air enters the plenum above the distribution plates through an adjustable air valve which can be set for varying air quantities and velocities.

### OUTLET LOCATION AND SELECTION

The design of the air conditioning plant for a building depends on the use to which the building is put, on its size, and its construction type; the design of the air transmission and air distribution system is influenced by the same factors. Therefore, these factors must be considered in designing the air transmission system, and in selecting the type and location of the supply outlets. The location and selection of the supply outlets is further influenced by the interior design of the building, local sources of heat gain or loss, and outlet performance and design.

#### Use, Size, Construction of Building

The use, size and construction of a building are three factors which may influence or even govern the selection of a particular type of air distribution system, as is shown by the development of special high-pressure or high-velocity transmission and distribution systems for multi-room and other buildings. Generally, the physical construction of the individual rooms of a building, such as height and shape and the location of beams and other obstructions, influences the possible location of the supply ducts which in turn influences the outlet locations. The location of the supply ducts—above the ceiling or within the walls, in a furred space above corridors, or in the conditioned room itself—has an important bearing, therefore, upon the design of the air distribution system. A particular method of air distribution may be highly desirable but it may be impossible to use it, due to the location of beams and masonry walls.

Refer to section Specific Applications for a discussion of air distribution methods in various buildings.

#### Heat Gain or Loss

Local sources of heat gain or loss promote convection currents or cause stratification, and may, therefore, determine both the type and location of the supply outlets.

Generally, the outlets should be located to neutralize any undesirable convection currents set up by a concentrated heating load. If a concentrated source of heat is located at the occupancy level of the room, the heating effect may be counteracted by blowing the supply air toward the heat source, or by locating an exhaust or return grille adjacent to the heat source. The second method is more economical, as heat will be withdrawn at its source rather than be dissipated into the conditioned space. Where lighting loads are heavy and ceilings relatively high (five watts per sq ft and above 15 ft), the outlets should be located below the lighting load, and the stratified warm air removed by an exhaust or return fan. An exhaust fan is recommended if the wet-bulb temperature of the air is above that of the outside temperature, a return fan, if it is below this temperature. Either method reduces the requirements for supply air. If the lights are exposed,

less saving can be realized than if they are enclosed, as a considerable portion of the energy is radiant.

An important function of any supply outlet during *winter heating* is to maintain the temperature difference between the floor and ceiling at the lowest possible value. Since the air within a room is never so perfectly mixed that all of it is at exactly the same temperature, a certain amount of stratification is inevitable. Unless the supply outlets are properly selected and located, the temperature difference will be large enough to result in discomfort to the occupants.

The proper selection and location of outlets is particularly difficult for rooms with large windows and exposed wall areas. Heat is lost primarily through these areas, and room air in contact with these surfaces is chilled and flows downward, causing drafts near the exposed surfaces and floor.

This condition can best be prevented by locating the air outlets under the windows, by discharging warm air across the exposed surfaces, or by providing supplementary radiation under the windows, in addition to the wall or ceiling air distribution outlets. This solution must be used for comfort installations in northern latitudes (outside temperatures below 40 F), when the building walls are uninsulated or single-glass windows are used.

In buildings located in regions where winter heating is a minor problem, high induction by ceiling or wall outlets may be employed to mix properly the entire room air with the supply air and to prevent downdrafts along the exposed surfaces. In northern latitudes, this solution can only be used if the buildings have double-glass windows and insulated walls, as otherwise the induction effort required for neutralization of the downdrafts is so great that the air motion in the room exceeds comfort limits. Where comfort conditions are not critical as in factories for heavy manufacturing, warehouses, etc., satisfactory results with high induction outlets can be obtained even in cold climates. For uninsulated walls and glass areas in these buildings some supplementary heating is often valuable. Wall diffusers, direct radiation or warm panels will satisfy these requirements for supplementary heating.

The location of exhaust or recirculating air openings at the base of large areas of glass is sometimes effective in reducing downdrafts into the occupied space.

Great care should be exercised in the use of supply-exhaust air outlets for heating in northern latitudes when considerable exposed wall and window surfaces are involved. In such cases additional radiation is usually required. When the system is used for ventilating only during the heating season, direct radiation should be regulated to provide heat until room and outside temperature are balanced. To avoid stratification, it is advisable to operate the fan continuously and to limit the temperature differential by supplying air at a high rate of change per hour.

#### Outlet Performance and Design

The physical laws of air distribution have, of course, a highly important influence upon the design of an acceptable distribution system.

Refer to section Ventilating Jets in Air Distribution for a discussion of the theory, and to section Outlet Performance for some specific advice with regard to such features as throw, drop, capacity, temperature differential, room air motion, permissible noise level, smudging and their influence upon practical air distribution.

Outlets should perform efficiently and conform to the esthetic appearance

of the room: The physical appearance of air outlets has been highly influenced by modern interior design, and to meet the demands of architects and engineers, outlets to be installed flush with the ceiling and outlets with built-in lighting as well as square and linear-type outlets have been developed in the past years. Linear-type outlets and perforated ceilings or panels have the advantage of unobtrusive appearance.

#### Procedure for Outlet Location and Selection

In determining outlet location and selecting the type of outlets, it is customary to proceed as follows:

1. Study the plan of the building and note the amount of air to be supplied to each room. (For computation of the *required air quantity* for heating and cooling refer to the formulas given in Chapters 12, Heating Load and 13, Cooling Load. The amount of outside air introduced into the room must be checked against the ventilation requirements of state or local codes.)
2. Select number of outlets for each room, considering air quantity required and distance available for throw or as radius of diffusion. The same factors, as well as distance from floor level available as mounting height, structural characteristics of the space and consideration of appearance, will determine the type of outlet used.
3. Arrange location of outlets in the room. Generally, the outlets must be evenly spaced to distribute the air uniformly throughout the room. More air, however, must be supplied and directed towards areas with exceptional heat gain or loss. An important point to consider is the combination of proper outlet location and efficient duct design (see Chapter 32). Consult manufacturers' tables for recommended location and spacing of outlets.

Refer to Chapter 30 for a discussion of zoning and zone control.

4. Select size of outlets according to air quantities handled, permissible throat or discharge velocities, or effective throw, taking into consideration other factors, such as permissible noise level, etc. In order to determine whether the selection made will satisfy the requirements of the job, type, size and location of the outlet must be checked against manufacturers' ratings. The most important questions to be considered are:
  - a. Will drafts be created because of divergence between rated throw (radius of diffusion) and distance between outlet and nearest obstacle of air stream (wall, beam, column, etc.)?
  - b. Will drafts be created because of excessive cooling temperature differential or too low mounting height of the outlet?
  - c. Will drafts be created because of too low velocity energy of the air stream, causing excessive downward air flow in cooling installations?
  - d. Will the air pass through the outlet at too high a velocity and thereby cause an excessive increase in noise level?

#### Balancing the System

In designing a system, the engineer aims to size ducts and outlets in such a manner that the supply of air is properly distributed. He may, however, feel it necessary to oversize certain trunks, branches or outlets to allow flexibility or to permit future redistribution, so that the system as designed may not be self-balancing. Even if ducts are designed for self-balancing and outlets are properly selected, all air systems must be balanced, that is, the amount of air through supply ducts, supply outlets, outside air intakes, exhausts, return outlets and ducts must be properly adjusted so that the air quantities correspond closely with the design quantities. Balancing, therefore, is part of the field test procedure to which each air conditioning system should be subjected in order to determine whether the capacity and performance of the equipment correspond with the design.

For balancing, air systems may be equipped with dampers in supply, return, and outside air ducts, splitter dampers, or dampers in outlets. In selecting the desired type of damper or balancing method, the following points should be kept in mind:

#### Air Distribution

1. Unfavorable effect on air stream and noise level should be avoided. This will often rule out blank-offs or dampers in outlets, unless such dampers are of special design.
2. It should be possible to alter outlet volume without altering the direction of discharged air, and to measure the amount of air handled without difficulty. Blanking off part of the area of supply outlets makes this difficult.

Generally speaking, it is most satisfactory to install dampers at some distance back of outlets so as to avoid disturbing the air flow. Dampers in both supply and return ducts form the most flexible means of controlling supply of air to the room and static pressure within the room. (Refer to section Directional and Volume Control for discussion of various air distribution control devices.)

Instruments for balancing include instruments for measuring air quantities, static pressure, temperature and humidity. Commonly used instruments are the rotating vane anemometer, deflecting vane anemometer, thermal anemometer, smoke gun, clamp type ammeter-voltmeter, sling psychrometer and thermometers. Pressure, humidity and temperature recorders are sometimes useful. The Pitot tube and a manometer may be used on higher velocities, but only with the technique prescribed for its use by the manufacturer for the tube used. (See Air Flow Measurement in Chapter 52.)

The following balancing procedure is recommended for air systems:

1. Open all duct and outlet dampers.
2. Measure fan capacity. This can most often be done with a rotating vane anemometer inside the fan inlet plenum. For exhaust fans the discharge outlet will often serve.
3. Measure fan motor input.
4. Determine approximate flow at each outlet.
5. Adjust outlets or branches so that outlet deviation (from design quantity) is approximately the same (percentagewise) as fan capacity deviation (from total design quantity).
6. Recheck fan capacity.
7. Adjust fan speed or main trunk damper to make fan capacity equal to design. (The fan laws apply when changing speeds; quantity varies directly with speed, power input as the cube of speed). Use power input readings to check possibility of overloading the motor.

The procedure outlined may be shortened depending on the type of installation. For instance, where many outlets serve one room, exact balancing of each outlet may not be required, so long as drafts, noise and temperature differences are checked. Experience and judgment are valuable in determining how carefully or thoroughly a system must be tested and adjusted.

#### DIRECTIONAL AND VOLUME CONTROL

##### Duct Approaches to Outlets

The importance of the manner in which the air stream is introduced into the outlet cannot be overestimated. To obtain correct air distribution, the velocity of the air stream must be as uniform as possible over the entire connection to the duct, and perpendicular to the outlet face. No air outlet can compensate for improper duct approach.

A wall grille installed at the end of a horizontal duct and a ceiling outlet at the end of a vertical duct receive the air perpendicularly and at (for practical purposes) uniform velocity over the entire duct cross-section, provided the system is carefully designed. However, very few outlets are installed in this manner. Most side wall outlets are installed either at the end of vertical ducts or in the side of horizontal ducts, and most ceiling



outlets are attached either directly to the bottom of horizontal ducts or to special vertical take-off ducts which connect the outlet with the horizontal duct. In all these cases, special devices for directing and equalizing the air flow are necessary to obtain proper direction and distribution of the air.

The influence of the duct approach on outlet performance has been investigated for vertical stack heads with plain openings<sup>12</sup> or equipped with grilles<sup>13</sup> and for side outlets on horizontal ducts.<sup>14</sup> In the tests conducted with the stack heads it was found that it is necessary to provide splitters or guide vanes in the elbows at the top of the vertical stacks regardless of the shape of the elbows, whether of rounded, square or expanding types. Cushion chambers at the top of the stack heads have no beneficial effect. Fig. 13 shows the direction of flow, distribution and velocity (measured 12 in. from opening) of the air for various types of stack heads tested, expanding from a 14 x 6 in. stack to a 14 x 9 in. opening, without grille. The air velocity for each was 500 fpm in the stack below the elbow, but the direction of flow and the distribution pattern are generally indicative of per-

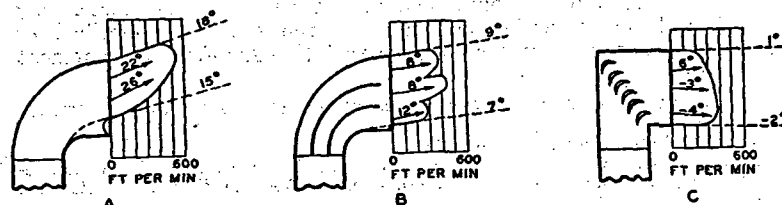


FIG. 13. OUTLET VELOCITY AND AIR DIRECTION DIAGRAMS FOR STACK HEADS WITH EXPANDING OUTLETS

Stack 14 in. x 6 in.    Outlets 14 in. x 9 in.    Stack Velocity 500 fpm  
A. Rounded Throat and Rounded Back.    B. Rounded Throat and Back and 2 Splitters.  
C. Square Throat and Back and 6 Guide Vanes.

formance obtainable with nonexpanding elbows of similar shapes for a range of velocities 200 to 1400 fpm.

In tests conducted with 3 x 10 in., 4 x 9 in., and 6 x 6 in. side outlets in a 6 x 20 in. horizontal duct at duct velocities of 200 to 1400 fpm (in the 6 x 20 in. section) it was found that multiple curved deflectors produced the best flow characteristics. Vertical guide strips in the outlet were not so effective as curved deflectors. A single scoop type deflector at the outlet did not improve the flow pattern obtained from a plain outlet, and was therefore not found to be desirable.

#### Directional Control

Many devices for directing and equalizing air flow in side wall and ceiling outlets are now commercially available, and should be used whenever necessary. They are indispensable for all side outlets in horizontal ducts and for most ceiling outlets.

Ceiling outlets are usually installed below horizontal supply ducts so that the supply air has to make a 90-deg turn before entering the outlet itself. The shorter the connection between bottom of duct and outlet, the greater is the need for directive devices to obtain uniformity of flow. Generally speaking, conditions and remedy in such cases strongly resemble those for side outlets in horizontal air ducts. Ceiling ducts often have a rectangular cross-section, while the connections to the ceiling outlets are circular. It will then be quite difficult to install turning vanes successfully, particularly

if the ducts are shallow and the connection areas are comparatively large. This will be the case when more than one outlet is installed on one duct run, and restrictions of duct areas must be avoided. In such cases good results have been obtained by using a series of vertical guide strips, installed at right angles to the direction of air approach in the outlet connection where it leaves the horizontal air duct.

#### Volume Control

Various methods are used to regulate volume of supply and return (exhaust) air. Some of these accomplish only minor changes in volume; most of them however permit a range of adjustment from maximum air supply to complete shut-off.

When selecting type and location of such dampers, the following points must be considered, especially when the volume control feature is to be located near the air outlet itself: (1) deflection of air stream by the damper;

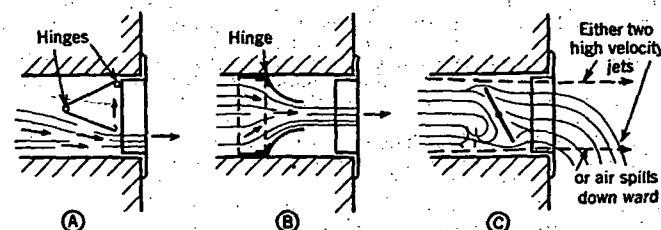


FIG. 14. EFFECT OF VARIOUS DAMPER ARRANGEMENTS DESIGNED FOR STRAIGHT BLOW

(2) need and feasibility of directional control; (3) increase of noise level due to irregular and localized high air velocities caused by damper operation.

The following types of volume control are most frequently encountered:

1. *Slide Damper.* A single plate which can be pushed across the duct. Since its operation changes the free area of air passage in a one-sided manner, it should not be located near any air outlet, and its use is practicable only where no intermediate setting between full open and closed is required.
2. *Hit-and-Miss Damper.* Two slotted plates or discs, closely adjacent; by moving one of the two plates the respective slots may be opened or closed. This type of volume control may be installed close to an air outlet and it is easy to operate, but its main disadvantage is that even in the open position the air passage area is blocked by at least 50 percent. This requires oversizing of the air outlet in order to avoid excessive increase of noise level.
3. *Splitter Damper.* A single blade sheet metal plate hinged at one edge, usually located at the branch connection of a duct or outlet. It is easy to operate, but often causes irregular air flow in the duct. When used in connection with, and near an outlet, additional directional control is required.
4. *Butterfly Damper.* A single blade sheet metal plate hinged in the middle, usually located in a straight duct run. It is easier to handle than a splitter damper, since only half the motion is necessary to change its setting. However, if located too close to an air outlet, it is objectionable because its operation frequently results in a condition whereby two high velocity jets are created along the sides of the duct, or the air spills immediately downward into the occupied zone (see C Fig. 14).
5. *Louver Dampers.* Numerous designs have been developed incorporating a series of splitter or butterfly dampers across the duct or air outlet. Their main advantage consists in retaining greater uniformity of air flow, and in requiring less depth for installation. Some designs provide for louver blades moving in opposite directions, and while decreasing free air passage area, retain a constant air flow direction along the axis of the duct air outlet connection (see A and B in Fig. 14).

TABLE 2. RECOMMENDED RETURN INTAKE FACE VELOCITIES

| INTAKE LOCATION                                    | VELOCITY<br>OVER GROSS AREA<br>FPM |
|----------------------------------------------------|------------------------------------|
| Above occupied zone.....                           | 800 up                             |
| Within occupied zone, not near seats.....          | 600-800                            |
| Within occupied zone, near seats.....              | 400-600                            |
| Door or wall louvers.....                          | 200-300                            |
| Undercutting of doors (through undercut area)..... | 200-300                            |

## RETURN AND EXHAUST INTAKES

The selection of return and exhaust intakes depends on: (1) velocity in occupied zone near intake; (2) permissible pressure drop through intake; and (3) noise.

1. *Velocity.* The control of the room air motion for the maintenance of comfort conditions depends on the proper selection of the supply outlets. The effect of air flow through return intakes upon air movement in the room is slight. Air handled by the intake approaches the opening from all directions and its velocity decreases rapidly as the distance from the opening increases. Therefore, drafty conditions will rarely be encountered near return intakes. Recommended return intake face velocities are given in Table 2.

2. *Permissible Pressure Drop.* The permissible pressure drop will depend on the choice of the designer. Table 3 gives pressure drop through plain lattice intakes as a function of free area and face velocity.

Proper pressure drop allowance should be made for control or directive devices.

3. *Noise.* The problem of noise generated by return intakes is the same as that for supply outlets. In computing resultant room noise levels from the operation of an air conditioning system, the return intake must be included as a part of the total grille area. The major difference between the supply outlets and return intakes is the frequent installation of the latter at ear level. When so located, it is recommended that the return intake velocity be not in excess of 75 percent of the maximum permissible outlet velocity.

The location of return and exhaust intakes does not critically affect air motion, unless room air velocities in the occupied zone near the intake exceed comfort limits. The locations of return or exhaust intakes are, however, important for obtaining the desired room temperature equalization.

*Ceiling locations* for exhaust outlets are recommended for bars, kitchens, lavatories, dining rooms, club rooms, etc. where warm air will rise to the ceiling level. In heating installations, location of the return grilles in the ceiling or high on the wall is not recommended, as it may result in stratification of the conditioned air, and—depending on the relative location of supply and return outlets—in short-circuiting. (Refer to section Outlet Location and Selection).

Some ceiling outlets combine the supply and return openings in a single

TABLE 3. APPROXIMATE PRESSURE DROPS FOR LATTICE RETURN INTAKES  
Inches Water Gage—Standard Air

| PER CENT FREE AREA | FACE VELOCITY, FPM |      |      |      |      |      |      |
|--------------------|--------------------|------|------|------|------|------|------|
|                    | 400                | 500  | 600  | 700  | 800  | 900  | 1000 |
| 50                 | 0.06               | 0.09 | 0.13 | 0.17 | 0.22 | 0.28 | 0.35 |
| 60                 | 0.04               | 0.06 | 0.09 | 0.12 | 0.16 | 0.20 | 0.24 |
| 70                 | 0.03               | 0.05 | 0.07 | 0.09 | 0.12 | 0.15 | 0.18 |
| 80                 | 0.02               | 0.03 | 0.05 | 0.07 | 0.09 | 0.11 | 0.14 |

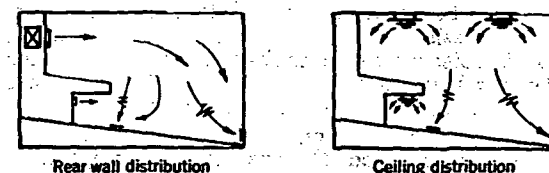


FIG. 15. AIR DISTRIBUTION METHODS FOR THEATERS, CHURCHES, AND AUDITORIUMS

unit. This method is used for heating as well as for cooling applications. However, the application for heating is more critical and requires consideration of ceiling height, amount of outside wall area, and number of air changes required. In some cases, stratification of warm air may cause short-circuiting. (Refer to section Outlet Location and Selection).

*Floor locations* of returns are used in heating installations for ceiling or side wall supply. When located so that air is drawn across exposed walls, the performance of the system may be somewhat improved. In general, floor locations tend to collect dirt and refuse.

*Wall and door locations* of exhaust outlets depending on their elevation, have the characteristics of either floor or ceiling returns. In large buildings with many small rooms, the return air may be brought through door grilles or door undercuts into the corridors, and then to a common return or exhaust. The pressure drop through door returns should not be excessive; otherwise the air distribution to the room may be seriously unbalanced with the opening or closing of the doors. Outward leakage through doors or windows cannot be counted upon for dependable results.

## SPECIFIC APPLICATIONS

For theaters and auditoriums the air distribution methods used are the downward distribution system with ceiling diffusers, and the horizontal distribution system with ejector nozzles or wall diffusers. Fig. 15 shows both methods. Ceiling distribution is accomplished by ceiling outlets under main ceiling and balcony. It is indicated when main ceiling or balcony is cut up by architectural treatment or beams. The only critical points are under the balcony, and (occasionally) above the very rear of the balcony, where ceiling heights are low and where direct impingement of air is sometimes a hazard.

Wall or ejector distribution is particularly applicable for relatively long and narrow theaters. It is essential with this type of distribution that there

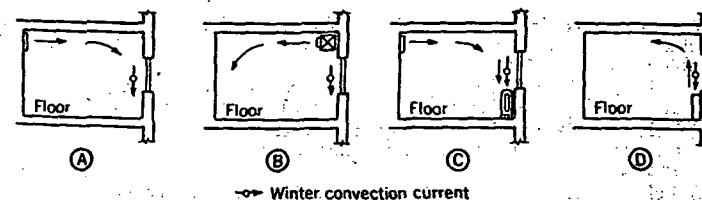


FIG. 16. DISTRIBUTION METHODS FOR SMALL ROOMS

- A. Satisfactory for cooling. Unsatisfactory for heating in severe climates where the outside temperature is consistently below 40 F, and single glass and uninsulated walls are prevalent.
- B. Performance approximately that of A when small diffusers are used in bottom of the duct.
- C. Satisfactory for cooling. Satisfactory for heating if direct radiation is properly controlled.
- D. Satisfactory for both cooling and heating. The air should be discharged slightly away from the wall and for low velocities, should be fanned out parallel to the wall.



be no interference with the movement of air throughout its entire path from the high velocity nozzles to the front of the theater. The ceiling should be smooth, without projecting beams or obstructing ornamentation. For large theaters, relatively high velocities can be used. These will work satisfactorily if adjustable outlets are used to avoid areas of local turbulence.

In small or medium size theaters, it is sometimes practicable to use side wall or front wall distribution. For the satisfactory operation of such a

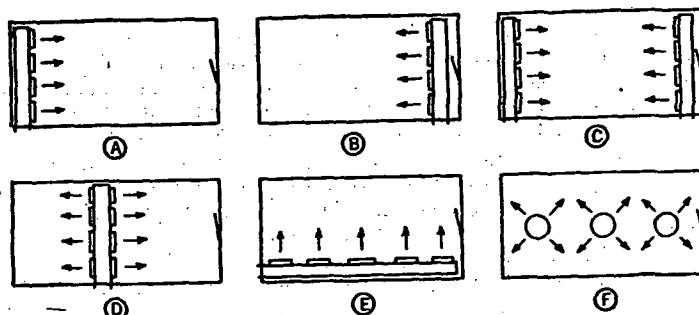


Fig. 17. SMALL STORE COOLING DISTRIBUTION

- A. Rear Wall. High outlet velocity, satisfactory if properly designed; possibility of excessive air motion and drafts if used for wrong application.  
 B. Front Wall. High outlet velocity, results same as A.  
 C. Front and Rear Walls. Moderate room air motion, outlet blows should not impinge giving rise to down-drafts in center.  
 D. Center. Moderate air motion, no impingement of air streams. Good results.  
 E. One Side. Moderate room air motion; should blow toward exposed wall. Good results.  
 F. Ceiling. Low room air motion. Good results. Outlets should be selected of sufficient size to allow for blocking when not located in perfect squares.

system during the winter heating period, the returns should preferably be located at the floor level and near the front of the theater to prevent cold spots resulting from exposed wall convection or infiltration from exits.

For multi-room buildings diagrams shown in Fig 16 illustrate distribution methods for small rooms with exposed wall, such as offices, hotel (guest) rooms, hospital (patients) rooms, apartments, etc.

For a small store the cooling performance of various distribution methods is illustrated in Fig. 17.

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## CHAPTER 32

### AIR DUCT DESIGN

Pressure Changes, Friction Losses, Circular Equivalents of Rectangular Ducts, Dynamic Losses, Pressure Losses in Elbows, Pressure Losses in Divided-Flow Fittings, Losses Due to Area Changes, Pressure Changes, Duct Design Methods and Examples, Duct Construction Details, Heat Losses from Ducts

IN THE design of air duct systems, the objective is to provide a system that, within prescribed limits of noise and space available for ducts, efficiently transmits the required flow rate of air (cfm) to each space while maintaining a proper balance between investment and operating cost. When the heating, cooling or ventilation load is established, the total flow rate of air required can be determined by methods shown in Chapters 12 and 13. The problem is then to distribute the supply air properly among the spaces.

#### PRESSURE CHANGES

Ductwork imposes resistance to air flow which must be overcome by the expenditure of mechanical energy; this energy is ordinarily supplied by a fan. The portion of the air flow rate from the fan that is transmitted to a particular space is governed by the law that the loss in total pressure from the fan outlet must be the same along each air path. This also holds for the return-air system except that the loss in total pressure refers to the fan inlet. In air conditioning and ventilating work the pressure differences are ordinarily so small that the equations for incompressible flow can be applied. Additional simplicity is obtained by considering the air to be at the standard density of 0.075 lb per cu ft.

At any cross section in a duct the total pressure  $H$  is the sum of the static pressure  $P$  and the velocity pressure  $H_v$ . Thus,

$$H = P + H_v \quad (1)$$

Pressures are considered in units of inches of water. The velocity pressure is then given by

$$H_v = \left( \frac{V}{4005} \right)^2 \quad (2)$$

where  $V$  is defined by the equation

$$V = \frac{Q}{A} \quad (3)$$

where

$V$  = mean velocity of flow, feet per minute.

$Q$  = air flow rate, cubic feet per minute.

$A$  = cross-sectional area of duct, square feet.

The total pressure  $H$  is a measure of the total mechanical energy at a cross section. In any duct system, the total pressure always decreases in

the direction of the air flow. Static and velocity pressure are mutually convertible and either can increase or decrease in the direction of flow.

Typical pressure changes in a duct system are illustrated in Fig. 1. Between Sections A and B, the static and total pressures decrease uniformly because of friction between air molecules along the sides of the duct. Pressure losses in straight pipes are termed *friction losses* and are characterized by dependence upon Reynolds number. (See Chapter 4.)

Section BC is a converging section. The duct area is reduced, and consequently the flow is accelerated. This is a stable and efficient process and

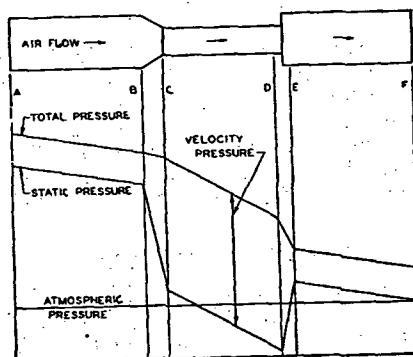


FIG. 1. PRESSURE CHANGES DURING FLOW IN DUCTS

the loss in total pressure is seen to be small. The marked decrease in static pressure is caused by conversion of static to velocity pressure in accordance with the equations above.

Section CD presents the friction loss in the section of smaller duct. Since friction losses increase with nearly the square of the velocity, the pressure line falls much more rapidly than in Section AB.

An abrupt expansion occurs at DE. The duct area is abruptly increased and the flow decelerated. The process is an inefficient one and the loss in total pressure is therefore large. The velocity pressure is decreased at E in accordance with Equations 2 and 3, and the static pressure rises. This and the pressure loss at BC are termed *dynamic losses*, and are characterized by being essentially independent of Reynolds number. Dynamic losses occur because of changes in the direction or velocity of the air, and hence occur at duct transitions, bends (elbows) and obstructions such as dampers. As will be shown later, dynamic losses can be specified in terms of a constant times the velocity pressure at a reference cross section.

Beginning at Section E the velocity pressure is constant, and the static and total pressures again decrease uniformly due to wall friction. The static pressure at F is zero, as referred to atmospheric. The total pressure is the velocity pressure and is a measure of the kinetic energy of the stream as it discharges from the duct.

The distinction between *static* and *total pressure* is important, because the former is conventionally used as the basis for system design, but the latter dictates the actual mechanical energy that must be supplied to the

system. Note in Fig. 1 that the static pressure decreases and then increases in the direction of flow. Moreover, it even becomes negative (below atmospheric). Therefore, in dealing with static pressures, distinction must always be made between static pressure *loss* (Section AB) and static pressure *change* as a result of conversion of velocity pressure (Section BC).

### FRICTION LOSSES

Pressure drop in a *straight* duct is caused by surface friction, and this friction loss is most readily calculated by means of the Air Friction Charts, Figs. 2 and 3, covering volume ranges of 10 to 2000 cfm, and 1000 to 100,000 cfm, respectively. These charts were developed by the A.S.H.A.E. Research Laboratory.<sup>1</sup>

The charts, Figs. 2 and 3, were constructed from the basic flow equation for the pressure loss in circular ducts (see Chapter 4):

$$H_f = f \left( \frac{l}{D} \right) H_v \quad (4)$$

where

$H_f$  = head loss due to friction, inches of water.

$f$  = a non-dimensional friction coefficient, which for air conditioning work depends upon Reynolds number and the relative roughness of the conduit. Approximate values of  $f$  were taken from the work of Moody<sup>2</sup> where  $e = 0.0005$  ft. (See Chapter 4, Fig. 4, Relation Between Friction Factor and Reynolds number.) It is numerically equivalent to the reciprocal of the number of duct diameters required to cause a pressure loss equivalent to one velocity pressure.

$l$  = length of conduit, feet.

$D$  = inside diameter of conduit, feet.

$H_v$  = velocity pressure of mean velocity, inches of water.

The air friction chart is based on standard air with a density of 0.075 lb per cu ft, flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 ft. Fig. 2 should not be used to obtain values below the charts by extrapolation, because critical flow would occur in this region and values so obtained would be unreliable. For the average application, values from the charts should have sufficient precision, without corrections, for any air temperature from 50 F to 90 F, for any relative humidity, and for any normal variation in barometric pressure. For widely varying air pressures or temperatures, or for unusual duct conditions, the friction values obtained from the chart should be corrected.<sup>3</sup>

For ordinary ventilating work, friction may be assumed to vary directly as the density without serious error, and therefore

$$h_o = h_s \left( \frac{\rho_o}{\rho_s} \right) \quad (5)$$

where

$h_o$  = friction loss under actual operating conditions, any consistent units.

$h_s$  = friction loss under standard conditions, any consistent units.

$\rho_o$  = density of air under actual operating conditions, any consistent units.

$\rho_s$  = density of air under standard conditions, any consistent units.

For ducts of other than standard sheet metal construction, correction

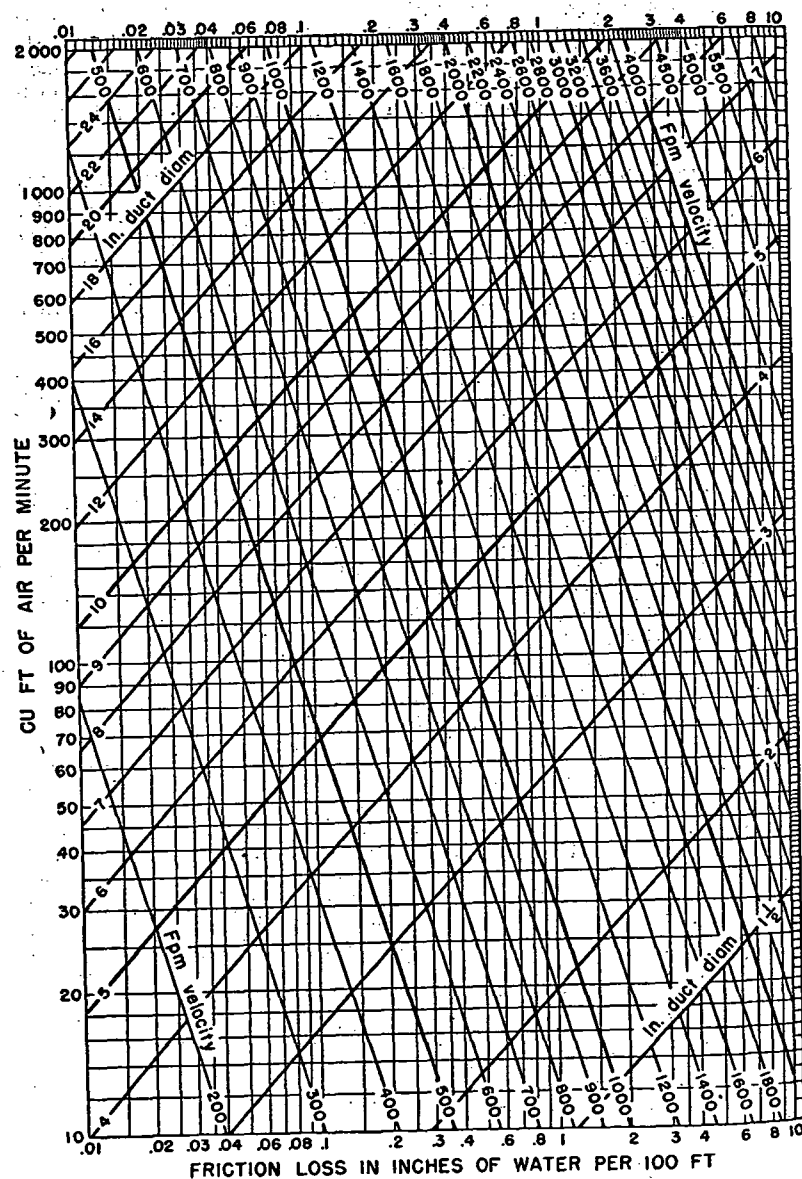


FIG. 2. FRICTION OF AIR IN STRAIGHT DUCTS

For Volumes of 10 to 2000 cfm

(Based on Standard Air of 0.075 lb per cu ft density flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 ft.) Caution: Do not extrapolate below chart.

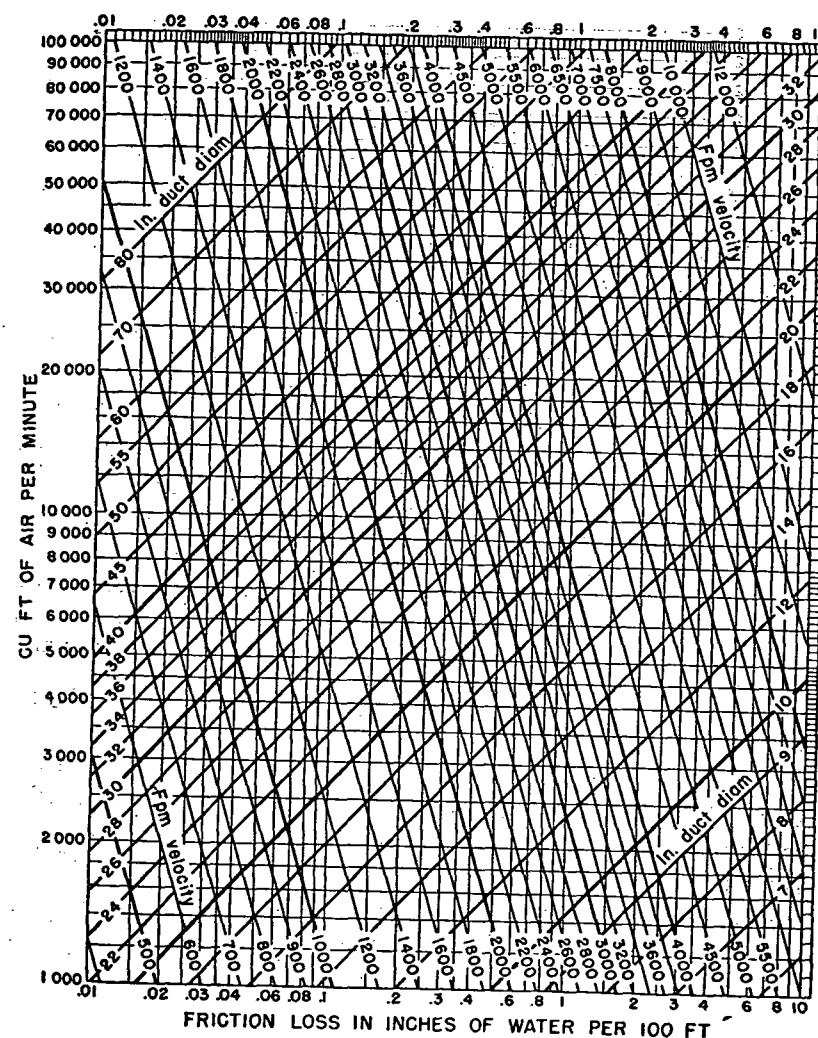


FIG. 3. FRICTION OF AIR IN STRAIGHT DUCTS

For Volumes of 1000 to 100,000 cfm

(Based on Standard Air of 0.075 lb per cu ft density flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 ft.)

factors may be obtained from Fig. 4.<sup>3</sup> Most ductwork today is fabricated from galvanized iron or aluminum sheet metal, or flexible tubing. Fig. 5 presents in graphical form the recommended correction factors for aluminum ductwork.<sup>4</sup> The correct friction loss for ducts other than sheet metal

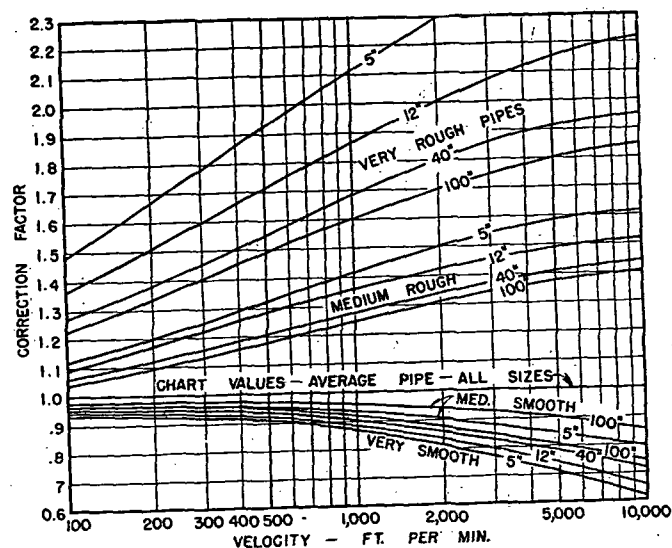


FIG. 4. CORRECTION FACTORS FOR PIPE ROUGHNESS

To correct for pipe roughness multiply friction loss obtained from Figs. 2 and 3 by correction factor obtained from Fig. 4.

construction may be determined by multiplying the losses obtained from Figs. 2 and 3 by these factors.

Accurate experimental data on the absolute roughness for flexible tubing are not yet available.

*Example 1* illustrates the use of Fig. 3 to determine friction loss in a galvanized sheet metal duct. *Examples 2* and *3* illustrate the use of Figs. 4 and 5 in applying correction factors for ducts of other than sheet metal construction.

*Example 1:* Determine the friction loss when circulating 10,000 cfm of air through 75 ft of 24 in. diameter galvanized duct.

*Solution:* Find 10,000 cfm on the left scale of Fig. 3 and move horizontally right to the diagonal line marked 24 in. The other intersecting diagonal shows that the velocity in the pipe is 3200 fpm. Directly below the intersection it is found that the friction per 100 ft is 0.50 in.; then for 75 ft the friction will be  $0.75 \times 0.50 = 0.38$  in. In a like manner, any two variables may be determined by the intersection of the lines representing the other two variables.

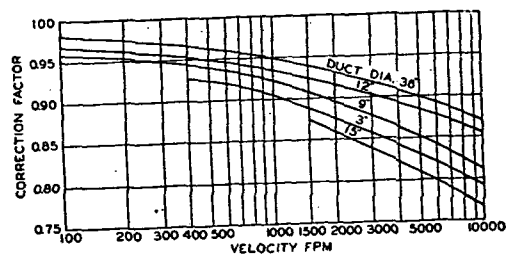


FIG. 5. CORRECTION FACTORS FOR ALUMINUM DUCT

*Example 2:* If the duct in *Example 1* is very rough, instead of galvanized, with 40 joints per 100 ft, find the total friction.

*Solution:* On Fig. 4 find (by interpolation between 12 in. and 40 in. pipe) the intersection of the 24 in. very rough pipe line and the 3200 fpm velocity ordinate, and at the left margin read a correction factor of 2. The friction loss in the rough duct is therefore  $2 \times 0.38 = 0.76$  in.

*Example 3:* If the duct in *Example 1* is made of aluminum, instead of galvanized iron, find the total friction.

*Solution:* On Fig. 5 find (by interpolation between 12-in. and 36-in. pipe) the intersection of the 24-in. line and the 3200-fpm velocity ordinate, and at the left margin read a correction factor of 0.91. The friction loss in the aluminum duct is therefore  $0.91 \times 0.38 = 0.35$  in.

### CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS

An air handling system is usually sized first for round ducts. Then, if rectangular ducts are desired, their sizes are selected to provide air carrying capacities equivalent to those of the round ducts originally selected.

A recent comprehensive study at the A.S.H.A.E. Research Laboratory proved that for most practical purposes rectangular ducts of aspect ratios not exceeding 8:1 will have the same static friction pressure loss for equal lengths and mean velocities of flow as a circular duct of the same hydraulic diameter. When duct sizes are expressed in terms of hydraulic diameter, and when equations for friction loss in round and rectangular ducts are equated for equal flow rate and equal length, Equation 6 giving the circular equivalent of a rectangular duct is obtained.<sup>5</sup>

$$d_e = 1.30 \frac{(ab)^{0.625}}{(a+b)^{0.250}} = 1.30 \sqrt[4]{\frac{(ab)^5}{(a+b)^2}} \quad (6)$$

where

$a$  = length of one side of rectangular duct, inches.

$b$  = length of adjacent side of rectangular duct, inches.

$d_e$  = circular equivalent of a rectangular duct for equal friction and capacity, inches.

Table 1 gives the circular equivalents of rectangular ducts for equal friction and capacity for aspect ratios not greater than 11.7:1 based on Equation 6.<sup>5</sup>

Multiplying or dividing the length of each side of a duct by a constant is the same as multiplying or dividing the equivalent round size by the same constant. Thus, if the circular equivalent of an 80- x 24-in. duct is required, it will be twice that of a 40- x 12-in. duct, or  $2 \times 23.0 = 46.0$  in.

TABLE 1. CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS FOR EQUAL FRICTION AND CAPACITY  
Dimensions in Inches

| SIDE RECTANGULAR DUCT | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | 9.5 | 10.0 |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 3.0                   | 3.8 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 4.9 | 5.1 | 5.2 | 5.4 | 5.5 | 5.6 | 5.7  |
| 3.5                   | 4.1 | 4.3 | 4.6 | 4.8 | 5.0 | 5.2 | 5.3 | 5.5 | 5.7 | 5.8 | 6.0 | 6.1 | 6.3  |
| 4.0                   | 4.4 | 4.6 | 4.9 | 5.1 | 5.3 | 5.5 | 5.7 | 5.9 | 6.1 | 6.3 | 6.4 | 6.6 | 6.8  |
| 4.5                   | 4.6 | 4.9 | 5.2 | 5.4 | 5.6 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 6.9 | 7.0 | 7.2  |
| 5.0                   | 4.9 | 5.2 | 5.5 | 5.7 | 6.0 | 6.2 | 6.4 | 6.7 | 6.9 | 7.1 | 7.3 | 7.4 | 7.6  |
| 5.5                   | 5.1 | 5.4 | 5.7 | 6.0 | 6.3 | 6.5 | 6.8 | 7.0 | 7.2 | 7.4 | 7.6 | 7.8 | 8.0  |

TABLE 1. CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS FOR EQUAL FRICTION AND CAPACITY (CONTINUED)

Dimensions in Inches

| SIDE<br>RECTANGULAR<br>DUCT | 10.0 | 10.5 | 11.0 | 11.5 | 12.0 | 12.5 | 13.0 | 13.5 | 14.0 | 14.5 | 15.0 | 15.5 | 16.0 |
|-----------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 3.0                         | 5.7  | 5.9  | 6.0  | 6.1  | 6.2  | 6.3  | 6.4  | 6.5  | 6.6  | 6.7  | 6.8  | 6.9  | 7.0  |
| 3.5                         | 6.3  | 6.4  | 6.5  | 6.7  | 6.8  | 6.9  | 7.0  | 7.1  | 7.2  | 7.3  | 7.4  | 7.5  | 7.6  |
| 4.0                         | 6.8  | 6.9  | 7.1  | 7.2  | 7.3  | 7.5  | 7.6  | 7.7  | 7.8  | 7.9  | 8.1  | 8.2  | 8.3  |
| 4.5                         | 7.2  | 7.4  | 7.5  | 7.7  | 7.8  | 8.0  | 8.1  | 8.2  | 8.4  | 8.5  | 8.6  | 8.7  | 8.9  |
| 5.0                         | 7.6  | 7.8  | 8.0  | 8.1  | 8.3  | 8.4  | 8.6  | 8.7  | 8.9  | 9.0  | 9.1  | 9.3  | 9.4  |
| 5.5                         | 8.0  | 8.2  | 8.4  | 8.6  | 8.7  | 8.8  | 9.0  | 9.2  | 9.4  | 9.5  | 9.6  | 9.8  | 9.8  |

| SIDE<br>RECTANGULAR<br>DUCT | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   | 16   | 17   | 18   | 19   |
|-----------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 6                           | 6.6  |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 7                           | 7.1  | 7.7  |      |      |      |      |      |      |      |      |      |      |      |      |
| 8                           | 7.5  | 8.2  | 8.8  |      |      |      |      |      |      |      |      |      |      |      |
| 9                           | 8.0  | 8.6  | 9.3  | 9.9  |      |      |      |      |      |      |      |      |      |      |
| 10                          | 8.4  | 9.1  | 9.8  | 10.4 | 10.9 |      |      |      |      |      |      |      |      |      |
| 11                          | 8.8  | 9.5  | 10.2 | 10.8 | 11.4 | 12.0 |      |      |      |      |      |      |      |      |
| 12                          | 9.1  | 9.9  | 10.7 | 11.3 | 11.9 | 12.5 | 13.1 |      |      |      |      |      |      |      |
| 13                          | 9.5  | 10.3 | 11.1 | 11.8 | 12.4 | 13.0 | 13.6 | 14.2 |      |      |      |      |      |      |
| 14                          | 9.8  | 10.7 | 11.5 | 12.2 | 12.9 | 13.5 | 14.2 | 14.7 | 15.3 |      |      |      |      |      |
| 15                          | 10.1 | 11.0 | 11.8 | 12.6 | 13.3 | 14.0 | 14.6 | 15.3 | 15.8 | 16.4 |      |      |      |      |
| 16                          | 10.4 | 11.4 | 12.2 | 13.0 | 13.7 | 14.4 | 15.1 | 15.7 | 16.3 | 16.9 | 17.5 |      |      |      |
| 17                          | 10.7 | 11.7 | 12.5 | 13.4 | 14.1 | 14.9 | 15.5 | 16.1 | 16.8 | 17.4 | 18.0 | 18.6 |      |      |
| 18                          | 11.0 | 11.9 | 12.9 | 13.7 | 14.5 | 15.3 | 16.0 | 16.6 | 17.3 | 17.9 | 18.5 | 19.1 | 19.7 |      |
| 19                          | 11.2 | 12.2 | 13.2 | 14.1 | 14.9 | 15.6 | 16.4 | 17.1 | 17.8 | 18.4 | 19.0 | 19.6 | 20.2 | 20.8 |
| 20                          | 11.5 | 12.5 | 13.5 | 14.4 | 15.2 | 15.9 | 16.8 | 17.5 | 18.2 | 18.8 | 19.5 | 20.1 | 20.7 | 21.3 |
| 22                          | 12.0 | 13.1 | 14.1 | 15.0 | 15.9 | 16.7 | 17.6 | 18.3 | 19.1 | 19.7 | 20.4 | 21.0 | 21.7 | 22.3 |
| 24                          | 12.4 | 13.6 | 14.6 | 15.6 | 16.6 | 17.5 | 18.3 | 19.1 | 19.8 | 20.6 | 21.3 | 21.9 | 22.6 | 23.2 |
| 26                          | 12.8 | 14.1 | 15.2 | 16.2 | 17.2 | 18.1 | 19.0 | 19.8 | 20.6 | 21.4 | 22.1 | 22.8 | 23.5 | 24.1 |
| 28                          | 13.2 | 14.5 | 15.6 | 16.7 | 17.7 | 18.7 | 19.6 | 20.5 | 21.3 | 22.1 | 22.9 | 23.6 | 24.4 | 25.0 |
| 30                          | 13.6 | 14.9 | 16.1 | 17.2 | 18.3 | 19.3 | 20.2 | 21.1 | 22.0 | 22.9 | 23.7 | 24.4 | 25.2 | 25.9 |
| 32                          | 14.0 | 15.3 | 16.5 | 17.7 | 18.8 | 19.8 | 20.8 | 21.8 | 22.7 | 23.6 | 24.4 | 25.2 | 26.0 | 26.7 |
| 34                          | 14.4 | 15.7 | 17.0 | 18.2 | 19.3 | 20.4 | 21.4 | 22.4 | 23.3 | 24.2 | 25.1 | 25.9 | 26.7 | 27.5 |
| 36                          | 14.7 | 16.1 | 17.4 | 18.6 | 19.8 | 20.9 | 21.9 | 23.0 | 23.9 | 24.8 | 25.8 | 26.6 | 27.4 | 28.3 |
| 38                          | 15.0 | 16.4 | 17.8 | 19.0 | 20.3 | 21.4 | 22.5 | 23.5 | 24.5 | 25.4 | 26.4 | 27.3 | 28.1 | 29.0 |
| 40                          | 15.3 | 16.8 | 18.2 | 19.4 | 20.7 | 21.9 | 23.0 | 24.0 | 25.1 | 26.0 | 27.0 | 27.9 | 28.8 | 29.7 |
| 42                          | 15.6 | 17.1 | 18.5 | 19.8 | 21.1 | 22.3 | 23.4 | 24.5 | 25.6 | 26.6 | 27.6 | 28.5 | 29.4 | 30.4 |
| 44                          | 15.9 | 17.5 | 18.9 | 20.2 | 21.5 | 22.7 | 23.9 | 25.0 | 26.1 | 27.2 | 28.2 | 29.1 | 30.0 | 31.0 |
| 46                          | 16.2 | 17.8 | 19.2 | 20.6 | 21.9 | 23.2 | 24.3 | 25.5 | 26.7 | 27.7 | 28.7 | 29.7 | 30.6 | 31.6 |
| 48                          | 16.5 | 18.1 | 19.6 | 20.9 | 22.3 | 23.6 | 24.8 | 26.0 | 27.2 | 28.2 | 29.2 | 30.2 | 31.2 | 32.2 |
| 50                          | 16.8 | 18.4 | 19.9 | 21.3 | 22.7 | 24.0 | 25.2 | 26.4 | 27.6 | 28.7 | 29.8 | 30.8 | 31.8 | 32.8 |
| 52                          | 17.0 | 18.7 | 20.2 | 21.6 | 23.1 | 24.4 | 25.6 | 26.8 | 28.1 | 29.2 | 30.3 | 31.4 | 32.4 | 33.4 |
| 54                          | 17.3 | 19.0 | 20.5 | 22.0 | 23.4 | 24.8 | 26.1 | 27.3 | 28.5 | 29.7 | 30.8 | 31.9 | 32.9 | 33.9 |
| 56                          | 17.6 | 19.3 | 20.9 | 22.4 | 23.8 | 25.2 | 26.5 | 27.7 | 28.9 | 30.1 | 31.2 | 32.4 | 33.4 | 34.5 |
| 58                          | 17.8 | 19.5 | 21.1 | 22.7 | 24.2 | 25.5 | 26.9 | 28.2 | 29.3 | 30.5 | 31.7 | 32.9 | 33.9 | 35.0 |
| 60                          | 18.1 | 19.8 | 21.4 | 23.0 | 24.5 | 25.8 | 27.3 | 28.7 | 29.8 | 31.0 | 32.2 | 33.4 | 34.5 | 35.5 |
| 62                          | 18.3 | 20.1 | 21.7 | 23.3 | 24.8 | 26.2 | 27.6 | 29.0 | 30.2 | 31.4 | 32.6 | 33.8 | 35.0 | 36.0 |
| 64                          | 18.6 | 20.3 | 22.0 | 23.6 | 25.2 | 26.5 | 27.9 | 29.3 | 30.6 | 31.8 | 33.1 | 34.2 | 35.5 | 36.5 |
| 66                          | 18.8 | 20.6 | 22.3 | 23.9 | 25.5 | 26.9 | 28.3 | 29.7 | 31.0 | 32.2 | 33.5 | 34.7 | 35.9 | 37.0 |
| 68                          | 19.0 | 20.8 | 22.5 | 24.2 | 25.8 | 27.3 | 28.7 | 30.1 | 31.4 | 32.6 | 33.9 | 35.1 | 36.3 | 37.5 |
| 70                          | 19.2 | 21.1 | 22.8 | 24.5 | 26.1 | 27.6 | 29.1 | 30.4 | 31.8 | 33.1 | 34.3 | 35.6 | 36.8 | 37.9 |

## Air Duct Design

TABLE 1. CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS FOR EQUAL FRICTION AND CAPACITY (CONCLUDED)

| ANALYSIS OF RECTANGULAR DUCTS FOR EQUAL FRICTION AND CAPACITY (CONCLUDED) |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|---------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Dimensions in Inches                                                      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Side<br>RECTANGULAR<br>DUCT                                               | 20   | 22   | 24   | 26   | 28   | 30   | 32   | 34   | 36   | 38   | 40   | 42   | 44   | 46   | 48   | 50   | 52   | 54   | 56   | 58   | 60   | 62   | 64    | 66    | 68    | 70    | 72    | 74    | 76    | 78    | 80    | 82    | 84    | 86    | 88    | 90    | 92    | 94    | 96    |
| 20                                                                        | 21.9 | 24.1 | 26.2 | 28.4 | 30.6 | 32.8 | 35.0 | 37.2 | 39.4 | 41.6 | 43.8 | 46.0 | 48.2 | 50.4 | 52.6 | 54.8 | 57.0 | 59.2 | 61.4 | 63.6 | 65.8 | 68.0 | 70.2  | 72.4  | 74.6  | 76.8  | 79.0  | 81.2  | 83.4  | 85.6  | 87.8  | 90.0  | 92.2  | 94.4  | 96.6  | 98.8  | 101.0 | 103.2 | 105.4 |
| 22                                                                        | 22.9 | 25.1 | 27.2 | 29.4 | 31.6 | 33.8 | 36.0 | 38.2 | 40.4 | 42.6 | 44.8 | 47.0 | 49.2 | 51.4 | 53.6 | 55.8 | 58.0 | 60.2 | 62.4 | 64.6 | 66.8 | 69.0 | 71.2  | 73.4  | 75.6  | 77.8  | 80.0  | 82.2  | 84.4  | 86.6  | 88.8  | 91.0  | 93.2  | 95.4  | 97.6  | 99.8  | 102.0 | 104.2 | 106.4 |
| 24                                                                        | 23.9 | 26.1 | 28.2 | 30.4 | 32.6 | 34.8 | 37.0 | 39.2 | 41.4 | 43.6 | 45.8 | 48.0 | 50.2 | 52.4 | 54.6 | 56.8 | 59.0 | 61.2 | 63.4 | 65.6 | 67.8 | 70.0 | 72.2  | 74.4  | 76.6  | 78.8  | 81.0  | 83.2  | 85.4  | 87.6  | 89.8  | 92.0  | 94.2  | 96.4  | 98.6  | 100.8 | 103.0 | 105.2 | 107.4 |
| 26                                                                        | 24.9 | 27.1 | 29.2 | 31.4 | 33.6 | 35.8 | 38.0 | 40.2 | 42.4 | 44.6 | 46.8 | 49.0 | 51.2 | 53.4 | 55.6 | 57.8 | 60.0 | 62.2 | 64.4 | 66.6 | 68.8 | 71.0 | 73.2  | 75.4  | 77.6  | 79.8  | 82.0  | 84.2  | 86.4  | 88.6  | 90.8  | 93.0  | 95.2  | 97.4  | 99.6  | 101.8 | 104.0 | 106.2 | 108.4 |
| 28                                                                        | 25.9 | 28.1 | 30.2 | 32.4 | 34.6 | 36.8 | 39.0 | 41.2 | 43.4 | 45.6 | 47.8 | 50.0 | 52.2 | 54.4 | 56.6 | 58.8 | 61.0 | 63.2 | 65.4 | 67.6 | 69.8 | 72.0 | 74.2  | 76.4  | 78.6  | 80.8  | 83.0  | 85.2  | 87.4  | 89.6  | 91.8  | 94.0  | 96.2  | 98.4  | 100.6 | 102.8 | 105.0 | 107.2 | 109.4 |
| 30                                                                        | 26.9 | 29.1 | 31.2 | 33.4 | 35.6 | 37.8 | 40.0 | 42.2 | 44.4 | 46.6 | 48.8 | 51.0 | 53.2 | 55.4 | 57.6 | 59.8 | 62.0 | 64.2 | 66.4 | 68.6 | 70.8 | 73.0 | 75.2  | 77.4  | 79.6  | 81.8  | 84.0  | 86.2  | 88.4  | 90.6  | 92.8  | 95.0  | 97.2  | 99.4  | 101.6 | 103.8 | 106.0 | 108.2 | 110.4 |
| 32                                                                        | 27.9 | 30.1 | 32.2 | 34.4 | 36.6 | 38.8 | 41.0 | 43.2 | 45.4 | 47.6 | 49.8 | 52.0 | 54.2 | 56.4 | 58.6 | 60.8 | 63.0 | 65.2 | 67.4 | 69.6 | 71.8 | 74.0 | 76.2  | 78.4  | 80.6  | 82.8  | 85.0  | 87.2  | 89.4  | 91.6  | 93.8  | 96.0  | 98.2  | 100.4 | 102.6 | 104.8 | 107.0 | 109.2 | 111.4 |
| 34                                                                        | 28.9 | 31.1 | 33.2 | 35.4 | 37.6 | 39.8 | 42.0 | 44.2 | 46.4 | 48.6 | 50.8 | 53.0 | 55.2 | 57.4 | 59.6 | 61.8 | 64.0 | 66.2 | 68.4 | 70.6 | 72.8 | 75.0 | 77.2  | 79.4  | 81.6  | 83.8  | 86.0  | 88.2  | 90.4  | 92.6  | 94.8  | 97.0  | 99.2  | 101.4 | 103.6 | 105.8 | 108.0 | 110.2 | 112.4 |
| 36                                                                        | 29.9 | 32.1 | 34.2 | 36.4 | 38.6 | 40.8 | 43.0 | 45.2 | 47.4 | 49.6 | 51.8 | 54.0 | 56.2 | 58.4 | 60.6 | 62.8 | 65.0 | 67.2 | 69.4 | 71.6 | 73.8 | 76.0 | 78.2  | 80.4  | 82.6  | 84.8  | 87.0  | 89.2  | 91.4  | 93.6  | 95.8  | 98.0  | 100.2 | 102.4 | 104.6 | 106.8 | 109.0 | 111.2 | 113.4 |
| 38                                                                        | 30.9 | 33.1 | 35.2 | 37.4 | 39.6 | 41.8 | 44.0 | 46.2 | 48.4 | 50.6 | 52.8 | 55.0 | 57.2 | 59.4 | 61.6 | 63.8 | 66.0 | 68.2 | 70.4 | 72.6 | 74.8 | 77.0 | 79.2  | 81.4  | 83.6  | 85.8  | 88.0  | 90.2  | 92.4  | 94.6  | 96.8  | 99.0  | 101.2 | 103.4 | 105.6 | 107.8 | 110.0 | 112.2 | 114.4 |
| 40                                                                        | 31.9 | 34.1 | 36.2 | 38.4 | 40.6 | 42.8 | 45.0 | 47.2 | 49.4 | 51.6 | 53.8 | 56.0 | 58.2 | 60.4 | 62.6 | 64.8 | 67.0 | 69.2 | 71.4 | 73.6 | 75.8 | 78.0 | 80.2  | 82.4  | 84.6  | 86.8  | 89.0  | 91.2  | 93.4  | 95.6  | 97.8  | 100.0 | 102.2 | 104.4 | 106.6 | 108.8 | 111.0 | 113.2 | 115.4 |
| 42                                                                        | 32.9 | 35.1 | 37.2 | 39.4 | 41.6 | 43.8 | 46.0 | 48.2 | 50.4 | 52.6 | 54.8 | 57.0 | 59.2 | 61.4 | 63.6 | 65.8 | 68.0 | 70.2 | 72.4 | 74.6 | 76.8 | 79.0 | 81.2  | 83.4  | 85.6  | 87.8  | 90.0  | 92.2  | 94.4  | 96.6  | 98.8  | 101.0 | 103.2 | 105.4 | 107.6 | 109.8 | 112.0 | 114.2 | 116.4 |
| 44                                                                        | 33.9 | 36.1 | 38.2 | 40.4 | 42.6 | 44.8 | 47.0 | 49.2 | 51.4 | 53.6 | 55.8 | 58.0 | 60.2 | 62.4 | 64.6 | 66.8 | 69.0 | 71.2 | 73.4 | 75.6 | 77.8 | 80.0 | 82.2  | 84.4  | 86.6  | 88.8  | 91.0  | 93.2  | 95.4  | 97.6  | 99.8  | 102.0 | 104.2 | 106.4 | 108.6 | 110.8 | 113.0 | 115.2 | 117.4 |
| 46                                                                        | 34.9 | 37.1 | 39.2 | 41.4 | 43.6 | 45.8 | 48.0 | 50.2 | 52.4 | 54.6 | 56.8 | 59.0 | 61.2 | 63.4 | 65.6 | 67.8 | 70.0 | 72.2 | 74.4 | 76.6 | 78.8 | 81.0 | 83.2  | 85.4  | 87.6  | 89.8  | 92.0  | 94.2  | 96.4  | 98.6  | 100.8 | 103.0 | 105.2 | 107.4 | 109.6 | 111.8 | 114.0 | 116.2 | 118.4 |
| 48                                                                        | 35.9 | 38.1 | 40.2 | 42.4 | 44.6 | 46.8 | 49.0 | 51.2 | 53.4 | 55.6 | 57.8 | 60.0 | 62.2 | 64.4 | 66.6 | 68.8 | 71.0 | 73.2 | 75.4 | 77.6 | 79.8 | 82.0 | 84.2  | 86.4  | 88.6  | 90.8  | 93.0  | 95.2  | 97.4  | 99.6  | 101.8 | 104.0 | 106.2 | 108.4 | 110.6 | 112.8 | 115.0 | 117.2 | 119.4 |
| 50                                                                        | 36.9 | 39.1 | 41.2 | 43.4 | 45.6 | 47.8 | 50.0 | 52.2 | 54.4 | 56.6 | 58.8 | 61.0 | 63.2 | 65.4 | 67.6 | 69.8 | 72.0 | 74.2 | 76.4 | 78.6 | 80.8 | 83.0 | 85.2  | 87.4  | 89.6  | 91.8  | 94.0  | 96.2  | 98.4  | 100.6 | 102.8 | 105.0 | 107.2 | 109.4 | 111.6 | 113.8 | 116.0 | 118.2 | 120.4 |
| 52                                                                        | 37.9 | 40.1 | 42.2 | 44.4 | 46.6 | 48.8 | 51.0 | 53.2 | 55.4 | 57.6 | 59.8 | 62.0 | 64.2 | 66.4 | 68.6 | 70.8 | 73.0 | 75.2 | 77.4 | 79.6 | 81.8 | 84.0 | 86.2  | 88.4  | 90.6  | 92.8  | 95.0  | 97.2  | 99.4  | 101.6 | 103.8 | 106.0 | 108.2 | 110.4 | 112.6 | 114.8 | 117.0 | 119.2 | 121.4 |
| 54                                                                        | 38.9 | 41.1 | 43.2 | 45.4 | 47.6 | 49.8 | 52.0 | 54.2 | 56.4 | 58.6 | 60.8 | 63.0 | 65.2 | 67.4 | 69.6 | 71.8 | 74.0 | 76.2 | 78.4 | 80.6 | 82.8 | 85.0 | 87.2  | 89.4  | 91.6  | 93.8  | 96.0  | 98.2  | 100.4 | 102.6 | 104.8 | 107.0 | 109.2 | 111.4 | 113.6 | 115.8 | 118.0 | 120.2 | 122.4 |
| 56                                                                        | 39.9 | 42.1 | 44.2 | 46.4 | 48.6 | 50.8 | 53.0 | 55.2 | 57.4 | 59.6 | 61.8 | 64.0 | 66.2 | 68.4 | 70.6 | 72.8 | 75.0 | 77.2 | 79.4 | 81.6 | 83.8 | 86.0 | 88.2  | 90.4  | 92.6  | 94.8  | 97.0  | 99.2  | 101.4 | 103.6 | 105.8 | 108.0 | 110.2 | 112.4 | 114.6 | 116.8 | 119.0 | 121.2 | 123.4 |
| 58                                                                        | 40.9 | 43.1 | 45.2 | 47.4 | 49.6 | 51.8 | 54.0 | 56.2 | 58.4 | 60.6 | 62.8 | 65.0 | 67.2 | 69.4 | 71.6 | 73.8 | 76.0 | 78.2 | 80.4 | 82.6 | 84.8 | 87.0 | 89.2  | 91.4  | 93.6  | 95.8  | 98.0  | 100.2 | 102.4 | 104.6 | 106.8 | 109.0 | 111.2 | 113.4 | 115.6 | 117.8 | 120.0 | 122.2 | 124.4 |
| 60                                                                        | 41.9 | 44.1 | 46.2 | 48.4 | 50.6 | 52.8 | 55.0 | 57.2 | 59.4 | 61.6 | 63.8 | 66.0 | 68.2 | 70.4 | 72.6 | 74.8 | 77.0 | 79.2 | 81.4 | 83.6 | 85.8 | 88.0 | 90.2  | 92.4  | 94.6  | 96.8  | 99.0  | 101.2 | 103.4 | 105.6 | 107.8 | 110.0 | 112.2 | 114.4 | 116.6 | 118.8 | 121.0 | 123.2 | 125.4 |
| 62                                                                        | 42.9 | 45.1 | 47.2 | 49.4 | 51.6 | 53.8 | 56.0 | 58.2 | 60.4 | 62.6 | 64.8 | 67.0 | 69.2 | 71.4 | 73.6 | 75.8 | 78.0 | 80.2 | 82.4 | 84.6 | 86.8 | 89.0 | 91.2  | 93.4  | 95.6  | 97.8  | 100.0 | 102.2 | 104.4 | 106.6 | 108.8 | 111.0 | 113.2 | 115.4 | 117.6 | 119.8 | 122.0 | 124.2 | 126.4 |
| 64                                                                        | 43.9 | 46.1 | 48.2 | 50.4 | 52.6 | 54.8 | 57.0 | 59.2 | 61.4 | 63.6 | 65.8 | 68.0 | 70.2 | 72.4 | 74.6 | 76.8 | 79.0 | 81.2 | 83.4 | 85.6 | 87.8 | 90.0 | 92.2  | 94.4  | 96.6  | 98.8  | 101.0 | 103.2 | 105.4 | 107.6 | 109.8 | 112.0 | 114.2 | 116.4 | 118.6 | 120.8 | 123.0 | 125.2 | 127.4 |
| 66                                                                        | 44.9 | 47.1 | 49.2 | 51.4 | 53.6 | 55.8 | 58.0 | 60.2 | 62.4 | 64.6 | 66.8 | 69.0 | 71.2 | 73.4 | 75.6 | 77.8 | 80.0 | 82.2 | 84.4 | 86.6 | 88.8 | 91.0 | 93.2  | 95.4  | 97.6  | 99.8  | 102.0 | 104.2 | 106.4 | 108.6 | 110.8 | 113.0 | 115.2 | 117.4 | 119.6 | 121.8 | 124.0 | 126.2 | 128.4 |
| 68                                                                        | 45.9 | 48.1 | 50.2 | 52.4 | 54.6 | 56.8 | 59.0 | 61.2 | 63.4 | 65.6 | 67.8 | 70.0 | 72.2 | 74.4 | 76.6 | 78.8 | 81.0 | 83.2 | 85.4 | 87.6 | 89.8 | 92.0 | 94.2  | 96.4  | 98.6  | 100.8 | 103.0 | 105.2 | 107.4 | 109.6 | 111.8 | 114.0 | 116.2 | 118.4 | 120.6 | 122.8 | 125.0 | 127.2 | 129.4 |
| 70                                                                        | 46.9 | 49.1 | 51.2 | 53.4 | 55.6 | 57.8 | 60.0 | 62.2 | 64.4 | 66.6 | 68.8 | 71.0 | 73.2 | 75.4 | 77.6 | 79.8 | 82.0 | 84.2 | 86.4 | 88.6 | 90.8 | 93.0 | 95.2  | 97.4  | 99.6  | 101.8 | 104.0 | 106.2 | 108.4 | 110.6 | 112.8 | 115.0 | 117.2 | 119.4 | 121.6 | 123.8 | 126.0 | 128.2 | 130.4 |
| 72                                                                        | 47.9 | 50.1 | 52.2 | 54.4 | 56.6 | 58.8 | 61.0 | 63.2 | 65.4 | 67.6 | 69.8 | 72.0 | 74.2 | 76.4 | 78.6 | 80.8 | 83.0 | 85.2 | 87.4 | 89.6 | 91.8 | 94.0 | 96.2  | 98.4  | 100.6 | 102.8 | 105.0 | 107.2 | 109.4 | 111.6 | 113.8 | 116.0 | 118.2 | 120.4 | 122.6 | 124.8 | 127.0 | 129.2 | 131.4 |
| 74                                                                        | 48.9 | 51.1 | 53.2 | 55.4 | 57.6 | 59.8 | 62.0 | 64.2 | 66.4 | 68.6 | 70.8 | 73.0 | 75.2 | 77.4 | 79.6 | 81.8 | 84.0 | 86.2 | 88.4 | 90.6 | 92.8 | 95.0 | 97.2  | 99.4  | 101.6 | 103.8 | 106.0 | 108.2 | 110.4 | 112.6 | 114.8 | 117.0 | 119.2 | 121.4 | 123.6 | 125.8 | 128.0 | 130.2 | 132.4 |
| 76                                                                        | 49.9 | 52.1 | 54.2 | 56.4 | 58.6 | 60.8 | 63.0 | 65.2 | 67.4 | 69.6 | 71.8 | 74.0 | 76.2 | 78.4 | 80.6 | 82.8 | 85.0 | 87.2 | 89.4 | 91.6 | 93.8 | 96.0 | 98.2  | 100.4 | 102.6 | 104.8 | 107.0 | 109.2 | 111.4 | 113.6 | 115.8 | 118.0 | 120.2 | 122.4 | 124.6 | 126.8 | 129.0 | 131.2 | 133.4 |
| 78                                                                        | 50.9 | 53.1 | 55.2 | 57.4 | 59.6 | 61.8 | 64.0 | 66.2 | 68.4 | 70.6 | 72.8 | 75.0 | 77.2 | 79.4 | 81.6 | 83.8 | 86.0 | 88.2 | 90.4 | 92.6 | 94.8 | 97.0 | 99.2  | 101.4 | 103.6 | 105.8 | 108.0 | 110.2 | 112.4 | 114.6 | 116.8 | 119.0 | 121.2 | 123.4 | 125.6 | 127.8 | 130.0 | 132.2 | 134.4 |
| 80                                                                        | 51.9 | 54.1 | 56.2 | 58.4 | 60.6 | 62.8 | 65.0 | 67.2 | 69.4 | 71.6 | 73.8 | 76.0 | 78.2 | 80.4 | 82.6 | 84.8 | 87.0 | 89.2 | 91.4 | 93.6 | 95.8 | 98.0 | 100.2 | 102.4 | 104.6 | 106.8 | 109.0 | 111.2 | 113.4 | 115.6 | 117.8 | 120.0 | 122.2 | 124.4 | 126.6 | 128.8 | 131.0 | 133.2 | 135.4 |
| 82                                                                        | 52.9 | 55.1 | 57.2 | 59.4 | 61.6 | 63.8 | 66.0 | 68.2 | 70.4 | 72.6 | 74.8 | 77.0 | 79.2 | 81.4 | 83.6 | 85.8 | 88.0 | 90.2 | 92.4 | 94.6 | 96.8 | 99.0 | 101.2 | 103.4 | 105.6 | 107.8 | 110.0 | 112.2 | 114.4 | 116.6 | 118.8 | 121.0 | 123.2 | 125.4 | 127.6 | 129.8 | 132.0 | 134.2 | 136.4 |
| 84                                                                        | 53.9 | 56.1 | 58.2 | 60.4 | 62.6 | 64.8 | 67.0 | 69.2 | 71.4 | 73.6 | 75.8 | 78.0 | 80.2 | 82.4 |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |



TABLE 2. PRESSURE LOSSES DUE TO ELBOWS  
(Additional Equivalent Losses in Excess of Friction to Intersection of Center Lines)

| TYPE                                       | ILLUSTRATION | CONDITIONS                                                         | PRESSURE LOSS                                        |                   |                   |
|--------------------------------------------|--------------|--------------------------------------------------------------------|------------------------------------------------------|-------------------|-------------------|
|                                            |              |                                                                    | C <sup>a</sup>                                       | L/D               | L/W               |
| N-DEG.                                     |              | RECTANGULAR OR ROUND; WITH OR WITHOUT VANES                        | N TIMES VALUE FOR SIMILAR 90-DEG. ELBOW <sup>b</sup> |                   |                   |
| 90-DEG. ROUND SECTION                      |              | MITER                                                              | 1.30 <sup>b</sup>                                    | 65 <sup>b</sup>   |                   |
|                                            |              | R/D=0.5                                                            | 0.90                                                 |                   |                   |
|                                            |              | 0.75                                                               | 0.45                                                 | 23                |                   |
|                                            |              | 1.0                                                                | 0.33                                                 | 17                |                   |
|                                            |              | 1.5                                                                | 0.24                                                 | 12                |                   |
|                                            |              | 2.0                                                                | 0.19                                                 | 10                |                   |
| 90-DEG. RECTANGULAR SECTION                |              | H/W                                                                | R/W                                                  |                   |                   |
|                                            |              | MITER                                                              | 1.25 <sup>b</sup>                                    |                   | 25 <sup>b</sup>   |
|                                            |              | 0.5                                                                | 1.25                                                 |                   | 25                |
|                                            |              | 0.25                                                               | 0.75                                                 |                   | 12                |
|                                            |              | 1.0                                                                | 0.37                                                 |                   | 7                 |
|                                            |              | 1.5                                                                | 0.19                                                 |                   | 4                 |
|                                            |              | MITER                                                              | 1.47                                                 |                   | 49                |
|                                            |              | 0.5                                                                | 1.10 <sup>b</sup>                                    |                   | 40                |
|                                            |              | 0.75                                                               | 0.50                                                 |                   | 16                |
|                                            |              | 1.0                                                                | 0.28                                                 |                   | 9                 |
|                                            |              | 1.5                                                                | 0.13                                                 |                   | 4                 |
|                                            |              | MITER                                                              | 1.50                                                 |                   | 75                |
|                                            |              | 0.5                                                                | 1.00                                                 |                   | 50                |
|                                            |              | 1.0                                                                | 0.75                                                 |                   | 21                |
|                                            |              | 1.5                                                                | 0.22                                                 |                   | 11                |
|                                            |              | MITER                                                              | 1.36                                                 |                   | 110               |
| 90-DEG. SQUARE SECTION WITH SPLITTER VANES |              | R/W                                                                | R <sub>1</sub> /W                                    | R <sub>2</sub> /W |                   |
|                                            |              | MITER 0.5                                                          | 0.5                                                  | 0.4               | 0.70 <sup>b</sup> |
|                                            |              | 0.7                                                                | 0.6                                                  |                   | 19                |
|                                            |              | 1.0                                                                | 1.0                                                  |                   | 12                |
|                                            |              | 1.5                                                                |                                                      |                   | 7.2               |
|                                            |              | MITER 0.3                                                          | 0.5                                                  |                   | 22 <sup>10</sup>  |
|                                            |              | 0.5                                                                | 0.2                                                  | 0.4               | 16                |
|                                            |              | 0.75                                                               | 0.4                                                  | 0.7               |                   |
|                                            |              | 1.0                                                                | 0.7                                                  | 1.0               |                   |
|                                            |              | 1.5                                                                | 1.3                                                  | 1.6               |                   |
| MITER WITH TURNING VANES                   |              | PLATE VANES                                                        | 0.35 <sup>b</sup>                                    |                   |                   |
| MITER TEE WITH VANES                       |              | FORMED VANES                                                       | 0.10 <sup>b</sup>                                    |                   |                   |
| RADIUS TEE                                 |              | CONSIDER EQUAL TO A SIMILAR ELBOW. BASE LOSS ON ENTERING VELOCITY. |                                                      |                   |                   |

<sup>a</sup> Values based on  $f$  values of approximately 0.02.

<sup>b</sup> Values calculated from  $L/D$  and  $L/W$  values of Reference 6 for  $f = 0.02$ .

Note: Superscript numbers refer to references at end of chapter.

### DYNAMIC LOSSES

Wherever eddying flow is present, brought about by sudden changes in the direction or magnitude of the velocity of the air flowing, a greater loss in pressure takes place than would occur in a steady flow through a similar length of straight duct having a uniform cross section. The amount of this loss, in excess of straight duct friction, is termed *dynamic loss*. Although dynamic losses may be assumed to be caused by changes in area actually occupied by the air flow, for convenience they are divided into two general classes: (1) those caused by *changes in direction* of the duct and (2) those caused by *changes in cross-sectional area* of the duct.

TABLE 3. PRESSURE LOSSES DUE TO AREA CHANGES

| TYPE                           | ILLUSTRATION | CONDITIONS | LOSS COEFFICIENT               |                               | TYPE                           | ILLUSTRATION | CONDITIONS | LOSS COEFFICIENT               |                               |
|--------------------------------|--------------|------------|--------------------------------|-------------------------------|--------------------------------|--------------|------------|--------------------------------|-------------------------------|
|                                |              |            | A <sub>1</sub> /A <sub>2</sub> | C <sub>1</sub> C <sub>2</sub> |                                |              |            | A <sub>1</sub> /A <sub>2</sub> | C <sub>1</sub> C <sub>2</sub> |
| ABRUPT EXPANSION               |              |            | 0.1                            | 0.81                          | ABRUPT CONTRACTION SQUARE EDGE |              |            | 0.0                            | 0.34 <sup>12</sup>            |
|                                |              |            | 0.2                            | 0.64                          |                                |              |            | 0.2                            | 0.32                          |
|                                |              |            | 0.3                            | 0.49                          |                                |              |            | 0.4                            | 0.25                          |
|                                |              |            | 0.4                            | 0.36                          |                                |              |            | 0.6                            | 0.16                          |
|                                |              |            | 0.5                            | 0.25                          |                                |              |            | 0.8                            | 0.06                          |
|                                |              |            | 0.6                            | 0.18                          | GRADUAL CONTRACTION            |              |            | 0                              |                               |
|                                |              |            | 0.7                            | 0.09                          |                                |              |            | 30°                            | 0.02 <sup>9</sup>             |
|                                |              |            | 0.8                            | 0.04                          |                                |              |            | 45°                            | 0.04                          |
|                                |              |            | 0.9                            | 0.01                          |                                |              |            | 60°                            | 0.07                          |
|                                |              |            | 0                              | C <sub>T</sub>                |                                |              |            |                                |                               |
| GRADUAL EXPANSION              |              |            | 5°                             | 0.17 <sup>9</sup>             | EQUAL AREA TRANSFORMATION      |              |            | A <sub>1</sub> /A <sub>2</sub> | C                             |
|                                |              |            | 7°                             | 0.22                          |                                |              |            | ≤ 14°                          | 0.15 <sup>9</sup>             |
|                                |              |            | 10°                            | 0.28                          |                                |              |            |                                |                               |
|                                |              |            | 20°                            | 0.45                          |                                |              |            |                                |                               |
|                                |              |            | 30°                            | 0.59                          |                                |              |            |                                |                               |
| ABRUPT EXIT                    |              |            | A <sub>1</sub> /A <sub>2</sub> | 1.00                          | FLANGED ENTRANCE               |              |            | A=∞                            | C                             |
|                                |              |            | (A <sub>2</sub> +∞)            |                               |                                |              |            |                                | 0.34 <sup>12</sup>            |
| SQUARE EDGE ORIFICE EXIT       |              |            | A <sub>2</sub> /A <sub>1</sub> | C <sub>0</sub>                | DUCT ENTRANCE                  |              |            | A=∞                            | C                             |
|                                |              |            | 0.0                            | 2.50 <sup>12</sup>            |                                |              |            |                                | 0.85 <sup>9</sup>             |
|                                |              |            | 0.2                            | 2.44                          |                                |              |            |                                |                               |
|                                |              |            | 0.4                            | 2.26                          |                                |              |            |                                |                               |
|                                |              |            | 0.6                            | 1.96                          |                                |              |            |                                |                               |
| BAR ACROSS DUCT                |              |            | E/D                            | C                             | FORMED ENTRANCE                |              |            | A <sub>1</sub> /A <sub>2</sub> | C <sub>0</sub>                |
|                                |              |            | 0.10                           | 0.79                          |                                |              |            | 0.0                            | 2.50 <sup>12</sup>            |
|                                |              |            | 0.25                           | 1.4                           |                                |              |            | 0.2                            | 1.90                          |
|                                |              |            | 0.50                           | 4.0                           |                                |              |            | 0.4                            | 1.39                          |
|                                |              |            |                                |                               |                                |              |            | 0.6                            | 0.96                          |
| PIPE ACROSS DUCT               |              |            | E/D                            | C                             | SQUARE EDGE ORIFICE IN DUCT    |              |            | 0.8                            | 0.61                          |
|                                |              |            | 0.10                           | 0.20 <sup>9</sup>             |                                |              |            | 1.0                            | 0.34                          |
|                                |              |            | 0.25                           | 0.55                          |                                |              |            |                                |                               |
|                                |              |            | 0.50                           | 2.0                           |                                |              |            |                                |                               |
|                                |              |            |                                |                               |                                |              |            |                                |                               |
| STREAM-LINED STRUT ACROSS DUCT |              |            | E/D                            | C                             | SQUARE EDGE ORIFICE IN DUCT    |              |            | A <sub>1</sub> /A <sub>2</sub> | C <sub>0</sub>                |
|                                |              |            | 0.10                           | 0.07 <sup>9</sup>             |                                |              |            | 0.0                            | 2.50 <sup>12</sup>            |
|                                |              |            | 0.25                           | 0.23                          |                                |              |            | 0.2                            | 1.86                          |
|                                |              |            | 0.50                           | 0.90                          |                                |              |            | 0.4                            | 1.21                          |
|                                |              |            |                                |                               |                                |              |            | 0.6                            | 0.64                          |

Note 1: Subscript on  $C$  indicates cross section at which velocity is calculated. (See, for example, Equation 10 in text.)

Note 2: Superscript numbers refer to references at end of chapter.

Dynamic losses vary substantially as the square of the mean velocity of the air, and are therefore conveniently expressed as a fraction of the velocity head:

$$H_d = C \left( \frac{V}{4005} \right)^2 \quad (7)$$

where

$H_d$  = dynamic pressure loss, inches of water.

$V$  = mean velocity of air flow, feet per minute.

$C$  = an experimentally determined constant (dynamic loss coefficient).

Where different areas are involved, subscripts are used to denote the area to which the coefficient applies, as  $C_1$  for inlet area,  $C_2$  for outlet area, and  $C_0$  for orifice area.

The dynamic loss coefficient  $C$  is dimensionless and represents the number of velocity heads lost at the conduit transition or bend. Values of the dynamic loss coefficient for elbows and other duct elements have been determined experimentally and are given in Tables 2 and 3. It should be



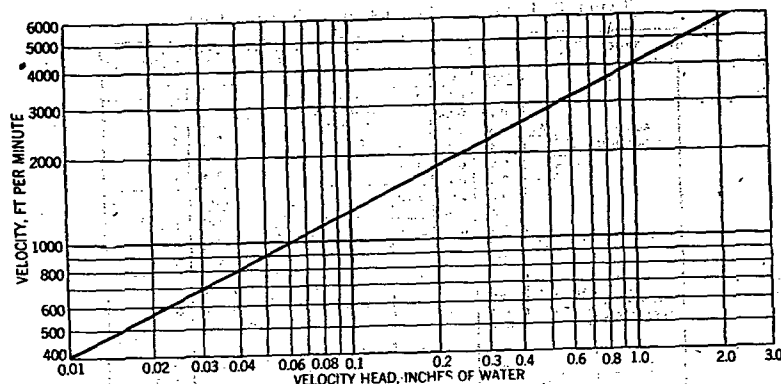


FIG. 6. RELATION BETWEEN VELOCITY AND VELOCITY HEAD FOR STANDARD AIR

noted, however, that absolutely reliable dynamic loss coefficients are not yet available for all duct elements and that the information available for pressure losses due to area changes is generally restricted to symmetrical area changes.

Fig. 6, which shows the relation of velocity pressure to velocity for standard air ( $V = 4005\sqrt{H_v}$ ), can be conveniently used to find the total dynamic pressure loss for any duct element with known dynamic loss coefficient  $C$ .

### PRESSURE LOSSES IN ELBOWS

Dynamic loss coefficients are nearly independent of the air velocity and are affected by the roughness of the duct walls only in the case of bends,

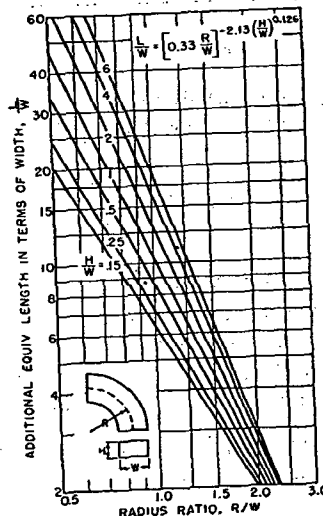


FIG. 7. LOSS IN 90-DEG ELBOWS OF RECTANGULAR CROSS SECTION

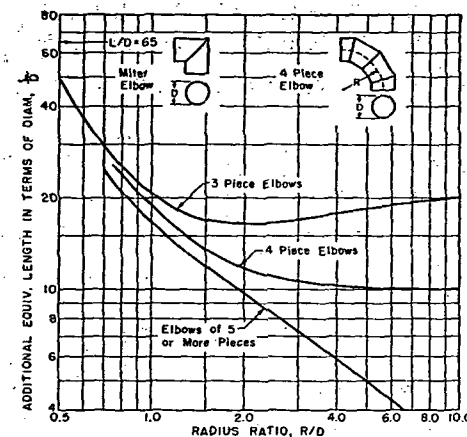


FIG. 8. LOSS IN 90-DEG ELBOWS OF ROUND CROSS SECTION

for which the dynamic losses are often grouped with the friction losses to facilitate design calculations. An A.S.H.A.E. survey<sup>6</sup> of available data has indicated that the method of expressing the combined dynamic and friction losses due to an elbow as equivalent to the loss in a length  $L$  of similar straight duct is justified for design purposes, owing to the relation of the loss to the corresponding friction factor,  $f$ .

Fig. 7 gives the *additional equivalent length* of duct in terms of widths  $W$  for elbows in rectangular ducts; Fig. 8 gives the *equivalent length* of duct in terms of diameters  $D$  for round ducts. When these curves for *additional equivalent length* are used, the straight lengths of duct between elbows should be measured to the intersection of their center lines.

*Example 4:* (Use of Fig. 7 for the calculation of elbow losses.)

Given the portion of a duct system shown in Fig. 9, it is required to determine the pressure loss between points A and D. Air at standard conditions is being supplied at the rate of 2000 cfm in a 6- by 24-in. galvanized duct of average construction. Elbows No. 1 and 2 have centerline radii of 18 and 9 in., respectively.

*Solution:* For elbow No. 1 the radius ratio is  $\frac{R_1}{W_1} = \frac{18}{24} = 0.75$  and the aspect ratio is  $\frac{H_1}{W_1} = \frac{6}{24} = 0.25$ . The additional equivalent length for elbow No. 1 in terms of  $W$

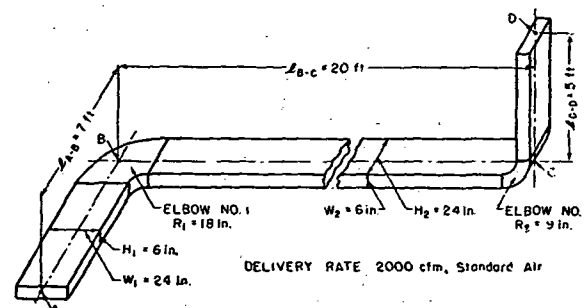


FIG. 9. PORTION OF DUCT SYSTEM FOR Example 4

is obtained from Fig. 7:  $(L/W)_1 = 11.5$ . Thus  $L_1 = 11.5 \times 24/12 = 23$  additional equivalent feet. Similarly for elbow No. 2, the ratio radius is  $\frac{R_2}{W_2} = \frac{9}{6} = 1.5$  and the aspect ratio is  $\frac{H_2}{W_2} = \frac{24}{6} = 4.0$ ; Fig. 7 gives  $(L/W)_2 = 6$ , so  $L_2 = 6 \times 6/12 = 3$  additional equivalent feet.

The total length of the straight runs from A to D is  $l = l_{A-B} + l_{B-C} + l_{C-D} = 7 + 20 + 5 = 32$  ft and the additional equivalent length due to the elbows is  $L = L_1 + L_2 = 23 + 3 = 26$  ft. Thus the equivalent length of the system from A to D is  $l + L = 32 + 26 = 58$  ft of 6 by 24 in. duct.

The diameter of a circular duct, equivalent in friction and capacity to this rectangular duct, is 12.4 in. as given by the table of circular equivalents, Table 1. At a delivery rate of 2000 cfm, the A.S.H.A.E. Friction Chart, Fig. 3, gives a loss of 0.6 in. of water per 100 ft. of 12.4-in. diameter duct. Thus the loss from A to D is  $0.6 \times 58/100 = 0.348$  in. of water.

The use of elbows of radius ratio,  $R/W = 1.5$ , is considered good practice with respect to both installation and operation. In a given rectangular duct 6 by 24 in., for example, the elbow loss will be greater for a flat bend where the aspect ratio,  $H/W = 1/4$ , then if the bend of the same radius ratio had been made in the plane of the narrow dimension giving an aspect ratio,  $H/W = 4$ .

Data now available for losses in compound bends,<sup>7, 8</sup> where two or more elbows are close together, do not warrant refinement of design calculations beyond use of the sum of the losses for the individual elbows. Actually, the losses are somewhat less than for two bends when they are placed to form a U bend, and somewhat more when they form a reversed, or S bend.

Where angles of other than 90-deg bend are encountered, the loss may be considered as directly proportional to the angle of bend. Losses for elbows discharging air directly into a large space are higher than those given for elbows within duct systems.

Turning vanes may be advantageously employed in elbows, both to reduce the pressure loss and to provide a more uniform velocity distribution downstream from the bend<sup>9, 10</sup>. Vanes and concentric splitters are particularly recommended where miter elbows are used, because even the simplest vane forms will produce a substantial saving in pressure loss.

Pressure loss data for elbows, both with and without vanes, are tabulated in condensed form, in Table 2.

#### PRESSURE LOSSES IN DIVIDED-FLOW FITTINGS

Data for losses at branch take-offs are quite meager and therefore an A.S.H.A.E. cooperative investigation is under way for the purpose of obtaining additional data on losses for typical take-off fittings. Analysis<sup>11</sup> of available data indicates that the loss in the straight-through section is about 35 percent of that for abrupt expansion (see next section, Losses Due to Area Changes) involving the same ratios of velocities; that the loss in the diverted-flow section depends on the ratio of the velocity of diverted flow to total flow and on the angle the take-off makes with the main, and is at a minimum for a natural relation that exists between these two variables. That is, there is a natural angle of efflux corresponding to the velocity ratio. Some representative branch losses are given in Table 4.

#### LOSSES DUE TO AREA CHANGES

Area changes in ducts, generally unavoidable, are necessitated frequently by the building construction or changes in the volume of air carried. Experimental investigations<sup>12, 13, 14, 15</sup> of pressure changes, and pressure losses

TABLE 4. RATIO OF PRESSURE LOSS TO BRANCH VELOCITY PRESSURE

| TAKE-OFF ANGLE | RATIO OF VELOCITY IN BRANCH TO VELOCITY IN MAIN DUCT |     |      |      |      |      |      |
|----------------|------------------------------------------------------|-----|------|------|------|------|------|
|                | 0.4                                                  | 0.6 | 0.8  | 1.0  | 1.5  | 2.0  | 3.0  |
| 90-deg         | 6.5                                                  | 3.1 | 2.0  | 1.5  | 0.95 | 0.74 | 0.62 |
| 60-deg         | 5.0                                                  | 2.2 | 1.3  | 0.77 | 0.47 | 0.47 | 0.58 |
| 45-deg         | 3.5                                                  | 1.3 | 0.64 | 0.43 | 0.40 | 0.45 | 0.54 |

at changes of the area of duct cross sections, indicate that the excess pressure loss over the normal friction loss is a dynamic loss due to a faster stream expanding into a slower stream, as determined by the actual areas occupied by the flow rather than the areas of the duct. No perceptible dynamic loss is due to the converging of the air stream itself where the flow is contracted, but the air stream continues to converge beyond the edge of the contraction and reaches a minimum at the *vena contracta*. For contraction, therefore, the dynamic loss is caused by expansion from the *vena contracta* to the full area following the contraction. Abrupt contraction in area may therefore be considered as a special condition of abrupt expansion. Fig. 10 illustrates (a) abrupt enlargement and (b) abrupt contraction.

For a sudden symmetrical enlargement, a theoretical expression for the loss is

$$H_e = \frac{(V_1 - V_2)^2}{4005} = \left(1 - \frac{A_1}{A_2}\right) \left(\frac{V_1}{4005}\right)^2 = C_1 \left(\frac{V_1}{4005}\right)^2 = C_2 \left(\frac{V_2}{4005}\right)^2 \quad (8)$$

where

$H_e$  = pressure loss due to sudden enlargement, based on standard air, inches of water.

$V_1$  = velocity of standard air in the inlet duct, feet per minute.

$V_2$  = velocity of standard air in the outlet duct, feet per minute.

$A_1$  = area of the inlet duct, square feet.

$A_2$  = area of the outlet duct, square feet.

$C_1$  = loss coefficient based on area  $A_1$ .

$C_2$  = loss coefficient based on area  $A_2$ .

For a gradual symmetrical enlargement, Equation 8 changes to

$$H_{eg} = C_r \left(\frac{V_1 - V_2}{4005}\right)^2 = C_r C_1 \left(\frac{V_1}{4005}\right)^2 = C_r C_2 \left(\frac{V_2}{4005}\right)^2 \quad (9)$$

where

$H_{eg}$  = pressure loss due to gradual enlargement, inches of water.

$C_r$  = coefficient of loss, as ratio of loss to loss for abrupt expansion, dependent upon the total angle included between the sides of the duct.

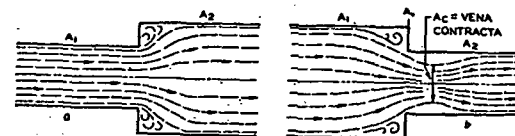


FIG. 10. AIR FLOW AT ABRUPT ENLARGEMENT OR CONTRACTION OF AIR STREAM

The loss for a sudden symmetrical contraction can be expressed as

$$H_c = C_2 \left( \frac{V_2}{4005} \right)^2 = C_1 \left( \frac{V_1}{4005} \right)^2 = C_o \left( \frac{V_o}{4005} \right)^2 \quad (10)$$

where

$H_c$  = pressure loss due to sudden contraction (Fig. 10b)

$C_o$  = loss coefficient based on orifice area  $A_o$

$V_o$  = velocity of air through orifice, feet per minute.

The loss for a gradual symmetrical contraction can be similarly expressed as

$$H_{gc} = C_2 \left( \frac{V_2}{4005} \right)^2 \quad (11)$$

where the coefficient of loss,  $C_2$ , depends on the included angle of the sides of the duct and the sharpness of the edges at the junction of taper to following duct section.

Pressure loss data for a variety of duct elements are given in Table 3.

### DUCT DESIGN

The following discussion refers to ducts for commercial and industrial heating, ventilating, and air conditioning systems of the central station type. The design procedures given yield the static pressure required to overcome the resistance of the ductwork, including the supply outlets and return intakes. The fan selected for the duct system must not only produce this pressure but also the additional pressure required by the central equipment such as washers or spray chambers, heating or cooling coils, and filters. Pressure losses of these components should be obtained from the manufacturers' catalogs.

Special duct design procedures for heating ducts used in residences can be found in Chapter 19, Gravity Warm Air Systems, and Chapter 20, Forced Warm Air Systems. The design of ducts in industrial exhaust systems is discussed in Chapter 46.

General rules which should be followed in the design are:

1. The air should be conveyed as directly as possible at the permissible velocities to obtain the desired results with minimum noise and greatest economy of power, material and space.
2. Sudden changes in the direction or velocity of the air should be avoided. When sudden changes are necessary at bends, turning vanes should be used to minimize the pressure loss.
3. Diverging transition pieces should be made as gradual as practicable. As shown in the section on area changes, losses in abrupt enlargements are high and therefore such transitions should be avoided. The included angle of divergence for enlargement should not exceed 20 deg. Losses in contractions are low but the included angle of convergence should not be greater than 60 deg.
4. Where the greatest air carrying capacity per square foot of sheet metal is desired, rectangular ducts should be made as nearly square as possible. Aspect ratios (ratio of width to depth) greater than 10 to 1 should be avoided.
5. Ducts should be constructed of smooth material, such as steel or aluminum sheet metal. For ducts made from other materials, proper allowance for the change in roughness should be made.<sup>\*</sup>
6. Through the design procedures which follow, a reasonably precise estimate of the flow resistances offered by the system can be obtained. However, it should be recognized that in actual installations, resistances may vary considerably from the

calculated values because of variation in the smoothness of materials, types of joints used, and the ability of workmen to fabricate the system in accordance with the design. Fans and motors should therefore be selected to provide at least a slight factor of safety, and dampers should be installed in each branch outlet for balancing the system.

### Procedure for Duct Design

The general procedure is as follows:

1. Study the plan of the building and arrange the positions of the supply outlets to provide proper distribution of air within each space. Select outlet sizes from manufacturers' catalog data.
2. Draw a sketch of the most convenient system of ductwork, connecting the supply outlets and return intakes with the central station apparatus, taking cog-

TABLE 5. RECOMMENDED AND MAXIMUM DUCT VELOCITIES

| DESIGNATION          | RECOMMENDED VELOCITIES, FPM |                                     |                      | MAXIMUM VELOCITIES, FPM |                                     |                      |
|----------------------|-----------------------------|-------------------------------------|----------------------|-------------------------|-------------------------------------|----------------------|
|                      | Residences                  | Schools, Theaters, Public Buildings | Industrial Buildings | Residences              | Schools, Theaters, Public Buildings | Industrial Buildings |
| Outside Air Intakes* | 500                         | 500                                 | 500                  | 800                     | 900                                 | 1200                 |
| Filters*             | 250                         | 300                                 | 350                  | 300                     | 350                                 | 350                  |
| Heating Coils*       | 450                         | 500                                 | 600                  | 500                     | 600                                 | 700                  |
| Air Washers          | 500                         | 500                                 | 500                  | 500                     | 500                                 | 500                  |
| Suction Connections  | 700                         | 800                                 | 1000                 | 900                     | 1000                                | 1400                 |
| Fan Outlets          | 1000-1600                   | 1300-2000                           | 1600-2400            | 1700                    | 1500-2200                           | 1700-2800            |
| Main Ducts           | 700-900                     | 1000-1300                           | 1200-1800            | 800-1200                | 1100-1600                           | 1300-2200            |
| Branch Ducts         | 600                         | 600-900                             | 800-1000             | 700-1000                | 800-1300                            | 1000-1800            |
| Branch Risers        | 500                         | 600-700                             | 800                  | 650-800                 | 800-1200                            | 1000-1600            |

\* These velocities are for total face area, not the net free area; other velocities in table are for net free area.

nizance of the building construction, avoiding all obstructions in steel work and equipment, and at the same time maintaining a simple design.

3. Calculate the sizes of all main and branch ducts by one of the procedures given in the following section.

4. Determine the total pressure requirement of the supply and return duct systems. Although the loss in total pressure of each duct run connecting the fan and each supply outlet (or return intake) should be calculated and made the same for all runs, ordinarily only the pressure loss of the duct run apparently having the greatest resistance is referred to as the pressure loss of the duct system. Dampers are relied upon for balancing the system.

### Design Velocities

It is not possible to give specific rules for selecting duct velocities. Since the fan horsepower increases approximately as the square of the velocity, and noise generation increases with static pressure, velocities should be kept low for quiet and economical operation. On the other hand, from Equation 3, at a given flow rate the duct size increases with decreasing velocity. For multi-story buildings, it is sometimes possible to reduce the height between floors by using very small ducts, thereby effecting a considerable reduction in building investment cost. Velocities as high as 6000 fpm in main ducts have been used in *high-velocity* duct systems. Special outlets for such systems have recently been marketed; they incorporate a device for reducing the pressure and attenuating the noise before introducing the supply air into the conditioned space. High-velocity duct sys-

tems are becoming increasingly numerous and design experiences reported are the present best guide.<sup>16-23</sup>

For residences and low pressure commercial systems, the values given in Table 5 may be used. As a general guide, design velocities in main ducts are frequently 1000 fpm in residences and 2000 fpm in commercial buildings. For the branch ducts and branch risers, design velocities are usually about two-thirds and one-half, respectively, of the main duct velocity.

### DESIGN METHODS

In the design of air duct systems, three methods are employed: (1) *velocity reduction*, (2) *equal friction*, and (3) the *static regain*. The three methods and their refinements represent different design levels of accuracy and complexity, and they should be selected, therefore, to suit the application. Simple duct systems may be designed as quickly and easily as possible, but for large installations the system static-pressure requirement must be determined as precisely as possible, the most accurate method being recommended.

#### Velocity Reduction Method

This method consists of selecting the velocity at the fan discharge and designing for progressively lower velocities in the main at each branch duct. With the selected velocities and known air-flow rates, the various duct diameters are read directly from Figs. 2 or 3, and the equivalent rectangular sizes are obtained from Table 1. The pressure loss of the run having apparently the highest resistance is determined by adding the straight pipe, elbow, and transition losses; this total value represents the fan static pressure required for the supply-duct system. The return-air system is sized similarly, starting with the lowest velocities at the return intakes and increasing them progressively in the direction of the fan inlet. Dampers are relied upon for balancing the system.

A refinement is to size the several branch ducts to dissipate the pressure available at the entrance to each. The pressure loss of the duct work between the fan inlet and first branch take-off is subtracted from the now known fan static pressure to obtain the available pressure at each junction. By trial, a branch velocity is found that results in the branch pressure loss being equal to, or somewhat less than, that available. The procedure is repeated for each branch.

If the fan is specified so that the static pressure available for the duct work is known, the method consists of finding, by trial, the velocities in the main duct that will require a pressure loss equal to that available. The branch ducts are then sized as previously explained if such a refinement is deemed necessary.

The merits of the *velocity reduction* method are that (1) duct sizes are determined very easily; and (2) velocities can be limited to those known to be safe from causing noise problems. Its weaknesses are: (1) proper choice of velocities requires experience and judgment; and (2) the designer cannot always determine by inspection which run probably has the highest resistance.

#### Equal Friction Method

The principle of this method is to make the pressure loss per foot of length the same for the entire system. With this method little balancing is required for symmetrical layouts in which all runs have about the same

### Air Duct Design

resistance. For layouts having both short and long runs, the shortest run will require considerable dampering.

Usual practice is to select the velocity in the main duct near the fan from the standpoint of noise for the particular application. Since the flow rate (cfm) is known, this establishes a value of friction loss per 100 ft of duct in Figs. 2 or 3. This same friction loss value is maintained throughout the design. For example, the flow rate in the main after the first branch take-off is reduced by that handled by the branch. Therefore, proceed vertically downward in Figs. 2 or 3 to the new flow rate value, and read the velocity and diameter. Note that the velocity is reduced by this procedure; a merit of this method is that it *automatically* reduces the duct velocities in the direction of flow, thereby insuring that noise will not be a problem. The equivalent rectangular size of any diameter is obtained from Table 1. By continuing the procedure, all sections, including branch ducts, are sized from Figs. 2 and 3 at the same friction loss per foot of actual length.

After sizing the system the pressure loss of the run having apparently the highest resistance is calculated. In so doing, the pressure losses of all elbows and transitions are included, and are expressed in terms of *equivalent length* of straight pipe.

The principal limitation of the *equal friction* method is that it does not differentiate between runs having several transitions, elbows, etc., and runs having none. Only the *actual length* of duct is considered; this and the flow rate fix the duct size. Moreover, when computing the system resistance, care must be exercised that the pressure losses of transitions, elbows, etc., are included and added to the straight pipe losses.

If the pressure available for the duct work is known, as it is for packaged equipment, this pressure can be divided by the total equivalent length of the run apparently having the highest resistance to obtain a design friction loss value per foot, for use with Fig. 2 or Fig. 3. Hence, for these applications, it is not necessary to select an initial velocity. However, the method then has the weakness that the resistances of fittings must be expressed in terms of *equivalent length*. Since transitions, elbows, etc., have predominantly dynamic losses, the equivalent length of a particular fitting varies considerably with its actual size. Note, for example, that the values for elbows in Fig. 4 of Chapter 20 and also that the elbow losses in Fig. 7 of this chapter are given in terms of the number of *diameters*. Hence, when the available pressure is known, the method requires that the duct size be estimated in advance. The calculated duct size should therefore be compared with the initial estimate, and if considerably different, a recalculation should be made using the calculated size.

Less dampering is required if the method is modified so that only the main duct is sized by the equal friction method. The fan is selected for this total duct resistance and the pressure available at each branch take-off is found in the manner described for the *velocity reduction* method. The pressure available at each branch is divided by its equivalent length, in hundreds of feet, to obtain a design friction loss value for use with Fig. 2 or Fig. 3 in conjunction with the branch flow rate. The branch ducts are therefore sized as nearly as possible to dissipate all of the available pressure.

When using this modified method, care should be exercised that the velocities in short branches do not become excessive from a noise standpoint. This is easily guarded against during the design process, because the velocity can be read directly from the friction chart. If it is excessive, move horizontally to the left on the chart and select a diameter which yields a reasonable velocity. The damper for this run will have to dissipate

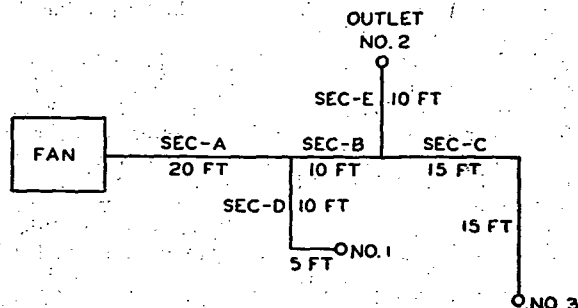


FIG. 11. DUCT LAYOUT FOR EXAMPLES

the excess pressure. Since duct work attenuates noise to some extent, the damper should be located as close to the main as possible. Sound treatment for this branch should also be considered. An alternative solution may be to revise the duct layout to increase the resistance of the run, for example, by relocating the branch take-off so that the total duct length is increased.

**Example 5: (Equal Friction Method).** A duct layout is shown in Fig. 11. Outlets Nos. 1 and 2 deliver 750 cfm each and outlet No. 3 delivers 1000 cfm. Selecting a velocity of 1600 cfm in Section A, size the duct system and determine its static pressure requirement.

**Solution:** The total cfm to be handled is 2500 cfm. From Fig. 3, with 2500 cfm and 1600 cfm velocity, read a diameter of 17 in. and a friction loss of 0.2 in. of water per 100 ft. By subtraction, the flow rate in Section B is 1750 cfm. Along the 0.2 friction line in Fig. 3, all of the ducts can be sized immediately because the flow rates are known. Results are presented in Table 6.

The rectangular equivalents were selected from Table 1 with the objective of having the same duct depth for all three branch runs.

The duct run to outlet No. 3 has the highest apparent resistance. It is decided to fabricate the elbow in Section C with a radius ratio of 1.2; hence, from Fig. 7 with  $H/W = 1.9$ ,  $L/W = 8$ . Since  $W = 1.25$  ft (15 in.), the additional equivalent length due to the elbow  $L$  is 10 ft. The total equivalent length of the run is therefore  $(20 + 10 + 15 + 10 + 15) = 70$  ft. Therefore, at 0.2 per 100 ft the duct resistance is  $0.2 \times 70 = 0.14$  in. of water. Adding to this the outlet pressure of 0.12 in., the static pressure requirement of the duct system is 0.26 in. of water. The design is now complete, and dampers will be relied upon for adjusting the outlets to the design flow rates.

If refinement is deemed necessary, the modified method can be applied to Sections D and E. First, the static pressures available at the junctions with the main of the Section D and E branch ducts are obtained. For Section D it is the system pressure of 0.26 minus the friction pressure loss in Section A. The latter is  $0.20 \times (20/100) = 0.04$ ; hence, the pressure at the entrance of Section B is 0.22 in. of water. Deducting the outlet pressure loss of 0.12, that available for the duct work is 0.10. Assume

TABLE 6. TABULATION OF RESULTS (Example 5)

| SECTION | FLOW RATE<br>cfm | FRICTION PER 100<br>FT, IN. OF WATER | DUCT DIAM<br>INCHES | VELOCITY<br>fpm | RECTANGULAR<br>DUCT INCHES |
|---------|------------------|--------------------------------------|---------------------|-----------------|----------------------------|
| A       | 2500             | 0.2                                  | 17.0                | 1600            | 20 x 12                    |
| B       | 1750             | 0.2                                  | 14.8                | 1480            | 15 x 12                    |
| C       | 1000             | 0.2                                  | 12.0                | 1290            | 15 x 8                     |
| D       | 750              | 0.2                                  | 10.7                | 1190            | 12 x 8                     |
| E       | 750              | 0.2                                  | 10.7                | 1190            | 12 x 8                     |

the equivalent lengths of the branch take-off and the elbow to be 10 ft each. The total equivalent length of Section D is then  $(10 + 10 + 10 + 5) = 35$ , and the friction loss per 100 ft required to dissipate 0.10 in. of water is  $0.10 \times (100/35) = 0.29$ . With this unit friction loss and a flow rate of 750 cfm, Fig. 2 yields a diameter of 10.0 in. and a velocity of 1380 fpm.

Section E is sized in a similar manner. The pressure available is 0.26 minus the friction loss in Sections A and B; hence, 0.20. With the outlet pressure loss of 0.12 deducted, the available duct-work pressure loss is 0.08 in. Assuming that the branch take-off loss is equivalent to 10 ft of duct, the total equivalent length is 20 ft. The required friction loss is  $0.08 \times (100/20) = 0.40$ . With this unit friction loss and a flow rate of 750 cfm, Fig. 2 yields a diameter of 9.4 in. and a velocity of 1580 fpm. An equivalent rectangular size is 9 x 8 in.

Comparing these results with those in Table 5, it is evident that the modified method has reduced the size of Section D somewhat and that of Section E considerably. The reduced sizes accomplish more economically what would otherwise have to be done with dampers.

### Static Regain Method

Consider a straight run of duct with several branch take-offs attached. The flow rate of air along the run is progressively reduced by the amount diverted into each successive take-off. If, for example, the size of the run were the same throughout its length, the velocity would become progressively less in accordance with Equation 3. When velocities are reduced, a conversion of velocity pressure into static pressure occurs (as well as a loss in total pressure). The principle of the *static regain* method is to size a duct run so that the increase in static pressure (regain) at each take-off junction just offsets the pressure loss of the succeeding section of the run.

The method provides a convenient means of designing a long run of duct having several take-offs so that essentially the same static pressure exists at the entrance to each branch. If, instead of branch ducts, supply outlets are connected directly to the run, then essentially the same static pressure will exist behind each outlet. As a consequence, outlet selection and system balancing is simplified. The method is particularly suited to large installations having several long runs of duct, with each run having many take-offs or supply outlets attached. For this type of application, little or no dampering is ordinarily required to balance the system.

The initial velocity in the main duct is selected from noise and pressure loss considerations, and the branch ducts are sized by the modified equal friction method.

If the distance between branch take-offs is either very small or very great, it may not be feasible or economically desirable to design for the same static pressure at each junction. In such cases, the method can be used to size the main for either a progressively lower static pressure (net static pressure loss) or a progressively higher pressure (net static pressure gain).

If no friction or dynamic losses occurred at the junction, there would be no loss in total pressure, and the change in velocity pressure would be completely converted into a regain (rise) in static pressure, which for standard air would be:

$$P_s = \left( \frac{V_1}{4005} \right)^2 - \left( \frac{V_2}{4005} \right)^2 \quad (12)$$

where

$P_s$  = theoretical static pressure regain, inches of water.

$V_1$  = velocity in main upstream of branch, feet per minute.

$V_2$  = velocity in main downstream of branch, feet per minute.

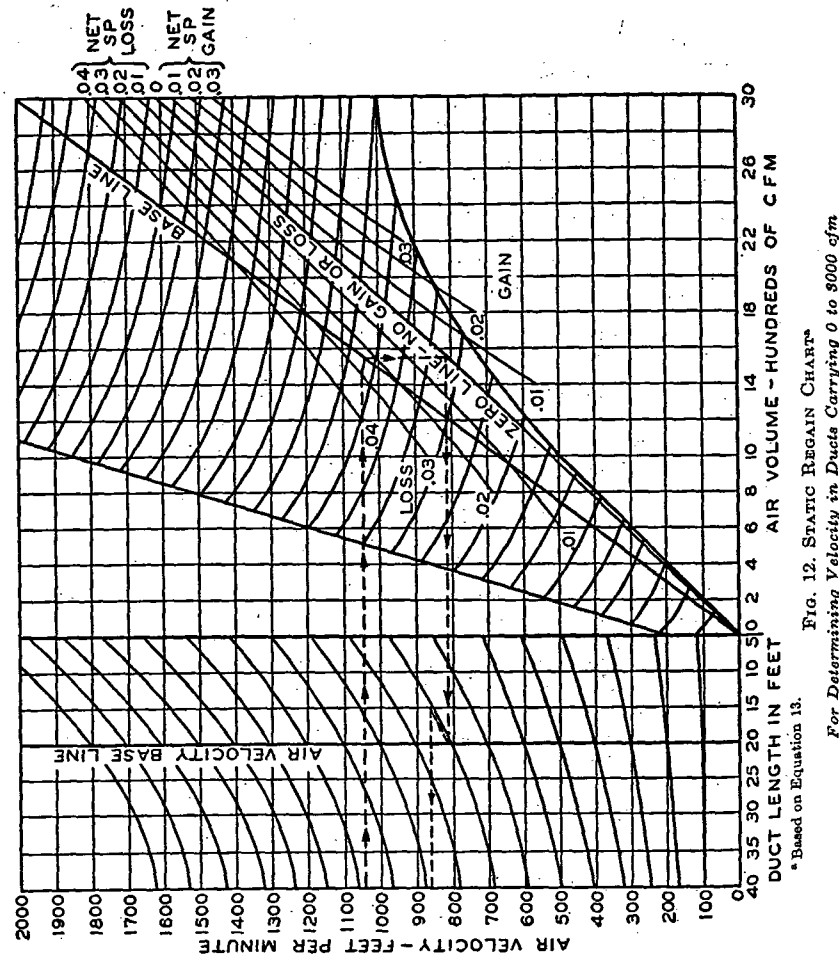


FIG. 12. STATIC REGAIN CHART\*

For Determining Velocity in Ducts Carrying 0 to 8000 cfm

Under the best practice, 0.7 to 0.8 of the change in velocity pressure is actually recovered, but for practical design an average recovery of 0.5 is assumed. Hence, the actual regain  $P_r$  is:

$$P_r = 0.5 \left[ \left( \frac{V_1}{4005} \right)^2 - \left( \frac{V_2}{4005} \right)^2 \right] \quad (13)$$

Design charts based on Equation 13 and rectangular ducts having aspect ratios of 3 to 1 or less are presented in Figs. 12 and 13.

The *duct length* of any section should include the equivalent length of any elbows or transitions within the section. The charts apply to constructions where regain takes place unaccompanied by radical change in direction; namely, to *straight-through sections* of divided-flow fittings.

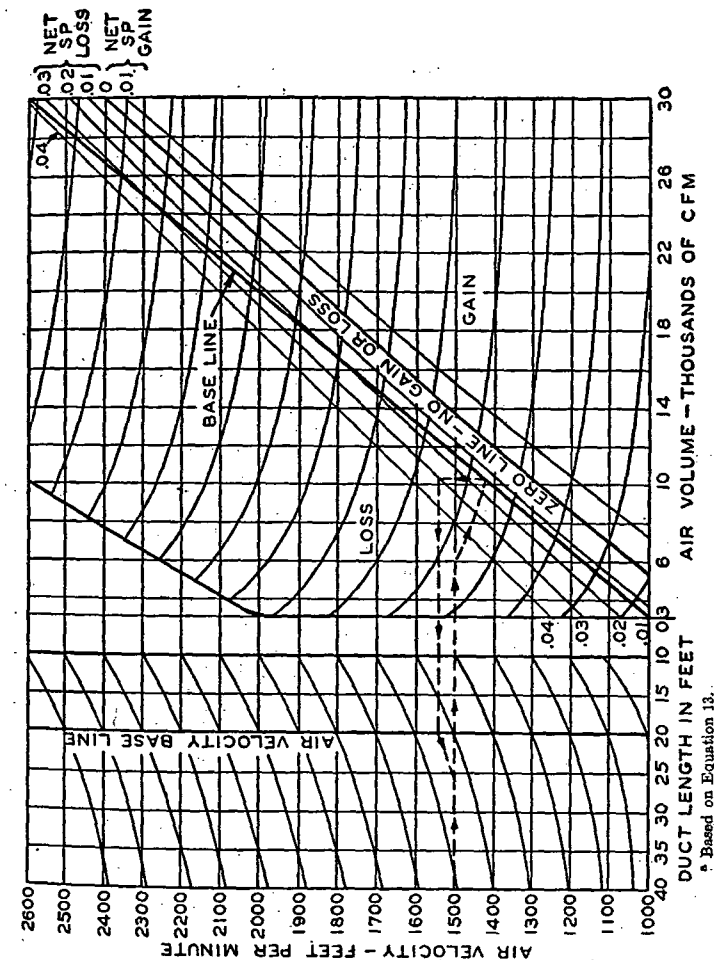


FIG. 13. STATIC REGAIN CHART\*

For Determining Velocity in Ducts Carrying 8000 to 30,000 cfm

**Example 6: (Static Regain Method).** A duct layout is shown in Fig. 14. The fan delivers 8000 cfm. Outlets 1, 2, 3 and 4 deliver 1500 cfm each, and outlets 5 and 6, 1000 cfm each. The operating pressure loss at all outlets is 0.12 in. water. Initial trunk velocity is assumed as 1500 fpm; the area of the trunk duct will then be 5.33 sq ft, and the size will be 48 x 16 in. It is assumed that for this example it is desirable to maintain a 16-in. depth on all duct sections. Determine the sizes of duct Sections B, C, D, E, F and G so that substantially the same static pressure will be obtained at each of the outlets, and find the total pressure loss of the system.

**Solution:**

1. Size Section F by the equal friction method so that it has the same rate of friction loss as Section A. Section A is equivalent to a 29.2 in. round duct (Table 1) and the pressure loss from Fig. 3 is 0.13 in. per 100 ft. For 2000 cfm flowing at this rate of pressure loss, the indicated round duct diameter for Section F is approxi-



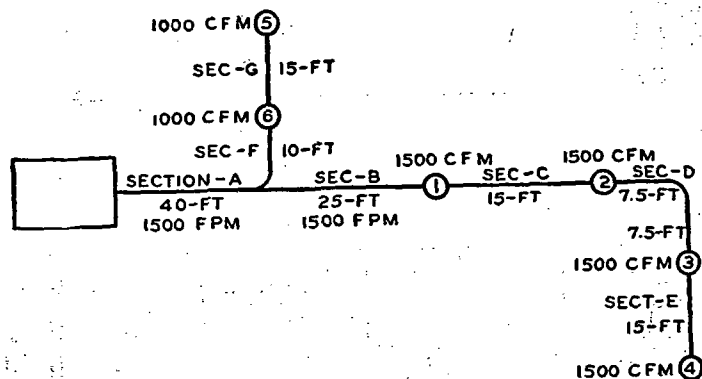


FIG. 14. DUCT LAYOUT FOR EXAMPLE 6

Duct sizes determined by the given procedure are listed in Table 7.

TABLE 7. TABULATION OF RESULTS (EXAMPLE 6)

| SECTION | AIR VOLUME<br>cfm | EQUIVALENT LENGTH<br>ft | VELOCITY<br>fpm | RECTANGULAR DUCT<br>in. | DIAM.<br>in. | FRICTION PER 100 FT<br>in. H <sub>2</sub> O | NET PRESSURE LOSS<br>in. H <sub>2</sub> O |
|---------|-------------------|-------------------------|-----------------|-------------------------|--------------|---------------------------------------------|-------------------------------------------|
| A       | 8000              | 40                      | 1500            | 48 x 16                 | 29.2         | 0.13                                        | .05                                       |
| B       | 6000              | 25                      | 1500            | 36 x 16                 | —            | —                                           | .03                                       |
| C       | 4500              | 15                      | 1300            | 31 x 16                 | —            | —                                           | 0                                         |
| D       | 3000              | 26*                     | 1040            | 26 x 16                 | —            | —                                           | 0                                         |
| E       | 1500              | 15                      | 860             | 16 x 16                 | —            | —                                           | 0                                         |
| F       | 2000              | 22.5                    | 1200            | 15 x 16                 | 17.          | 0.13                                        | .03                                       |
| G       | 1000              | 15                      | 900             | 10 x 16                 | —            | —                                           | 0                                         |

\* Includes additional equivalent length of elbow between outlets 2 and 3, which is assumed as 5.5 W, or 11 ft equivalent length of duct. (Based on 3000 cfm at estimated velocity of 1100 fpm).

Total Pressure Loss = 0.20 in.

## DUCT CONSTRUCTION DETAILS

Heavy canvas connections (asbestos cloth if there is a fire hazard) are recommended on both the inlet and outlet to all fans. Self-vulcanizing adhesive tapes are available for this purpose and for sealing joints in duct work. The fan discharge connections shown in Fig. 15 are marked *good*, *fair*, and *poor* in the order of the amount of turbulence produced. An inspection of the heater connections shown in Fig. 15 will readily show that uniform velocity through the heater cannot be expected in the diagram noted *poor*. When obstructions cannot be avoided, the duct area should never be decreased more than 10 percent, and then a *streamlined* collar should be used. Larger obstructions require an increase in the duct size in order to maintain as nearly uniform velocity as possible. Branch take-



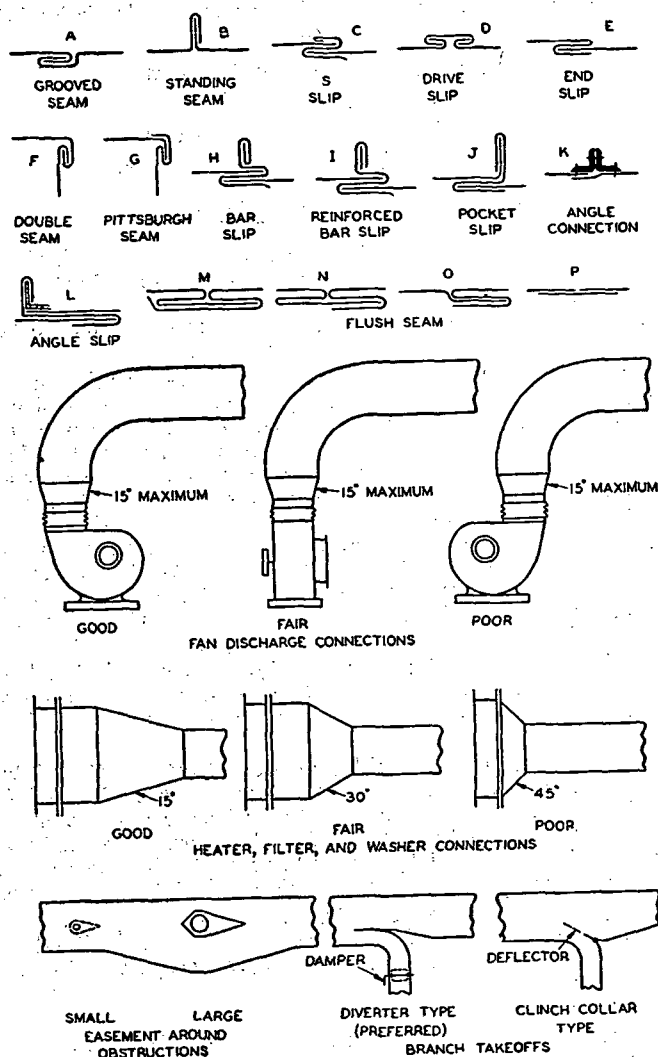


FIG. 15. SHEET METAL DUCT AND ARRANGEMENT DETAILS

offs should always be arranged to cut or slice into the air stream in order to reduce as far as possible the losses in velocity head.

Wherever ducts pass through fire walls or connect two fire areas of a building, automatic fire dampers should be provided. For design of such dampers and other fire protective details, see Pamphlet No. 90 of the National Board of Fire Underwriters.<sup>24</sup>

The recommended gages for steel (or iron) and aluminum sheet metal rectangular ducts are given in Table 8. Steel or iron sheets are specified

## Air Duct Design

according to the manufacturers or U. S. Standard Gage System. Aluminum sheets are specified according to the American or Brown & Sharpe Gage System. Weights of black and galvanized steel and iron sheets per square foot of surface for various gages are given in Table 9. Similar data for 2S aluminum sheets will be found in Table 10. Weights of standard copper sheets are given in Table 11. In calculating the total weight of a given length of duct work from these tables, it is customary to add 20 percent for the weight of joints and bracings.

Aluminum sheets of the 2S and 3S type alloy and  $\frac{3}{4}$  hard temper are

TABLE 8. RECOMMENDED SHEET METAL GAGES FOR RECTANGULAR DUCT CONSTRUCTION\*

| ALUMINUM B. & S. GAGE | STEEL U. S. STD. GAGE | MAXIMUM SIDE, INCHES | TYPE OF TRANSVERSE JOINT CONNECTIONS <sup>b</sup>                                                                                      | BRACING                                                                    |
|-----------------------|-----------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| 24                    | 26                    | Up to 12             | S. Drive, Pocket or Bar Slips, on 7 ft 10 in. centers                                                                                  | None                                                                       |
| 22                    | 24                    | 13 to 24             | S, Drive, Pocket or Bar Slips, on 7 ft 10 in. centers                                                                                  | None                                                                       |
|                       |                       | 25 to 30             | S, Drive, 1 in. Pocket or 1 in. Bar Slips, on 7 ft 10 in. centers <sup>c</sup>                                                         | 1 x 1 x $\frac{1}{2}$ in. angles 4 ft from joint                           |
| 20                    | 22                    | 31 to 40             | Drive, 1 in. Pocket or 1 in. Bar Slips, on 7 ft 10 in. centers <sup>c</sup>                                                            | 1 x 1 x $\frac{1}{2}$ in. angles 4 ft from joint                           |
|                       |                       | 41 to 60             | 1½ in. Angle Connections, or 1½ in. Pocket or 1½ in. Bar Slips with 1½ in. x ½ in. bar reinforcing on 7 ft 10 in. centers <sup>c</sup> | 1½ x 1½ x ½ in. angles 4 ft from joint                                     |
| 18                    | 20                    | 61 to 90             | 1½ in. Angle Connections, or 1½ in. Pocket or 1½ in. Bar Slips 3 ft 9 in. maximum centers with 1½ x ½ in. bar reinforcing              | 1½ x 1½ x ½ in. diagonal angles, or 1½ x 1½ x ½ in. angles 2 ft from joint |
| 16                    | 18                    | 91 and up            | 2 in. Angle Connections or 1½ in. Pocket or 1½ in. Bar Slips 3 ft 9 in. maximum centers with 1½ x ½ in. bar reinforcing <sup>d</sup>   | 1½ x 1½ x ½ in. diagonal angles, or 1½ x 1½ x ½ in. angles 2 ft from joint |

\* For normal pressures and velocities (see Table 5) utilized in typical ventilating and air conditioning systems. Where special rigidity or stiffness is required, ducts should be constructed of metal two gages heavier. All uninsulated ducts 18 in. and larger should be cross-braced. Cross-bracing may be omitted on uninsulated ducts if two gages of heavier metal are used.

<sup>b</sup> Other joint connections of equivalent mechanical strength and air tightness may be used.

<sup>c</sup> Duct sections of 3 ft 9 in. may be used with bracing angles omitted, instead of 7 ft 10 in. lengths with joints indicated.

<sup>d</sup> Ducts 91 in. and larger require special field study for hanging and supporting methods.

readily workable, and can be used for practically all duct work. The 2S type (commercially pure aluminum) is suitable for all, except very large ducts. For large ducts, where more strength is desired, the 3S alloy with  $\frac{3}{4}$  or  $\frac{1}{2}$  hard temper is frequently used. The higher tempers, particularly full hard, do not have the formability of the lower tempers. For very large ducts, where considerable strength is required, aluminum sheets should be 2 gages heavier than indicated in Table 8, and should be amply stiffened. Joints can be of any of the standard designs, and can be fabricated in the same manner as iron. Repeated sharp bending and rebending should be avoided, as aluminum has a tendency to crack under such treat-

TABLE 9. WEIGHTS OF BLACK AND GALVANIZED SHEETS

| U. S.<br>Std.<br>GAGE | BLACK SHEETS                  |        |                           |        | GALVANIZED SHEETS*            |        |                           |        |
|-----------------------|-------------------------------|--------|---------------------------|--------|-------------------------------|--------|---------------------------|--------|
|                       | Approximate<br>Thickness, In. |        | Weight Per<br>Square Foot |        | Approximate<br>Thickness, In. |        | Weight Per<br>Square Foot |        |
|                       | Steel                         | Iron   | Ounces                    | Pounds | Steel                         | Iron   | Ounces                    | Pounds |
| 30                    | 0.0123                        | 0.0125 | 8                         | 0.500  | 0.0163                        | 0.0165 | 10.5                      | 0.656  |
| 28                    | 0.0153                        | 0.0156 | 10                        | 0.625  | 0.0193                        | 0.0196 | 12.5                      | 0.781  |
| 26                    | 0.0184                        | 0.0188 | 12                        | 0.750  | 0.0224                        | 0.0228 | 14.5                      | 0.906  |
| 24                    | 0.0245                        | 0.0250 | 16                        | 1.000  | 0.0285                        | 0.0290 | 18.5                      | 1.156  |
| 22                    | 0.0306                        | 0.0313 | 20                        | 1.250  | 0.0346                        | 0.0353 | 22.5                      | 1.406  |
| 20                    | 0.0368                        | 0.0375 | 24                        | 1.500  | 0.0408                        | 0.0415 | 26.5                      | 1.656  |
| 18                    | 0.0490                        | 0.0500 | 32                        | 2.000  | 0.0530                        | 0.0540 | 34.5                      | 2.156  |
| 16                    | 0.0613                        | 0.0625 | 40                        | 2.500  | 0.0653                        | 0.0665 | 42.5                      | 2.656  |
| 14                    | 0.0766                        | 0.0781 | 50                        | 3.125  | 0.0806                        | 0.0821 | 52.5                      | 3.281  |
| 12                    | 0.1072                        | 0.1094 | 70                        | 4.375  | 0.1112                        | 0.1134 | 72.5                      | 4.531  |
| 11                    | 0.1225                        | 0.1250 | 80                        | 5.000  | 0.1265                        | 0.1290 | 82.5                      | 5.156  |
| 10                    | 0.1379                        | 0.1406 | 90                        | 5.625  | 0.1419                        | 0.1446 | 92.5                      | 5.781  |

\* Galvanized sheets are gaged before galvanizing and are therefore approximately 0.004 in. thicker.

TABLE 10. WEIGHTS AND THICKNESSES OF 2S ALUMINUM (DENSITY 0.098 LB/CU IN.)

| B. & S. GAGE | THICKNESS, INCHES |                  | WEIGHT PER SQUARE FOOT |        |
|--------------|-------------------|------------------|------------------------|--------|
|              | Decimal           | Nearest Fraction | Ounces                 | Pounds |
| 28           | 0.012             | 1/64             | 2.7                    | 0.169  |
| 26           | 0.016             | 1/64             | 3.6                    | 0.226  |
| 24           | 0.020             | 1/64             | 4.5                    | 0.282  |
| 22           | 0.025             | 1/32             | 5.4                    | 0.353  |
| 20           | 0.032             | 1/32             | 7.2                    | 0.452  |
| 18           | 0.040             | 3/64             | 9.0                    | 0.563  |
| 16           | 0.051             | 3/64             | 11.5                   | 0.720  |
| 14           | 0.064             | 1/16             | 14.4                   | 0.903  |

TABLE 11. WEIGHTS AND THICKNESSES OF STANDARD COPPER SHEETS\*  
Rolled to Weight

| WEIGHT PER SQUARE FOOT |        | THICKNESS, INCHES  |                  | NEAREST GAGE NO. |       |            |
|------------------------|--------|--------------------|------------------|------------------|-------|------------|
| Ounces                 | Pounds | Decimal Equivalent | Nearest Fraction | B. & S.          | Stubs | U. S. Std. |
| 10                     | 0.625  | 0.0135             | 3/64             | 27               | 29    | 29         |
| 12                     | 0.750  | 0.0162             | 3/64             | 26               | 27    | 28         |
| 14                     | 0.875  | 0.0189             | 3/64             | 25               | 26    | 26         |
| 16                     | 1.000  | 0.0216             | 3/64             | 23               | 24    | 25         |
| 18                     | 1.125  | 0.0243             | 3/64             | 22               | 23    | 24         |
| 20                     | 1.250  | 0.0270             | 3/64             | 21               | 22    | 23         |
| 24                     | 1.500  | 0.0324             | 3/64             | 20               | 21    | 22         |
| 28                     | 1.750  | 0.0378             | 3/64             | 19               | 20    | 20         |
| 32                     | 2.000  | 0.0432             | 3/64             | 17               | 19    | 19         |
| 36                     | 2.250  | 0.0486             | 3/64             | 16               | 18    | 18         |
| 40                     | 2.500  | 0.0540             | 3/64             | 15               | 17    | 17         |
| 44                     | 2.750  | 0.0594             | 3/64             | 15               | 17    | 17         |
| 48                     | 3.000  | 0.0648             | 3/64             | 14               | 16    | 16         |
| 56                     | 3.500  | 0.0756             | 3/64             | 13               | 15    | 15         |
| 64                     | 4.000  | 0.0864             | 3/64             | 11               | 14    | 13         |

\* Variations from these weights must be expected in practice.

ment. Aluminum of 16 B. & S. gage or heavier can readily be welded by the metallic arc or acetylene process. Soldering is difficult and is not generally recommended. Riveting is done in the same manner as in iron or steel sheet. Self-tapping screws tend to loosen because of the softness of aluminum.

## HEAT LOSSES FROM DUCTS

In designing duct systems, the heat gains or losses of the ducts can be quite considerable, not only if the duct passes through unconditioned space, but also on long duct runs within conditioned space. Proper insulation will remedy this situation considerably, but sometimes a redistribution of the supply air is necessary in order to compensate for the heat exchanges that occur.

The heat loss from a given length of duct can be expressed by:

$$Q_w = UPI \left[ \left( \frac{t_1 + t_2}{2} \right) - t_4 \right] \quad (14)$$

where

$Q_w$  = heat loss through duct walls, Btu per hour.

$P$  = perimeter of duct, feet.

$l$  = length of duct, feet.

$t_1$  = temperature of air entering duct, Fahrenheit.

$t_2$  = temperature of air leaving duct, Fahrenheit.

$t_4$  = temperature of air surrounding duct, Fahrenheit.

To obtain the temperature drop in warm air for a given distance of transmission, or the temperature rise if the duct carries air cooler than the room through which it passes, the following formulas can be used:

$$t_1 = \frac{t_2(y+1) - 2t_4}{(y-1)} \quad (15) \quad t_2 = \frac{t_1(y-1) + 2t_4}{(y+1)} \quad (16)$$

where

$$y = \frac{28.8AV\rho}{UPI} \text{ for rectangular ducts or,}$$

$$y = \frac{7.2DV\rho}{UI} \text{ for round ducts,}$$

$A$  = cross-sectional area of duct, square feet.

$\rho$  = density of air, pounds per cubic foot.

$V$  = mean velocity of fluid, feet per minute.

$D$  = diameter of round duct, feet.

In using Equations 15 and 16, one of the duct air temperatures will be unknown and will be obtained by substitution of the other known or assumed values.

Heat loss coefficients for insulated ducts with various conductivities are given in Fig. 16. The conductivities of various materials, which are based on mean temperatures, about 70 F, will be found in Table 2 of Chapter 9. For cases where the mean temperature is other than that at which the test was conducted, a correction should be made. However, in most cases the effect of this factor will be small and may be neglected.

Example 7: Determine the entering air temperature and heat loss for a duct 24 ×

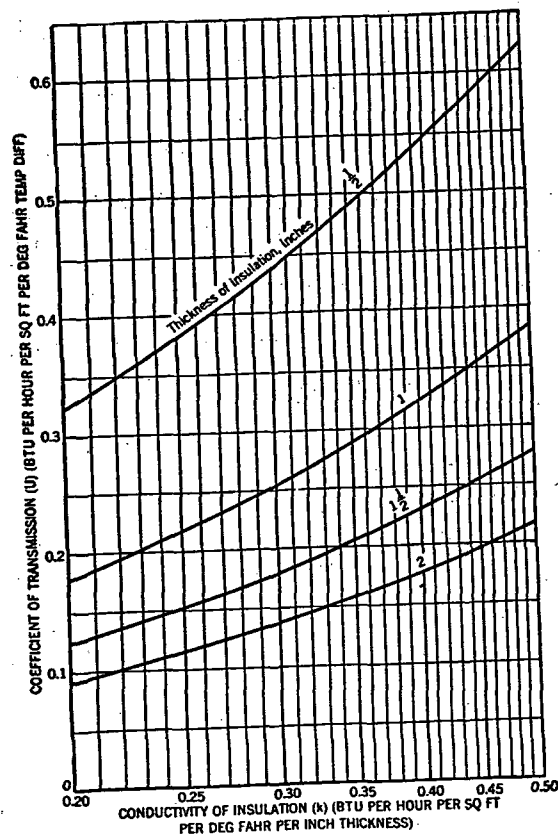


FIG. 16. HEAT LOSS COEFFICIENTS FOR INSULATED DUCTS\*

\* For round ducts less than 30 in. diameter, increase heat transmission values by the percentages shown below.

| THICKNESS OF INSULATION (Inches) | $\frac{1}{4}$ | 1  | $1\frac{1}{2}$ | 2  |
|----------------------------------|---------------|----|----------------|----|
| 12 to 21 in. Duct Diameter.....  | 3%            | 5% | 7%             | 9% |
| 21 to 30 in. Duct Diameter.....  | 1%            | 2% | 3%             | 4% |

36 in. cross section and 70 ft in length, insulated with  $\frac{1}{4}$  in. of a material having a conductivity of 0.35 Btu at 86 F mean temperature, carrying air at a velocity of 1200 fpm, measured at 70 F, to deliver air at 120 F with air surrounding the duct at 40 F.

**Solution:** Referring to Fig. 16, the overall heat transmission coefficient is found to be 0.49 Btu. From Table 1, Chapter 3 the density of air at 70 F and 29.921 in Hg is found to be  $1/13.348 = 0.0749$  lb per cu ft. Substituting these and the other given values in Equation 16,  $y$  and  $t_1$  will be as follows:

$$y = \frac{28.8 \times 6 \times 1200 \times 0.0749}{0.49 \times 10 \times 70} = 45.3$$

$$t_1 = \frac{120(45.3 + 1) - 80}{45.3 - 1} = 123.7 \text{ F}$$

Substituting in Equation 14:

$$Q = 0.49 \times 10 \times 70 \left[ \left( \frac{123.7 + 120}{2} \right) - 40 \right] = 28,100 \text{ Btu per hr.}$$

For special considerations which apply to insulation of ducts in marine installations see Chapter 48.

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## CHAPTER 33

## FANS

Types, Fan Performance, Fan Laws, Fan Performance Curves, System Characteristics, Fan Arrangements, Fan Control, Motive Power, Fan Selection, Fan Installation, Fan Applications

**I**N HEATING, ventilating and air conditioning practice, the devices used to produce air flow are variously known as fans, blowers, exhausters or propellers. The A.S.M.E. Test Code<sup>1</sup> limits fans to those in which the fluid density change does not exceed 7 percent (one psi at atmospheric pressure) and labels as compressors those devices operating beyond that pressure range. Since air conditioning rarely requires pressures of over  $\frac{1}{2}$  psi, all such devices will be known as fans and the air will be considered non-compressible.

## Types

Fans are divided into two general classifications: (1) *centrifugal or radial flow* in which the air flows radially through the impeller within a scroll type housing, and (2) *axial flow* in which the air flows axially through the impeller within a cylinder or ring.

*Centrifugal fans* are further subdivided into types denoted by the curvature or slope of the impeller blades, the angle of which largely determines the operating characteristics. For a given output, a forward inclination of blade indicates a relatively low speed of operation, and a backward inclination, a relatively high speed of operation. Many intermediate forms are also found.

*Axial flow fans* are subdivided into types differentiated mainly by their enclosures and refinements of impellers and appurtenances. All types vary in shape, number and angles of blades; ratios of hub diameter to impeller diameter; materials and methods of fabrication, depending upon design and preference of manufacturer. *Tubeaxial* and *vaneaxial* fans, usually used against appreciable resistance, commonly have relatively large hubs and helical blades (the angle varies radially along the blade). The blades may be of uniform thickness, either flat or cambered, and either cast or made of plates; or they may be of air foil sections, either cast or of double thickness sheet. Streamlining of both impeller and enclosure is common practice. *Vaneaxial* fans incorporate guide vanes to modify performance and increase efficiency. *Propeller* fans customarily used for free delivery, or against low resistance, also are found with a variety of blade conformations, but are simple in construction. They are merely mounted within a plate or ring.

The fan nomenclature in Fig. 1 has been standardized by the *National Association of Fan Manufacturers*.<sup>2</sup>

## FAN PERFORMANCE

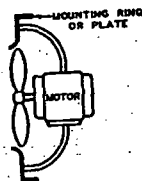
Fan performance is a statement of volume, total pressures, static pressures, speed, power input, mechanical and static efficiency, at a stated density. These terms are defined by the *National Association of Fan Manufacturers*<sup>2</sup> as follows:

1. Volume handled by a fan is the number of cubic feet of air per minute expressed at fan outlet conditions.

2. *Total pressure* of a fan is the rise of pressure from fan inlet to fan outlet.
3. *Velocity pressure* of a fan is the pressure corresponding to the average velocity determination from the volume of air flow at the fan outlet area.
4. *Static pressure* of a fan is the total pressure diminished by the fan velocity pressure.
5. *Power output* of a fan is expressed in horsepower and is based on fan volume and the fan total pressure.
6. *Power input* to a fan is expressed in horsepower and is measured horsepower delivered to the fan shaft.
7. *Mechanical efficiency* of a fan is the ratio of power output to power input.
8. *Static efficiency* of a fan is the mechanical efficiency multiplied by the ratio of static pressure to the total pressure.
9. *Fan outlet area* is the inside area of the fan outlet.
10. *Fan inlet area* is the inside area of the inlet collar.

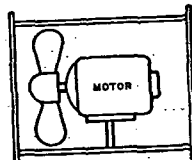
While the total pressure truly represents the actual pressure developed by the fan, the static pressure may best represent the useful pressure for overcoming resistance. In many installations, since the outlet velocity of the fan is greater than the duct velocity, some of the velocity pressure may be utilized by conversion to static pressure within the system. However, due to the uncertainty of the flow at the points of velocity change, the amount of conversion is seldom known and therefore, most fan tables list only the static pressure as available to overcome the system resistance.

FIG. 1. NAMES AND DEFINITIONS OF TYPES OF FANS



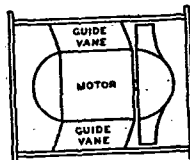
#### Propeller Fan

A propeller fan consists of a propeller or disc wheel within a mounting ring or plate.



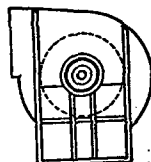
#### Tubeaxial Fan

A tubeaxial fan consists of an axial flow wheel within a cylinder.



#### Vaneaxial Fan

A vaneaxial fan consists of an axial flow wheel within a cylinder, combined with a set of air guide vanes located either before or after the wheel.



#### Centrifugal Fan

A centrifugal fan consists of a fan rotor or wheel within a scroll type of housing.

## Fans

According to the Standard Test Code<sup>3</sup> the efficiencies may be determined by the formulas:

Mechanical (total) Efficiency =

$$\frac{0.0001573 \times (\text{cfm}) \times \text{total pressure (inches water)}}{\text{horsepower input}}$$

$$\text{Static Efficiency} = \frac{0.0001573 \times (\text{cfm}) \times \text{static pressure (inches water)}}{\text{horsepower input}}$$

As the static pressure is often more useful than total pressure, static efficiency is likewise many times more useful than mechanical efficiency. However, where a high outlet velocity can be effectively utilized, the static efficiency fails to be a satisfactory measurement of performance; also when a fan operates against no resistance, the static efficiency becomes zero and is meaningless. Under such circumstances, many engineers prefer to use mechanical efficiency.

Sound developed by a fan is a characteristic which is becoming increasingly important. Unfortunately, no method has yet been devised for accurately measuring the sound actually discharged into a duct system. The A.S.H.A.E. Research Laboratory, in cooperation with the U. S. Navy, has a program underway seeking to find a method. Many manufacturers list the average sound (for various fan operating conditions) measured at seven stations near the fan. These stations, as specified in the N.A.F.M. Test Code,<sup>4</sup> are located in a horizontal plane passing through the fan shaft, and are at a distance of one wheel diameter (but not less than 5 ft) from the fan. Such values are useful in comparing the relative sound generated by various types and sizes of fans under comparable operating conditions.

## FAN LAWS<sup>5</sup>

The performances of fans of all types follow certain laws which are useful in predicting the effect upon performance of changes in the conditions of operation, the duty required of the installation, or the size of the equipment due to the space, power, or speed limitations. In the following laws, groups 1 to 6,  $Q$  = air volume and  $P$  = static, velocity or total pressure. The laws pertaining to fan size apply only to fans geometrically similar, i.e., those in which all dimensions are proportional to some linear dimension denoted as *size*. If the size number is also linearly proportional, it may be used; otherwise, wheel diameter is commonly used as a size criterion.

### 1. Variation in Fan Speed:

*Constant Air Density—Constant System*

- (a)  $Q$ : Varies as fan speed.
- (b)  $P$ : Varies as square of fan speed.
- (c) Power: Varies as cube of fan speed.

*Variation in Fan Size:*

*Constant Tip Speed—Constant Air Density*

*Constant Fan Proportions—Fixed Point of Rating*

- (a)  $Q$ : Varies as square of wheel diameter.
- (b)  $P$ : Remains constant.
- (c) RPM: Varies inversely as wheel diameter.
- (d) Power: Varies as square of wheel diameter.

## 3. Variation in Fan Size:

At Constant RPM—Constant Air Density

Constant Fan Proportions—Fixed Point of Rating

- (a)  $Q$ : Varies as cube of wheel diameter.  
 (b)  $P$ : Varies as square of wheel diameter.  
 (c) Tip Speed: Varies as wheel diameter.  
 (d) Power: Varies as fifth power of diameter.

## 4. Variation in Air Density:

Constant Volume—Constant System

Fixed Fan Size—Constant Fan Speed

- (a)  $Q$ : Constant.  
 (b)  $P$ : Varies as density.  
 (c) Power: Varies as density.

## 5. Variation in Air Density:

Constant Pressure—Constant System

Fixed Fan Size—Variable Fan Speed

- (a)  $Q$ : Varies inversely as square root of density.  
 (b)  $P$ : Constant.  
 (c) RPM: Varies inversely as square root of density.  
 (d) Power: Varies inversely as square root of density.

## 6. Variation in Air Density:

Constant Weight of Air—Constant System

Fixed Fan Size—Variable Fan Speed

- (a)  $Q$ : Varies inversely as density.  
 (b)  $P$ : Varies inversely as density.  
 (c) RPM: Varies inversely as density.  
 (d) Power: Varies inversely as square of density.

Examples 1 to 4 illustrate the application of the preceding fan laws.

**Example 1:** A certain fan delivers 12,000 cfm at a static pressure of 1 in. of water when operating at a speed of 400 rpm and requires an input of 4 hp. If in the same installation 15,000 cfm are desired, what will be the speed, static pressure, and power?

$$\text{Speed} = 400 \times \frac{15,000}{12,000} = 500 \text{ rpm}$$

$$\text{Static pressure} = 1 \times \left(\frac{500}{400}\right)^2 = 1.56 \text{ in.}$$

$$\text{Power} = 4 \times \left(\frac{500}{400}\right)^5 = 7.81 \text{ hp}$$

**Example 2:** A certain fan delivers 12,000 cfm at 70 F and normal barometric pressure (density 0.075 lb per cubic foot) at a static pressure of 1 in. of water when operating at 400 rpm, and requires 4 hp. If the air temperature is increased to 200 F (density 0.0602 lb) and the speed of the fan remains the same, what will be the static pressure and power?

$$\text{Static pressure} = 1 \times \frac{0.0602}{0.075} = 0.80 \text{ in.}$$

$$\text{Power} = 4 \times \frac{0.0602}{0.075} = 3.20 \text{ hp}$$

**Example 3:** If the speed of the fan of *Example 2* is increased so as to produce a static pressure of 1 in. of water at the 200 F temperature, what will be the speed, capacity, and power?

## Fans

$$\text{Speed} = 400 \times \sqrt{\frac{0.075}{0.0602}} = 446 \text{ rpm}$$

$$\text{Capacity} = 12,000 \times \sqrt{\frac{0.075}{0.0602}} = 13,392 \text{ cfm (measured at 200 F)}$$

$$\text{Power} = 4 \times \sqrt{\frac{0.075}{0.0602}} = 4.46 \text{ hp}$$

**Example 4:** If the speed of the fan of the previous examples is increased so as to deliver the same weight of air at 200 F as at 70 F, what will be the speed, capacity, static pressure, and power?

$$\text{Speed} = 400 \times \frac{0.075}{0.0602} = 498 \text{ rpm}$$

$$\text{Capacity} = 12,000 \times \frac{0.075}{0.0602} = 14,945 \text{ cfm (measured at 200 F)}$$

$$\text{Static pressure} = 1 \times \frac{0.075}{0.0602} = 1.25 \text{ in.}$$

$$\text{Power} = 4 \times \left(\frac{0.075}{0.0602}\right)^5 = 6.20 \text{ hp}$$

The fan laws stated may be combined to give other overall values. One useful combination is the product of laws 1 and 3 which gives the following relations:

Capacity varies as the ratio of size cubed, times the ratio of the rpm.

Pressure varies as the ratio of size squared, times the ratio of the rpm squared.

Horsepower varies as the ratio of the size to fifth power, times the ratio of the rpm cubed.

**Example 5:** Assuming that a fan with a 36 in. diameter blast wheel will deliver 12,000 cfm at 70 F at 1 in. static pressure, requiring 4.0 brake hp when operating at 400 rpm, what is the capacity, pressure and horsepower of a homologous fan having a 45 in. wheel at the same speed?

$$\text{Capacity} = \left(\frac{45}{36}\right)^3 \times \left(\frac{400}{400}\right) \times 12,000 = 23,400 \text{ cfm}$$

$$\text{Static pressure} = \left(\frac{45}{36}\right)^2 \times \left(\frac{400}{400}\right) \times 1 = 1.56 \text{ in.}$$

$$\text{Horsepower} = \left(\frac{45}{36}\right)^5 \times \left(\frac{400}{400}\right) \times 4 = 12.2 \text{ hp}$$

## FAN PERFORMANCE CURVES

Fan performance curves are the graphical presentation (for constant speed and air density) of the relation of total pressure, static pressure, power input, and mechanical and static efficiency, to actual volume, for the desired range of volumes. Figs. 2, 3 and 4 illustrate performance (sometimes called characteristic) curves of various types of fans.

Centrifugal fans<sup>6</sup> may be roughly divided into three classes: (1) those with the tip of the blades curved forward in the direction of rotation; (2) those with straight radial blades; and (3) those with the tip of the blades in-

clined backward away from direction of rotation. They are also characterized as slow speed, moderate speed and high speed types, respectively, although the actual speed range of each may be wide and overlapping. The highest speed type may operate as high as 200 percent of the speed of the lowest speed type, to deliver the same volume of air and the same pressure. The differentiating curvature is always the tip of the blade, since the inlet edge, if inclined, is always curved forward to minimize the shock loss at entrance. Straight radial blades are most frequently found in pressure fans and material handling fans.

Centrifugal fans produce pressure from two independent sources: (1) from the centrifugal force created by rotating the enclosed air column, and (2) from the kinetic energy imparted to the air by virtue of its velocity

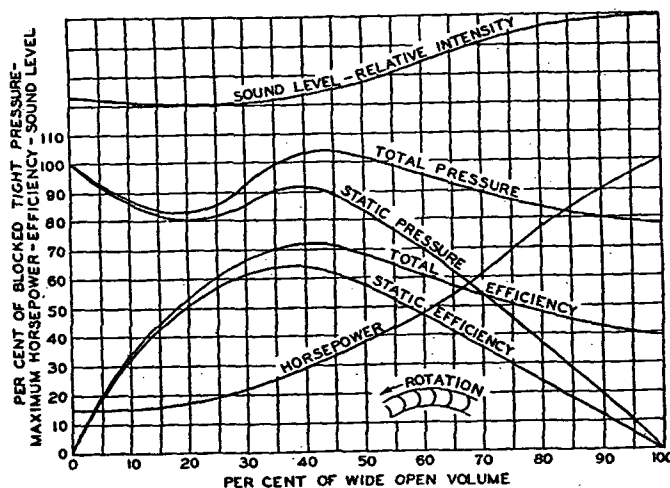


FIG. 2. PERCENTAGE PERFORMANCE CURVES OF A FORWARD-CURVED BLADE CENTRIFUGAL FAN

leaving the impeller. This velocity in turn is a combination of rotative velocity of the impeller and air speed relative to the impeller. When the blades tip forward, these two velocities are cumulative, and when backward, oppositional. Thus a fan with forward-curved blades depends less on centrifugal force for its pressure, and more on velocity pressure conversion in the scroll, with the result that it may run at relatively low speed. Conversely, a fan having backward-curved blades builds up more of its pressure by centrifugal force (a more efficient form of energy transfer) and less by velocity conversion and, therefore, must run at a higher speed. Likewise, a fan having forward-curved blades will produce the greatest capacity of any type of the same size when operating against no resistance.

Since the energy imparted to the air depends on the velocities, and since the velocities are cumulative with a fan having forward-curved blades, the theoretical energy per pound of air rises rapidly with an increase of air delivery. With the velocities oppositional in the fan having backward-curved blades, the energy per pound of air may decrease, and in a fan

having straight blades it is roughly constant. Thus the shape of the horsepower curve definitely identifies the blade angle.

Performance curves of a typical forward-curved blade centrifugal fan are shown in Fig. 2. The pressure rises from free delivery toward no delivery, with a characteristic drop at low capacities, because a large share of the pressure is being generated by conversion of velocity, which is small at low capacity. The maximum efficiency occurs at approximately maximum pressure. The horsepower curve reflects the increase in energy by rising rapidly from no delivery to free delivery. The sound is a minimum at maximum efficiency, and rises toward free delivery as the velocities increase.

Performance curves of a typical backward-curved blade centrifugal fan are shown in Fig. 3. The pressure is constantly rising from free delivery

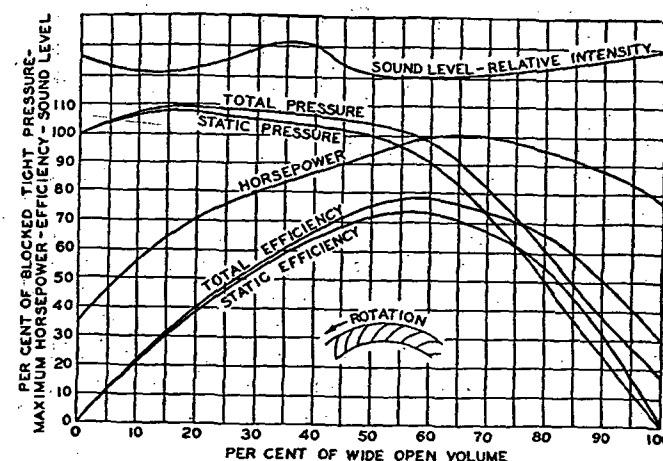


FIG. 3. PERCENTAGE PERFORMANCE CURVES OF A BACKWARD-CURVED BLADE CENTRIFUGAL FAN

nearly to point of no delivery. The horsepower reflects the energy-velocity relationship by rising to a maximum value as the capacity increases, and then decreasing with further increase in capacity to give a self-limiting horsepower characteristic. The maximum horsepower coincides approximately with the maximum efficiency. The sound is again a minimum near maximum efficiency, but is little or no higher at free delivery than at low capacities.

Between the extremes of forward and full-backward-curved blades, there exists a number of intermediate designs which show varying degrees of similarity to the curves in Figs. 2 and 3. A common variation is a fan having modified backward, single or double-curved blades and equipped with fixed inlet vanes. Such vanes applied to a partially backward-curved impeller give the steep, constantly rising pressure characteristic, and the self-limiting horsepower feature of the full-backward-curve. They also



stabilize the flow entering the impeller when adverse flow conditions exist in the approach to the inlet.

*Axial flow* fans develop none of their static pressure by centrifugal force, but all from the change in velocity in passing through the impeller, and its conversion into static pressure. They are thus inherently high velocity fans, and are very dependent on blade conformation for good characteristics. For that reason, an air foil section, such as developed in wind tunnels for aircraft work<sup>6</sup> is frequently used. Since any shape of blade can only be correct for a narrow range of capacity at constant speed, the performance curves for any blade show definite characteristics. To absorb energy, the air must be given a tangential motion in passing the impeller,<sup>7</sup> and when operating against higher pressures, must have guide vanes (see vaneaxial fans) to obtain best efficiencies.

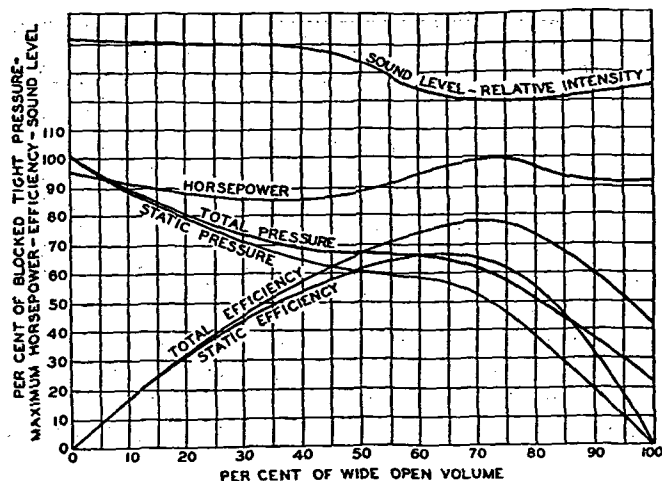


FIG. 4. PERCENTAGE PERFORMANCE CURVES OF AN AXIAL FLOW FAN

While *axial flow* fans are inherently a higher capacity type than centrifugal fans, they, too, may be designed with widely varying characteristics. As with a centrifugal fan, the pressure rises generally from free delivery to no delivery, but tubeaxial and vaneaxial fans may have a drop in pressure when the capacity decreases below a certain volume, a condition also found in the case of the centrifugal fan having forward-curved blades. The pressure drop is caused by the same condition for both fans, i.e., the static pressure is largely dependent on conversion of velocity pressure, and velocity pressure is small at low capacity. Tubeaxial and vaneaxial fans may also have performance curves resembling somewhat those of a centrifugal fan with backward-curved blades. Fig. 4 shows the performance curves for a typical design.

The horsepower curve may be flat with a self-limiting characteristic as in a backward-curved blade centrifugal fan, or it may have a generally

downward trend from no delivery to free delivery with the maximum at no delivery, contrary to that of a centrifugal fan. The type of guide vanes in a vaneaxial fan has a distinct bearing on the shape of the horsepower curve. The maximum efficiency tends to occur at a percentage of free delivery capacity higher than for a centrifugal fan.

The sound curve, which may have a minimum value comparable to centrifugal fans, is again lowest near maximum efficiency, but has a characteristic rise when the fan is operating at low capacities and the stall point of the blade section is reached.

Since *propeller fans* are designed for operation near free delivery, less attention is given the regaining of velocity to static pressure, and the pressure curve rises constantly from free delivery to no delivery. The

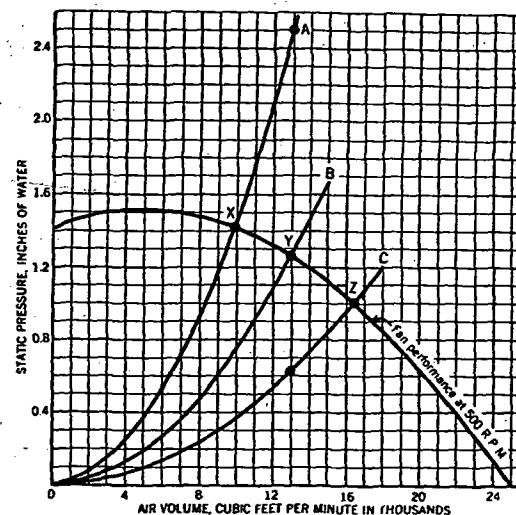


FIG. 5. PARABOLIC SYSTEM CHARACTERISTIC CURVES

horsepower is highest at no delivery, and decreases toward free delivery, in contrast to a centrifugal fan. Maximum total efficiency is obtained at a higher percentage of free delivery than for other types.

### SYSTEM CHARACTERISTICS

Any ventilating system consisting of duct work, heaters, air washers, filters, etc., has a system characteristic which is individual to that system, and is independent of any fan which may be applied to the system. This characteristic may be expressed in curve form in exactly the same manner that fan characteristics may be shown. Typical system characteristic curves are shown as A, B and C in Fig. 5. These curves are drawn to follow the simple parabolic law in which the static pressure or resistance to flow of air varies as the square of the volume flowing through the system. Heating and ventilating systems follow this law very closely, and no serious error is introduced by its use.

When a constant speed fan curve for a given size fan is super-imposed

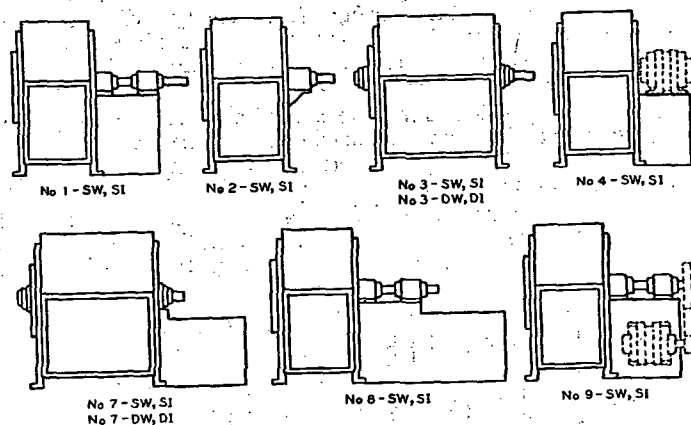


FIG. 6. ARRANGEMENT OF FAN DRIVES

- Arr. 1, SW, SI. For belt drive or direct connection. Wheel overhung. Two bearings on base.
- Arr. 2, SW, SI. For belt drive or direct connection. Wheel overhung. Bearings in bracket supported by fan housing.
- Arr. 3, SW, SI. For belt drive or direct connection. One bearing on each side and supported by fan housing. Not recommended in sizes 27 in. diameter wheel and smaller.
- Arr. 3, DW, DI. For belt drive or direct connection. One bearing on each side and supported by fan housing.
- Arr. 4, SW, SI. For direct drive. Wheel overhung on prime mover shaft. No bearings on fan. Base or equivalent for prime mover.
- Arr. 7, SW, SI. For belt drive or direct connection. Arrangement No. 3 plus base for prime mover. Not recommended in sizes 27 in. diameter and smaller.
- Arr. 7, DW, DI. For belt drive or direct connection. Arrangement No. 3 plus base for prime mover.
- Arr. 8, SW, SI. For belt drive or direct connection. Arrangement No. 1 plus base for prime mover.
- Arr. 9, SW, SI. For belt drive. Arrangement No. 1 designed for mounting prime mover on side of base.

upon a system characteristic curve, the relation between the two is at once apparent. The only point common to the two curves is the point at the intersection of the system characteristic curve and the fan characteristic curve, and it is at this point that the combination will operate. In Fig. 5, system characteristic curves A, B and C cross the fan characteristic curve at points X, Y and Z. The fan whose curve is shown, when applied to systems having characteristic curves A, B and C, will deliver 10,000, 13,000 or 16,400 cfm, respectively.

The curves in Fig. 5 also illustrate the effect of errors which may be made in calculating the resistance of a ventilating system. For instance, if a given system requires 13,000 cfm, and the resistance to flow of the system has been computed as 1.25 in. static pressure, such a system would be represented by system characteristic curve B in Fig. 5. If a 100 percent error had been made and the resistance were 2.5 in. instead of 1.25 in., then the system characteristic would be as shown in curve A, and would cross the fan curve at 10,000 cfm. Such an error would cause the flow of air to be decreased from a design volume of 13,000 cfm to 10,000 cfm. If the resistance to flow had been over-estimated and the resistance

## Fans

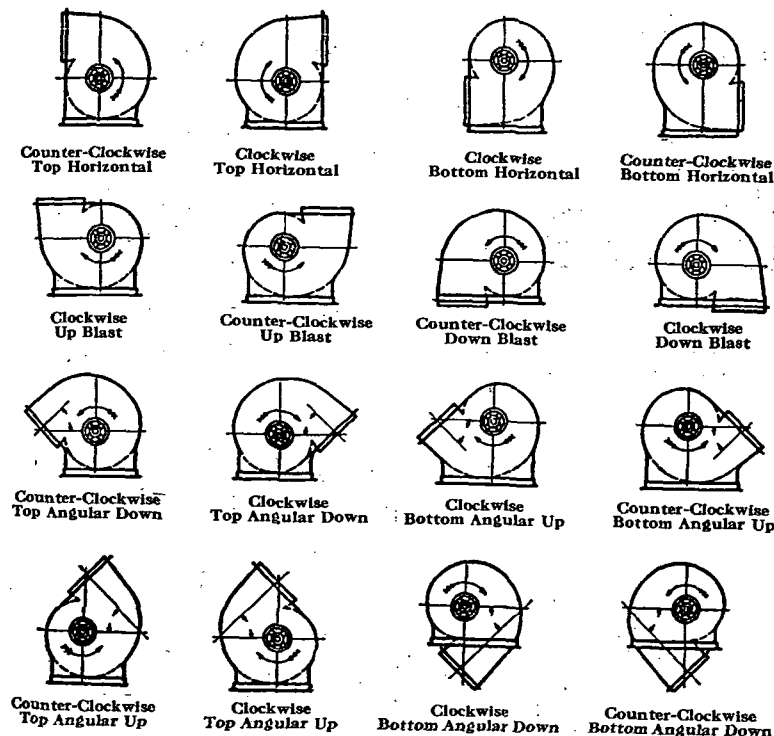


FIG. 7. DESIGNATION OF DIRECTION OF ROTATION AND DISCHARGE

Note: Direction of Rotation is determined from the drive side for either single or double width or single or double inlet fans. (The driving side of a single inlet fan is considered to be the side opposite the inlet regardless of the actual location of the drive.) For fan inverted for ceiling suspension, direction of rotation and discharge is determined when fan is resting on floor.

actually were 0.625 in., the system characteristic curve would be as shown in curve C, and the fan would deliver 16,400 cfm to the system instead of the design volume of 13,000 cfm.

In this example, extreme errors have been selected to emphasize the effect the square function of the system characteristic has in maintaining the fan performance within comparatively narrow limits. In the first example, a system estimated at half what it should have been resulted in a drop of 23 percent in volume; and in the second example, a system estimated at twice what it should have been resulted in an increase of 26 percent in volume.

In some instances fans may be applied to variable flow systems. In such cases, the limiting systems may be plotted and the effect on fan performance examined. For instance, a system might have a characteristic curve between A, shown in Fig. 5, as one limit, and B as the other limit. The fan performance will then fall between points X and Y on the fan curve at a point determined by the system characteristics at that particular

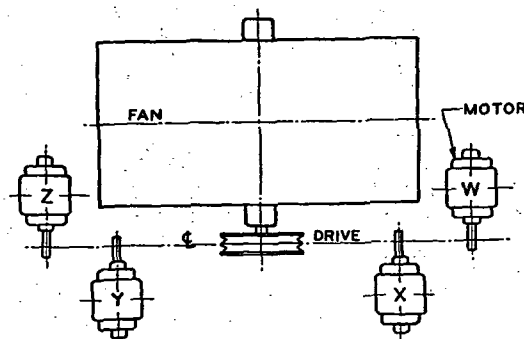
time. If A and B are the limiting characteristic curves of the systems, the fan performance will never be outside the points X or Y.

### FAN ARRANGEMENTS

Centrifugal fan arrangements have been standardized by the *National Association of Fan Manufacturers*. Figs. 6, 7 and 8 show the accepted designation as to arrangement of drive, rotation, discharge and motor position, for belt drive. Axial flow fans are either belt driven or direct connected, in accordance with individual manufacturer's arrangements. Usually a choice of anti-friction or sleeve bearings is available.

### FAN CONTROL

In some heating and ventilating systems it is desirable to vary the volume of air handled by the fan, and this may be accomplished by a



Location of motor is determined by facing the drive side of fan or blower and designating the motor position by letters W, X, Y or Z as the case may be.

FIG. 8. MOTOR POSITION, BELT OR CHAIN DRIVE

number of methods. Where the change is made infrequently, the pulley or sheave on the driving motor, or fan, may be changed to vary the speed of the fan and alter the air volume. Dampers may be placed in the duct system to vary the volume. Variable speed pulleys or transmissions, such as fan belt change boxes, or electric or hydraulic couplings, may be used to vary the fan speed. Variable speed motors and variable fan inlet vanes may also be used to adjust the fan volume. All of these methods will give control. From a power consumption consideration, a reduction of fan speed is most efficient. Inlet vanes save some power, while dampers save the least. From consideration of first cost, dampers usually are the lowest in cost. In some installations, adjustments of volume are desirable at various times during the day, or continuously. In others, an increased supply of air in summer, over that needed in winter, is demanded. The demands in each case will dictate which type of control is most desirable. Where noise is a factor, lowering the fan speed if possible is preferred as a control means, because of the resulting reduction in sound level.

In addition to the above types of control, *tubaxial* and *vaneaxial* fans

are sometimes made with adjustable blades to permit balancing the fan against the system, or making seasonal adjustment.

### MOTIVE POWER

Heating, ventilating and air conditioning fans are usually driven by electric motors, although other prime movers may be used. The small sizes of fans, and especially those operating in the higher speed range, are equipped with direct-connected motors. For larger size fans, and those operating at lower speed, V-belt drives are generally used.

In selecting the size of motor for operating a fan, it is advisable to select at least the standard size next larger than the fan requirements. Direct-connected motors do not require so great a safety factor as belted units. Justification for liberal power provision exists only in systems where it is possible that larger volumes of air may be required at intervals, and made available by use of by-pass dampers, thus greatly reducing the system resistance. If such a system includes a fan with forward-curved blades, it would be necessary that the motor be sized for the maximum volume and duty. If such a system includes fans with backward-curved blades, the volume peak would not make it necessary to provide additional motor power. In selecting fans for such a system, sound ratings should be given careful consideration.

Where a system is constant, and has no provision for volume change that would materially reduce the resistance, and when the resistance calculations are reasonably precise, there is no necessity for too liberal a motor allowance (even where fans with forward-curved blades are used) if the fan has been properly selected. Fig. 5 shows that the system resistance varies as the square of the volume, and the fan static pressure varies approximately inversely as the volume, thus greatly offsetting the trend toward both increase in air delivery and motor load. Reference to Fig. 5 indicates that there is no justification for allowing large spare motor capacity. It is generally more economical to operate motors well loaded.

Since the power consumption of fans varies as the cube of the speed, very little starting torque is required of the motor. Refer to Chapter 40 for characteristics of various types of motors.

### FAN SELECTION

The following information is required to select the proper type and size of fan:

1. Capacity in cubic feet per minute.
2. Static pressure or system resistance.
3. Air density if other than standard.
4. Type of application or service.
5. Arrangement of system.
6. Prevailing sound level or use of space served.
7. Nature of load.
8. Type of motive power available.

In order to facilitate the choice of apparatus, the various fan manufacturers supply fan tables or curves which usually show the following factors for each size of fan operating against a wide range of static pressures: (1) volume of air in cubic feet per minute (68 F, 50 percent relative humidity, 0.075 lb per cubic foot); (2) outlet velocity; (3) revolutions per minute; (4) brake horsepower; (5) tip or peripheral speed; and (6) static pressure. The most efficient operating point is usually shown by either bold-face or italicized figures in the capacity tables.

Often the service determines the type of fan. When operation occurs with little or no resistance, and particularly without a duct system, the propeller fan is indicated for convenience and low cost. When resistance is low the power required is low, and efficiency becomes a secondary importance. When a duct system is involved the choice is usually made between a centrifugal fan and a tubeaxial or vaneaxial. At times the capacity-pressure-speed relationship (specific speed)<sup>9</sup> dictates a choice. Usually, space, efficiency, sound, cost and serviceability must all be considered.<sup>10</sup> In general, centrifugal and axial fans are comparable in efficiency and sound, but the latter are lighter and require considerably less space, especially if arranged for straight-through operation. The comparison cannot be made on the cost of fans only, but the difference in cost of ductwork, mounting and servicing must be included. A vaneaxial is more efficient and quieter than a tubeaxial, but is more expensive, and frequently requires more space. While requiring less space than the centrifugal, the

TABLE 1. GOOD OPERATING VELOCITIES AND TIP SPEEDS FOR VENTILATING FANS

| STATIC PRESSURE INCHES OF WATER | FORWARD CURVED BLADE FANS       |                           | BACKWARD TIPPED AND DOUBLE CURVED BLADE FANS |                           | TUBEAXIAL AND VANEAXIAL FANS    |
|---------------------------------|---------------------------------|---------------------------|----------------------------------------------|---------------------------|---------------------------------|
|                                 | Outlet Velocity Feet per Minute | Tip Speed Feet per Minute | Outlet Velocity Feet per Minute              | Tip Speed Feet per Minute | Wheel Velocity* Feet per Minute |
| 1/8                             | 1000-1100                       | 1520-1700                 | 800-1100                                     | 2600-3100                 | 1100-1500                       |
| 1/4                             | 1000-1100                       | 1760-1900                 | 800-1150                                     | 3000-3500                 | 1250-1700                       |
| 3/8                             | 1000-1200                       | 1970-2150                 | 900-1300                                     | 3400-4000                 | 1400-1900                       |
| 1/2                             | 1200-1400                       | 2225-2450                 | 1000-1500                                    | 3800-4500                 | 1500-2100                       |
| 3/4                             | 1300-1500                       | 2480-2700                 | 1100-1650                                    | 4200-5000                 | 1650-2350                       |
| 1                               | 1400-1700                       | 2660-2910                 | 1200-1750                                    | 4500-5300                 | 1800-2500                       |
| 1 1/4                           | 1500-1800                       | 2820-3120                 | 1200-1900                                    | 4800-5750                 | 1900-2700                       |
| 1 1/2                           | 1600-1900                       | 3162-3450                 | 1300-2100                                    | 5300-6350                 | 2150-3000                       |
| 1 3/4                           | 1800-2100                       | 3480-3810                 | 1400-2300                                    | 5750-6950                 | 2350-3300                       |
| 2                               | 1900-2200                       | 3760-4205                 | 1500-2500                                    | 6200-7550                 | 2500-3550                       |
| 2 1/4                           | 2000-2400                       | 4000-4500                 | 1600-2700                                    | 6650-8050                 | 2700-3800                       |
| 2 1/2                           | 2200-2600                       | 4250-4740                 | 1700-2800                                    | 7050-8550                 |                                 |
| 2 3/4                           | 2300-2600                       | 4475-4970                 | 1800-2950                                    | 7450-9000                 |                                 |
| 3                               | 2500-2800                       | 4900-5365                 | 2000-3200                                    | 8200-9850                 |                                 |

\* Wheel velocity is the axial mean air velocity through the inside diameter of the housing cylinder at the point of wheel location.

axial flow fan is inherently less accessible for service. When high-temperature air or air containing corrosive elements is being conveyed, motors and bearings should be located outside of the air stream. This requirement may determine the type of fan to be used. Where the system resistance is indefinite or variable, the pressure, horsepower and noise characteristics of centrifugal fans usually indicate their selection. Under such conditions, a steep and constantly rising pressure curve permits less variation in air delivery when the resistance varies. Likewise, a flat sound curve minimizes the change of moving into a region of increased noise. A fan having a high efficiency over a wide range is more desirable than one which reaches an even higher maximum efficiency, but decreases more rapidly on either side of a narrow range. A self-limiting horsepower curve may permit more accurate selection of motor size.

The selection of size of fan usually involves balancing cost and space against sound and efficiency. Unless the pressure involved is so high that a smaller fan running at greater speed requires a higher class<sup>2</sup> of construction, the smallest fan is the cheapest in first cost of the fan only. However, as the cost of the driving equipment is also involved in the total installation

cost, fan efficiency must be considered for that reason as well as its bearing on the cost of operation. In some cases where large fans operate long hours per year, selection at absolute maximum efficiency is indicated. Generally, however, the power saving by selecting for optimum efficiency does not justify the extra cost, and a slightly smaller fan gives the best balance of cost and efficiency. Reference to Figs. 2 to 4 shows that all types tend to have a minimum sound near maximum efficiency so, when noise is a consideration, selection approaching maximum efficiency is indicated. Too large a fan may not only mean an unnecessary investment and an increased power consumption and sound, but may also give faulty performance if of a type having an unstable pressure characteristic at low capacity.

Table 1 shows the outlet velocities and impeller tip speeds recognized as good practice for various static pressures for centrifugal, tubeaxial and vaneaxial fans applied to average heating, ventilating and air conditioning applications. Fans for churches, schools, residences and other buildings having a low prevailing noise level should be selected for lower than average outlet velocities.

## FAN INSTALLATION

In designing heating, ventilating and air conditioning systems, the characteristics of the fans available for use therewith should not be ignored. If double inlet fans or multiple fans in parallel are used, care must be taken that both inlets have the same free area and general approach conditions.

The dimensions of the ductwork and the size of the various devices whose individual resistances determine the static pressure, dictate the fan selection. Often a minor modification of the system may permit use of a smaller motor, and even a lower class<sup>2</sup> of fan, with considerable saving of cost. Invariably, the sound generated is affected, as fans operating at high pressure produce more noise than at lower pressure (see Chapter 41). Minimizing the resistance may be the best insurance against noise. On the other hand, sometimes the lowest overall cost results from selecting the minimum size of system equipment, and then installing adequate acoustical and vibration treatment.

All ducts should be connected to fan outlets and inlets by means of unpainted canvas or other flexible material. Access should be provided in the connections for periodic removal of any accumulations tending to unbalance the rotor. When operating against high resistance, or when ambient noise levels are low, it is preferable to locate the fan in a room removed from occupied areas or acoustically treated to prevent sound transmission. The lighter building constructions which are common today, make it desirable to mount fans and driving motors on resilient bases designed to prevent transmission of vibrations through floors to the building structure. Conduits, pipes and other rigid members should not be attached to fans. Noises due to high velocities, abrupt turns, grilles and other items not connected with the fan, may be present. Treatment of such problems, as well as the design of sound and vibration absorbents, are covered in Chapter 41.

## FAN APPLICATIONS

Many fan applications and the corresponding types of fan commonly used are listed in the following paragraphs. Reference is also made to the chapters where the applications are discussed.

*Central System Supply Fans* (Chapter 30) are usually of the centrifugal

type, since this application requires a wide range of satisfactory and quiet operation against relatively high pressures. They can readily be connected to apparatus of large cross-section on the inlet side, and to relatively small ducts on the outlet side.

Comparative sizes have been standardized among manufacturers,<sup>2</sup> and most rating tables cover a range of 700 to 500,000 cfm, and static pressures from  $\frac{1}{4}$  to 15 in. of water.

*Central system exhaust fans* are predominately centrifugal, but the space conservation of the axial is being increasingly utilized. Tubeaxial and vaneaxial fan sizes are not yet standardized, but several manufacturers list capacities from 2000 to 100,000 cfm, and static pressures up to 3 in. of water.

*Exhaust fans* are found in all types. *Wall fans* are predominantly of the propeller type, since they operate against little or no resistance. They are listed in capacities from 1000 to 75,000 cfm. They are sometimes incorporated in factory-built pent houses or roof caps, or are provided with matching automatic louvers. *Hood exhaust fans* (Chapter 46) involving ductwork, are predominantly centrifugal, especially if handling hot, corrosive or erosive fumes, where it is best to keep the bearings and drive remote from the air stream. Otherwise, axial fans are applicable, and where little or no ductwork is involved, propeller fans are suitable. *Spray booth exhaust fans* (Chapter 46) are frequently centrifugal, especially if built into self-contained booths. Tubeaxial fans lend themselves particularly well to this application where ease of cleaning and of suspension in a section of ductwork are advantageous. For such application built-in clean-out doors are desirable. *Material handling fans* (Chapter 46) are always straight radial (or modified) blade centrifugal type. They are of heavier construction, and have fewer blades and greater clearances than ventilating fans. Many characteristics are compromised to provide wear resistance and ease of maintenance. They are commonly listed in capacities from 600 to 60,000 cfm, and static pressures up to 15 in. water.

*Mine fan applications*<sup>11</sup> vary greatly and require fans ranging from small portable units for local ventilation, to immense slow speed centrifugal fans, often steam engine driven, for general or emergency ventilation. Vaneaxial fans are well suited to mine ventilation. For underground location, their compactness saves on cost of excavations, and above ground, their ready reversibility is valuable in emergencies, even if reversal causes a reduction in capacity.

*Marine fans* (Chapter 48) are of both centrifugal and vaneaxial types. The latter are particularly well adapted to both combatant and non-combatant ships, where compactness and light weight are invaluable.

*Unitary systems*, i.e., unit heaters, unit ventilators, unit humidifiers, unit air conditioners, unit air coolers and unit evaporative condensers are equipped with centrifugal or propeller fans, the latter usually being limited to the relatively small suspended type where no ductwork is involved. Fans for units having considerable internal or possible external resistance, are mostly of the forward-curved blade, or so-called mixed flow centrifugal type. The latter is really a centrifugal type with axial inlets, having a pressure curve resembling a backward-curved blade centrifugal fan. Both of these types have the high capacities (in relation to displacement) requisite for a compact unit. Ratings are frequently given for these units as separate fans, as well as in conjunction with the various internal resistances.

In multiple units on a common shaft they are listed up to 40,000 cfm capacities.

*Cooling tower fans* (Chapter 35) are predominantly of the propeller type, but axial types are also used for packed towers, and occasionally a centrifugal fan is used to supply forced draft.

*Circulating fans* are invariably of propeller or disk type, and are made in a vast variety of blade shapes and arrangements. They are designed for pleasing appearance, as well as utility.

*General purpose fans* are centrifugal fans of conventional design, built for service in the lower capacity ranges. They are built with the fan wheel mounted on the motor shaft, or connected to a self-contained belt driven arrangement. They are listed in capacities from 100 to 20,000 cfm, and static pressures up to  $1\frac{1}{2}$  in. water.

*Kitchen fans* for domestic use are small propeller fans arranged for window or wall mounting, and with various useful fixtures. Their capacities range from 300 to 800 cfm.

*Attic fans* are used during the warm seasons to draw large volumes of outside air through a house or other building whenever the inside temperature exceeds the outside, and thereby utilize the cooling effect of the relatively cool evening or night air. Research by the A.S.H.A.E.<sup>12</sup> indicates that a two to three-minute air change is desirable in the North; in the South, a one-minute change is recommended to provide the additional cooling effect of air motion.

Fans may be centrally located in an attic or other unused space, or in a hallway, and arranged to draw proportionately from several rooms; or local window units may be installed in a single room. Central units draw from the living quarters and discharge into the attic, whence the air escapes through windows or grilles; or the air may be drawn through grilles into the attic with the fan discharging directly outdoors. Discharge openings on the lee side are preferred.

Attic fans are usually of propeller type, and should be selected to operate at low velocities to minimize noise. Noise is more of a problem on local units, but care should be taken to prevent transmission of noise or vibration on all installations, because they operate during sleeping hours. Central units are available in sizes from 3,000 to 30,000 cfm, and window units up to 8,000 cfm.

#### Fans For Special Applications

Fans are used to handle many gases other than air at normal temperature. These range from heated air to many types of fumes, vapors, and industrial gases which may be corrosive, explosive, toxic, radio active or merely noxious.

For handling corrosive gases fans should be constructed of a material suitable for the particular gas being handled, although at times it is more practicable to plan on replacing a unit of standard material at more frequent intervals. Explosive combinations usually dictate a non-sparking fan in which either all of the fan, or only those parts which might strike together if mal-adjusted, are built of non-sparking materials. Noxious, toxic, radio-active or pure or valuable gases call for special construction to prevent leakage. This usually consists of a welded gas-tight housing, using flanged inlet and outlet, and some form of shaft seal.

In most of these special applications, since it is desirable to keep all bear-

ings, drives and motors outside the gas stream, centrifugal fans are usually used and in arrangements 1, 2, 4, or 8 (Fig. 6). The exception is in the case of fans handling explosive mixtures, where propeller or axial fans are permissible when built with explosion-proof motors and non-ferrous wheels.

Fans handling hot air or gas are generally of the centrifugal types and follow arrangements 1 or 8 so that bearings, drives and motors are remote from the heat. If of double inlet type, they have inlet boxes and long shafts to keep the bearings outside the stream. Propeller or axial types are rare when the temperature exceeds 150 F. With temperatures above 600 F special heat resistant materials may be required for the rotors. In addition to a remote location for the bearings, external cooling is frequently required when the temperature exceeds 200 to 250 F. This is often obtained by use of air cooled or water cooled jackets. With anti-friction bearings a heat radiating disk or a small circulating impeller between the fan and the nearest bearing is sometimes sufficient. Oil lubrication rather than grease lubrication is commonly recommended.

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#### CHAPTER 34

### AIR CLEANING

**Atmospheric Air Cleaners:** Airborne Particulate Matter, Viscous Impingement Filters, Dry Air Filters, Electronic Air Cleaners, Air Filter Performance, Selection, Maintenance, Installation, Adsorption of Vapors; **Industrial Air and Gas Cleaners:** Degree of Cleaning, Selection, Types, Application, Inertial Separators, Scrubbers, Wet Collectors, Filters, Electronic Precipitators, Adsorbers, Absorbers, Combustion Devices

AIR cleaning devices remove contaminants from an air or gas stream. They are available in a wide range of designs to meet various air cleaning requirements. Degree of removal required, quantity and characteristics of the contaminant to be removed, and conditions of the air or gas stream will have a bearing on the device selected for a given application. Definitions and a discussion of contaminant characteristics are given in Chapter 8, together with some consideration of their origin.

Air cleaning devices are divided in this chapter into two basic groups: Atmospheric Air Cleaners, described in Part I, and Industrial Air and Gas Cleaners, described in Part II.

*Atmospheric Air Cleaners* are ordinarily used to remove particulates such as are found in outside air, and are employed in ventilation, air conditioning, and heating systems where dust content seldom exceeds 4 grains per 1000 cu ft of air.

*Industrial Air and Gas Cleaners* are ordinarily used for the heavier concentrations encountered in local exhaust ventilation where the particulate content (loading) ranges from 100 to 20,000 grains per 1000 cu ft of air. Because of these heavier loadings, atmospheric air cleaners can seldom be used for the control of process aerosols in industrial applications.

#### PART I—ATMOSPHERIC AIR CLEANERS

Conventional air filters and electronic air cleaners are installed in air handling systems to remove dusts. These dusts constitute a mixture of particle sizes within the classification of temporary and permanent impurities listed in Fig. 1, Chapter 8, including bacteria, pollens, house dusts, and similar allergens which motivate attacks on persons of allergic sensitivity.<sup>1, 2</sup>

Since the purpose of the filter or cleaner is to free the air of as much existing contamination as practicable, the degree of air cleanliness required should influence the choice of apparatus. Atmospheric dusts are mixtures of particles in all sizes. The removal of these particles and fractions becomes progressively difficult as the particle size decreases. Smoke particles are of major importance in many applications. Air cleaners will justify their cost through a reduction in housekeeping expense in the



ventilated space, by the protection of the equipment in the ventilation system itself, and by providing relatively dust-free air for critical manufacturing processes.

Cleaning devices for atmospheric air are classified by the principle employed to collect dirt particles: i.e. impingement on viscous coated media, filtration through porous media, or electronic air cleaning. In some cases a filter may display a combination of these principles. Each type of air cleaner has certain advantages. There are applications where it is desirable to pass air through a series of two or more different types to obtain optimum results.

### AIRBORNE PARTICULATE MATTER

Suspensions of particulate matter in the air are called aerosols and consist of smokes, dusts, mists, and fumes. The characteristics of the aerosols which affect the performance of an air cleaner include particle size, concentration, shape, density, velocity, and surface characteristics. One of the most important of these is size.

The rate of settling of particles varies approximately as the square of the diameter. Particles larger than 10 microns in diameter settle so rapidly that the concentration of such particles decreases rapidly as the distance from the source increases. Particles less than 1 micron in size settle so slowly that the ordinary convection currents prevent sustained downward motion, and consequently such particles remain in the air for long periods.

If particles could be examined through a super microscope having a magnification of 250,000 diameters, a tobacco smoke particle of 0.1 micron would appear to be 1 in. in diameter, or approximately the size of a golf ball; a soft coal smoke particle 0.3 micron in diameter would appear like a baseball; a ragweed pollen grain of 20 microns in diameter would appear 16.5 ft in diameter, while the 50 micron particle (just visible to the naked eye and able to pass through a 270 mesh screen) would appear to be 50 ft in diameter. Consideration of this range in particle size from a golf ball to a sphere 50 ft in diameter will emphasize the difficulty of devising any single test to measure adequately the performance of air cleaning devices under all conditions of service.

The particles in the atmosphere can range in size from less than 0.01 micron up to things which are caught by an ordinary fly screen, such as lint, feathers, and insects. Almost all conceivable shapes and sizes are represented. The material is very commonly soot, ash, soil, lint, smoke, and fumes, but may include particles of almost any inorganic or organic material and even such living organisms as virus, bacteria,<sup>2</sup> and fungus spores.

This wide variety makes it impossible to design one type of cleaner which will be best for all applications. Mechanical filters of the low pressure type can remove large particles effectively. Other mechanical filters can remove extremely fine particles, but may be handicapped somewhat by high pressure drop and cost. Electronic air cleaners have the ability to give high effectiveness on normal atmospheric contamination, with a low operating pressure drop.

As a general rule, the removal of the coarser dust particles and lint from the ventilating air produces tangible results in so far as cleanliness in a house or building is concerned, because much of the finer dust remains

suspended in the air and is removed from the building by the circulating air. However, since some of the fine dusts, especially smoke and fume particles, are undoubtedly deposited by means other than settling, such as electrical or thermal precipitation<sup>4, 5</sup> and by contact, the ability to remove small particles is desirable in an air cleaner if it can be obtained at not too great a cost.

### VISCOUS IMPINGEMENT TYPE FILTERS

The viscous impingement type of filters consist of relatively coarse media constructed of a suitable fiber, screen, wire, mesh, metal stamping or plates, or a combination of medias. The filter may be of the unit type manually-cleaned, the replaceable type, or the self-cleaning type.

The medium in a viscous impingement type filter is usually a fiber pack for non-automatic types, or a series of metal plates for automatic self-cleaning types. In either case, the medium is treated with a viscous substance, often an oil or grease, called the *adhesive* or the *satrant*, intended to retain dust particles which come in contact with it. Also, in either case, the arrangement is such that the air stream is broken up into many small air streams, and these are caused to change direction abruptly a number of times in order to throw the dust particles, by momentum, against the adhesive. Several desirable characteristics of an adhesive for air cleaners of this type are: (1) its surface tension should be such as to produce a homogeneous film or coating on the filter medium; (2) the viscosity should vary only slightly with normal changes of temperature; (3) it should prevent the development of mold spores and bacteria on the filter medium; (4) the liquid should have high capillarity, or ability to wet and retain the dust at all operating temperatures; (5) evaporation should be slight; (6) it should be fire resistant; (7) it should be odorless.

Various fibrous materials have been used as filtering media in unit filters of the viscous impingement type. These include glass fiber, steel wool, similar wool of non-ferrous metals, wire screen, animal hair, hemp fibers, and other materials. In such filters, the medium is often packed more densely on the discharge than on the approach side, in order to increase the dust holding capacity. This results in a selective arrestance of dust with the larger particles nearer the approach face. The arrangement also permits some penetration of lint into (but not through) the filter, so that the amount of lint which can be tolerated on the filter is also increased. Due to plane surface area the viscous impingement type filter, however, may be inferior to some dry types if the air carries a high percentage of lint.

The resistance of air filters obviously increases with the rate of air flow through them. Face velocities of about 300 fpm, and resistances in the range from 0.1 to 0.2 in. water, when the device is new and clean, are usual for ventilation system filters.

Filters designated as high velocity units are also available. In most instances these filters employ a uniform media pack and give best performance at velocities about 500 fpm. Impingement type air filters should hold a substantial amount of adhesive so that the dirt collected by the filter will be retained. The design and construction should also provide a goodly proportion of free space through the media so that high velocities can be used without excessive resistances. The design should assure that the media throughout the thickness of the filter will be effectively utilized



and therefore, the filter should be designed to minimize the formation of a clogging dirt mat on the filter face. High velocity filters are apt to be adversely affected if the amount of lint in the air to be cleaned is excessive.

The resistance of filters increases with dust or lint loading, and it is the resistance due to this cause which ordinarily necessitates servicing. The rate of loading obviously depends upon the amount as well as the kind of dust in the air, and for this reason, periods between servicing cannot be predicted with certainty. Manometers are often installed to indicate the pressure drop across filter banks, and they serve to indicate when the filter requires cleaning. The pressure drop tolerated differs between operators and system designs. The resistance of a filter bank can be kept desirably low by periodically servicing some, but not all, of the units in the bank at one time. It is to be noted that a decline in efficiency may be the limiting factor in filter life rather than increased resistance due to load.

The method of cleaning viscous impingement unit filters differs for different types of filters and kinds of dust. Much dry dust or lint can often be removed by rapping the filter.

Throw-away filters are constructed of inexpensive materials, and are designed to be discarded after one period of use. The frame is frequently a combination of cardboard and wire.

Cleanable filters usually have metal frames. Various cleaning methods have been recommended including: air jet, water jet, steam jet, washing in kerosene, and dipping in an oil. The last may serve both to clean the filter and add the necessary adhesive.

It is not mandatory that unit filters be removed from their metal frames for cleaning outside of the system. Cleaning of unit filters in place is feasible by means of hot water sprayed from a hose or by means of fixed nozzles to accomplish washing and adhesive application. Where filters are cleaned in place, provision should be made to collect and drain the water so as to prevent leakage from the filter housing.

#### Moving-Curtain Viscous Filters

In the moving-curtain air filter, means are provided to remove the dust from the medium mechanically. Filters with moving cloth media are available essentially for lint removal.

The medium in a typical moving-curtain filter at present consists of a series of specially formed metal plates mounted on a pair of chains. The chains are mounted on sprockets located at the top and bottom of the filter housing, so that the filter medium can be moved as a continuous curtain up one side and down the other side of the sprockets. The arrangement is such that, at the bottom, the medium passes through a bath of special oil which both serves to remove the dirt from the plates, and acts as an adhesive when the cleaned plates next pass through the air stream. The plates forming the filtering medium or curtain usually overlap each other, and due to their special shape, many small air passages are formed between them. These air passages turn abruptly one or more times in order to give the impingement effect.

An electrically driven rotating device is usually supplied with a moving-curtain filter. The device may be set to move the curtain periodically, or a special switch, actuated by pressure drop, may be used to govern its motion. In operation, the resistance of an automatic filter will remain

approximately constant as long as proper operation is obtained. A resistance of  $\frac{1}{2}$  in. water at a face velocity of 500 fpm is typical of this class.

#### DRY AIR FILTERS

The media in such filters are usually fabrics or fabric-like materials. Media of wool felt, cotton batting (both glazed and unglazed), cellulose fiber and other materials have been used commercially. The medium in a filter of this class is usually supported by a wire frame in the form of pockets or V-shaped pleats in order to increase the area exposed to the passage of air. A 2-ft square unit may contain from 15 to 30 sq ft of medium.

Dry air filters, by virtue of the large area of medium used, have a comparatively high lint holding capacity. The efficiency of dry type filters is usually higher than that of viscous impingement filters, while the life of the former based on dust holding capacity, may be lower. Dust tends to clog the fine pores or openings of dry filters more quickly, thereby causing a higher rate of resistance rise than for viscous impingement filters. Efficiency with very fine particles equivalent to that of electronic air cleaners is not uncommon with certain types of dry filters. A comparatively deep bed,  $\frac{1}{2}$  to 1 in. thick, of filtering media having individual fibers in the order of 1 micron in diameter, is required for such high efficiency.

Dry filters may consist of a cleanable medium held in permanent frames, or a throw-away or replaceable filtering medium held in permanent frames, or the entire filter may be of the throw-away type. Usually the filtering medium alone is replaced after having collected its full dust load.

#### ELECTRONIC AIR CLEANERS

Two principal types of electronic air cleaners are available for air filter application: (1) ionizing type collectors where particles are given a definite charge by passing through an ionization zone, and (2) charged media type collectors where the energized, collecting medium induces a charge on the particles.

##### Ionizing Type Electronic Air Cleaner

Electronic air cleaners use electrostatic precipitation principles to collect particulate matter, see Fig. 1, but operate on much lower voltages than the type commonly used on industrial stacks. The designation Electronic Air Cleaner has been standardized to distinguish the class of electrostatic precipitator which alone is suitable for cleaning ventilating air.

In a typical case, a potential of 12,000 volts may be used to create the ionizing field, and some 6000 volts between the plates upon which the precipitation of dust occurs. These voltages, which are capable of momentary shock to personnel similar to that of a spark plug, necessitate some safety measures. A typical arrangement provides means for making the equipment inoperative when any door affording access to high voltage parts is opened. Operation can be resumed only after all doors are closed. The voltages necessary for operation of the equipment are usually obtained by means of electronic high voltage direct current power packs operating from a 110-120 volt, 60 cycle, single phase building service. Electric power consumption is about 10 watts per 1000 cfm, plus the approximately 40 watts required to energize the rectifier tube heaters.

Air cleaners of this type offer negligible resistance to air flow and,

therefore, care must be exercised in arranging the duct approaches on the entering and leaving sides of the cleaners in order that the air flow may be distributed uniformly over the cross-sectional area. The efficiency of the electronic air cleaner is sensitive to air velocity, and the device itself has much less tendency to rectify the air stream than filters which have higher resistances. In most systems, resistance is deliberately added in the form of a perforated plate, pre-filters or after-filters for the purpose of obtaining a uniform distribution of air. The resistance, including the baffles or after-filters, is constant and generally ranges from 0.15 to 0.25 in. of water at the usual velocities of 300 to 400 fpm. Such plates or filters, however, cannot compensate for defects in the duct layout ahead of the cleaner. Suitable screens of no coarser than 16 mesh should be installed across all

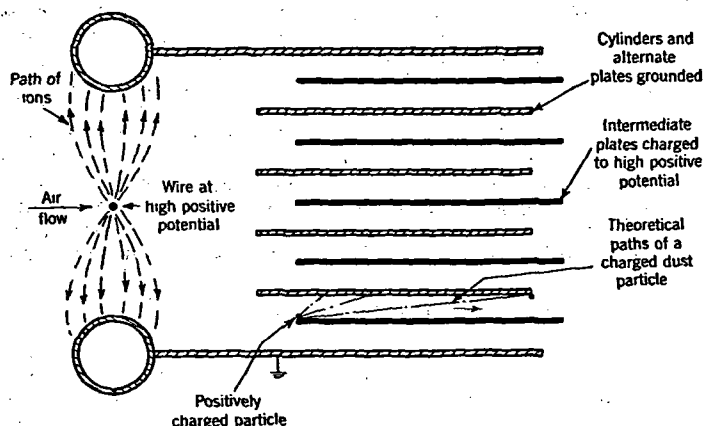


FIG. 1. DIAGRAMMATIC CROSS-SECTION OF IONIZING TYPE ELECTRONIC AIR CLEANER

outside air entrances to prevent insects, leaves, bits of paper and similar material from entering the cleaner. Where lint is present in appreciable quantities, devices for lint removal should be installed ahead of the cleaner.

Electronic air cleaners of the ionizing type are efficient, low pressure drop devices for removing fine dust and smoke particles. They are available in fixed collector-plate and moving collector-plate types. The fixed collector plates are often coated with a special oil as an adhesive. Cleaning is generally accomplished by washing the cells in place with hot water from a water hose or by means of fixed or moving nozzle systems. The bottom of the equipment is made water tight and provided with a drain. In one moving-plate type, the grounded elements on which the dirt collects are mounted on chains, and are alternately dipped in oil and exposed to the air stream.

#### Charged Media Electronic Air Cleaners

The charged media type air cleaner consists of a dielectric filtering medium, usually arranged in pleats as in typical dry filters. No ionization

means are employed. The dielectric filtering medium may consist of glass fiber mat, cellulose mat or other similar material, and is supported on or in contact with a gridwork consisting of alternately grounded and charged members, the latter usually being held at a potential of 12,000 volts d.c. An intense and non-uniform electrostatic field is thus created through the dielectric medium. Airborne particles approaching the field are polarized and drawn toward filaments or fibers of the media. The general arrangement illustrating this type of filter is shown in Fig. 2.

The precipitator of this type offers resistance to air flow, when clean, on the order of 0.10 in. of water at 250 fpm velocity and, unlike the ionizing type, the resistance of the charged media type electronic cleaner rises as dust is accumulated on the media. Because of these characteristics the filter tends to equalize the air distribution over the face of the filter. Like

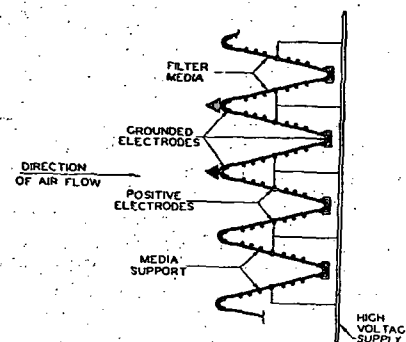


FIG. 2. CROSS-SECTION DIAGRAM OF CHARGED MEDIA TYPE ELECTRONIC AIR CLEANER

typical replaceable media mechanical filters, the charged media precipitator is serviced by replacing the filtering medium. The dielectric properties of the media are impaired when the relative humidity exceeds 70 percent.

#### AIR FILTER PERFORMANCE AND TESTING

Air filters are generally rated in terms of the total air flow for which they are designed, expressed in cubic feet per minute. Face velocity is defined as the average velocity of the air entering the filter, and it is determined by taking the air flow and dividing it by the area of the duct connection to the cleaner in square feet. Filters are often rated at a face velocity in the range of 250 to 500 fpm. Resistance to air flow is usually measured in inches of water column. The resistances of filters when new and clean, and when operated at rated capacity, are generally available from the manufacturer (see *Catalog Data Section*). A suitable allowance should be made in system design for increase of filter resistance due to the accumulation of dust.

The ability of air cleaners to clean air is called the efficiency or the arrestance, and may be denoted by the symbol  $E$ . The efficiency of an air

cleaner differs with the size and nature of the dust on which the cleaner operates. The efficiency of an air cleaner, algebraically expressed, is

$$E = \frac{D_1 - D_2}{D_1} \quad (1)$$

where

$D_1$  = amount of dust per unit volume in uncleaned air.

$D_2$  = amount of dust per unit volume in cleaned air.

Several methods have been investigated for evaluating  $D_1$  and  $D_2$ . The particle count method is not used for efficiency evaluation, except in investigation of filter performance on specific particles such as pollen, or on certain industrial dusts harmful to health. Dust particles can be captured on microscope slides by means of one of the various kinds of impingement devices. The process is useful if inspection and analysis of dust are desired, but particle counting is not sufficiently precise for evaluating the efficiency of a cleaner operating on a heterogeneous dust.

A weight method of evaluating efficiency was described in a former code of the AMERICAN SOCIETY OF HEATING AND AIR-CONDITIONING ENGINEERS and incorporated in a code.<sup>6</sup> For this test, a known weight of a prepared dust is injected into air supplied to the filter, and the quantity of dust in the cleaned air is determined by extracting and weighing the dust from a known volume of the cleaned air. Dust extraction from the air is accomplished by drawing the air through a porous crucible or thimble by means of a high vacuum.

Caution is to be exercised in interpreting published air filter arrestance data, since the test efficiency may be somewhat higher than that which will be obtained in an installation with respect to the ventilated space.

The *dust-spot* or *blackness* test for cleaner efficiency was developed at the National Bureau of Standards.<sup>7</sup> The test consists of drawing samples of cleaned air and of uncleaned air through filter papers simultaneously. One such test apparatus consists of a means of drawing samples of air simultaneously through two filter papers, one on each side of a light chamber. The intensity of light from a single bulb passes through these papers and falls on two photo-cells. The cells are connected to the same galvanometer and if the light falling on one cell decreases faster than the light falling on the other, the galvanometer moves off the zero position. The flows of air through the filter papers are kept in such ratio as to keep the galvanometer on the zero position, showing that the papers are becoming dirty at equal rates. The ratio of the sampling rates is then an index to the efficiency of the filter under test.<sup>7</sup> Actual atmospheric contamination is commonly used as the basis of test.

The National Bureau of Standards has also used prepared dust and lint in its air cleaner testing apparatus, two injectors for contaminant being used. One injector is used to contaminate the air stream with Cottrell precipitate, previously described. This dust is used to make both efficiency determination and dust-holding capacity tests. The other injector contaminates the air stream with cotton linters with which lint-holding capacity tests are made. The curves in Fig. 3 illustrate the difference in the characteristics of two filters, one a viscous-impingement type and the other a dry filter with a cellulose fiber medium. The two injectors can be operated either separately or simultaneously.

Dust-holding capacity is defined as the amount of dust which a filter can retain and have a resistance less than some arbitrary value. The term applies only to fixed type air cleaners. Determination of dust-holding capacity is an objective of each test under the former A.S.H.V.E. Code.<sup>6</sup> Curves are obtained during such tests to show the relation between dust load and resistance.

Fig. 4 indicates the range of resistance to air flow found in tests of four unit air filters. Type A is a dense pack used in bacterium control; Type B is a medium pack used for general ventilation work; Type C is a low resistance unit, for use where low resistance is the important factor and maximum cleaning efficiencies are not essential; and Type D is a high-velocity viscous-impingement filter.

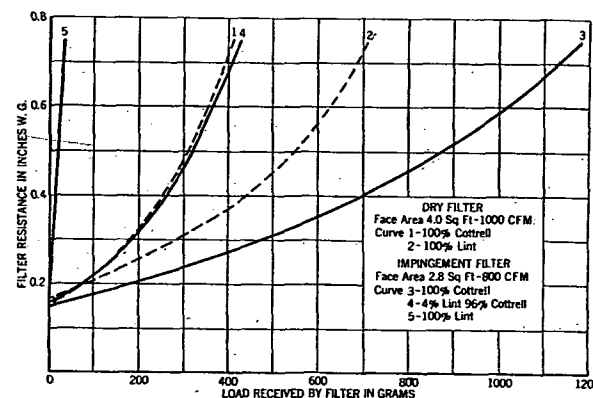


FIG. 3. DUST AND LINT HOLDING CAPACITY OF TWO FILTERS

### SELECTION AND MAINTENANCE

To evaluate filters and air cleaners properly for a particular application, two factors should be carefully weighed: (1) the degree of air cleanliness required and (2) disposal of the dirt after it is removed from the air. These factors affect initial costs, operating costs and the extent of maintenance that will be required. Savings that accrue through reduction in house-keeping expenses, protection of valuable property and equipment, ability to carry on dust-free manufacturing processes, improved working conditions, and even health benefits should be credited against the cost of installing and operating an adequate system. The capacity and physical size of the unit required may emphasize the need for self-cleaning features. Operating costs, predicted life, and efficiency are more important than first cost, because air cleaning is a continuing process.

While electronic air cleaners have a higher first cost, they exhibit very high efficiencies in cleaning atmospheric air, due largely to their ability to remove fine dust which shows no gravitational effect. They are equally effective on coolant oil mists from high speed cutting and grinding machines. System resistance remains unchanged as dirt is being collected, and the

resulting residue is disposed of directly to prepare the equipment for further duty. The charged-media type cleaners are less effective than the ionizing type, but are appreciably better than mechanical filters in the matter of small particle collection.

The advantage of the moving-curtain impingement type filter consists in the small amount of attention which it requires. Such devices are therefore to be recommended where labor is scarce, or where reliable and frequent attention to filters cannot be assumed. The constant pressure drop of this type of filter is an advantage. The first cost is substantially greater than that of unit filters, and the dust arrestance may not be any higher.

Unit filters constitute the majority of air cleaners now in use, and some choice is possible between the types available. Where lint in an eminently dry state predominates, a dry filter obviously may be preferable to other

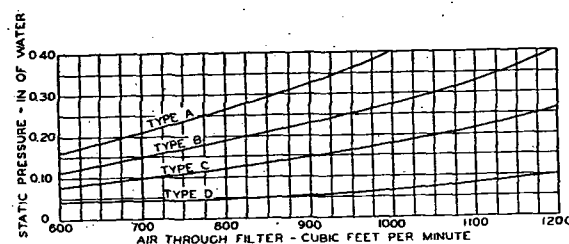


FIG. 4. RESISTANCE TO AIR FLOW OF FOUR UNIT AIR FILTERS

types because of its lint-holding capacity. If the lint is greasy, or if oil vapor exists in the air, the dry filter, if it is of the cleanable type, may be troublesome, since grease tends to make it difficult to clean. Most dry types, however, employ a throw-away type of medium which is held in permanent metal frames so that the difficulty of cleaning the medium is avoided. Some dry filters are capable of high efficiencies, compared to other unit filters on fine particles, but their dust-holding capacity for such dust may be inferior to that of the viscous impingement type.

Viscous impingement unit filters are practically standard in size, and their overall dimensions are small when compared with their ratings.

Throw-away units are often installed in series so that the one in front, which usually becomes plugged with lint, can be discarded, after which the downstream unit is moved to the front and replaced by a new unit.

Viscous impingement unit filters do not have efficiencies as high as can be expected with some other types of unit filters, but their first cost and upkeep are generally lower, whether of the cleanable or the throw-away type. They require more careful attention than the moving-curtain type if the resistance is to be maintained within reasonable limits.

#### FILTER INSTALLATION

Many air cleaners are available in units of convenient size for handling when installing, cleaning, or replacing. Such units are usually designated

as filters or unit filters. A typical unit filter may be 20 in. square and from one to several inches thick, depending on the manufacture and proposed use. In large systems, a number of such units are installed adjacent to each other and collectively called a bank of filters.

Air cleaners are commonly installed in the outdoor air intake ducts of buildings, and generally in the recirculating and by-pass air ducts as well. Cleaners are logically placed ahead of heating or cooling coils and other air conditioning equipment in the system to protect them from dust. The character of the dust arrested by the filters in an air intake duct is likely to be mostly particulate matter of a greasy nature, while lint may predominate in dust from within the building.

The published performance data for all air filters are based on *straight through* unrestricted air flow. Filters should be installed so that the face area is at right angles to the air flow whenever possible. Eddy currents and dead air spaces should be avoided, and air should be distributed uniformly over the entire filter surface, using baffles or diffusers if necessary.

Failure of air filter installations to give satisfactory results can, in most cases, be traced to faulty installation or improper maintenance or both.

The most important requirements of a satisfactory and efficiently operating air filter installation are:

1. The filter must be of ample size for the amount of air it is expected to handle. An overload of 10 to 15 percent is regarded as the maximum allowable. When air volume is subject to increase, a larger filter should be installed.
2. The filter must be suited to the operating conditions, such as degree of air cleanliness required, amount of dust in the entering air, type of duty, allowable pressure drop, operating temperatures, and maintenance facilities.
3. The filter type should be the most economical for the specific application. The first cost of the installation should be balanced against efficiency and depreciation as well as expense and convenience of maintenance.

The following recommendations apply to filters installed with central fan systems:

1. Duct connections to and from the filter should change size or shape gradually to insure even air distribution over the entire filter area.
2. Sufficient space should be provided in front as well as behind the filter to make it accessible for inspection and service. A distance of two feet may be regarded as the minimum.
3. Access doors of convenient size should be provided in the sheet metal connections leading to and from the filters.
4. All doors on the clean air side should be lined with felt to prevent infiltration of unclean air. All connections and seams of the sheet metal ducts on the clean air side should be as air-tight as possible.
5. Electric lights should be installed in the chamber in front of and behind the air filter.
6. Filters installed close to an air inlet should be protected from the weather by suitable louvers, in front of which a large mesh wire screen should be provided.
7. Filters, other than electronic air cleaners, should have permanent indicators to give a warning when the filter resistance reaches too high a value.

#### Safety Requirements

An investigation of safety ordinances should be made by the engineer when the installation of an air cleaner of any considerable size is contemplated. It is possible that combustible filtering media may not be permitted in accordance with some existing local regulations. Combustion

of dust and lint on a filtering medium is possible, though the medium itself may not burn.

### ADSORPTION OF VAPORS OTHER THAN WATER

Many of the foreign gases in the atmosphere are selectively adsorbed by charcoal. Included are many of the organic gases, such as those emanating from animals and people, some of the gaseous constituents of combustion, alcohols, ketones, esters, and gaseous products of putrefaction.

Charcoals differ widely in their adsorptive capacity. Those which have marked adsorption characteristics, such as properly prepared coconut shell charcoals, are sometimes called *activated charcoals* or *activated carbon*. These materials can adsorb approximately 50 percent of their own weight of many organic gases at 70 F. The charcoal may be used for a long time by reactivation at high temperatures, under which condition it gives up the adsorbed gases. Temperatures of approximately 1000 F are desirable for reactivation. Charcoals for use in air handling systems should be able to stand physical handling, including reactivation, without excessive loss by breakage or dusting.

As applied in air handling systems, the charcoal is placed in perforated metal containers which are grouped in frames and set in the air stream. The percentage removal of an organic gas, such as carbon tetrachloride, is 95 percent or above, when placed in intimate contact with the carbon at 70 F. In commercial apparatus there may be a by-pass effect which depends on the physical arrangement of the charcoal containers. This by-passing reduces the percentage removed in the total gas passing through the adsorber. Resistance to air flow is usually selected within the general range of resistance of impingement filters.

The required quantity of recirculated air to be treated is determined by dividing the requirements for contaminant-free air, minus the outdoor air, by the fraction denoting the percentage removal of the gas in question in the adsorber bank which is to be used.

Adsorbers may be applied to reduce objectionable gases entering through the outdoor air inlet. They may also be used to reduce the odors caused by exhausts from processing. Adsorber beds, in all cases, should be protected from dust, free oil and grease.

### PART II—INDUSTRIAL AIR AND GAS CLEANERS

Industrial development and growth of industrial areas have had a cumulative effect upon the problem of controlling contaminants. Not only has the atmosphere in many cities become more polluted, but the intensity of pollution at the points of control has increased. Accompanying this increase in pollution there has been a growing consciousness of the need for more effective air cleaning among housewives, store managers, industrialists and legal inspectors, and this has resulted in increasing severity of regulations pertaining to collection of dust and contaminants.

Air cleaning for the supply system is usually accomplished by means of some type of air filter. To prevent escape of industrial dust into the atmosphere, some type of collector is required. An industrial air cleaning installation is designed to perform one or more of the following 6 functions:

1. Prevent a nuisance or physical damage to an individual, a plant, or adjacent property.

2. Prevent re-entry of contaminants to working spaces.
3. Reclaim usable material.
4. Reduce fire, explosion, or other hazards.
5. Permit recirculation of cleaned air to working spaces.
6. Allow utilization of cleaned gases for processes.

### DEGREE OF AIR CLEANING REQUIRED

The amount of material which can be discharged is established by local or state regulations prepared by pollution control, labor or health departments. Standards are established to prevent injury to persons or property. The need for control within the plant is often of prime interest to the industrialist for protecting his equipment, improving his product, and providing a clean working environment. The re-entry of contaminants to working spaces is prevented by effective air cleaning devices since only a clean effluent is discharged to the ambient atmosphere. Public nuisance complaints often occur even when the effluent concentration discharged to the atmosphere is below the permissible limits of concentration and visibility. Plant location, contaminants involved, and meteorological condition of the areas must be evaluated in addition to existing regulations or codes of good practice.

Fire and explosion hazards are created by combustible dusts, vapors, or gases. Safety may be affected by loss of visibility, settlement, or accumulation of various materials. The cleaning device can prevent these hazards by providing an effluent below the inflammation limit, visibility index, and point where settlement or accumulation will occur.

The degree of air cleaning for the recovery of useable material is a matter of economic evaluation which will vary with such factors as quantity and value of material collected, capital cost, and operating cost.

Air cleanliness must be of the highest order where toxic materials are involved and the cleaned air is recirculated to the workroom. Such recirculation is considered poor practice and is prohibited by many regulations where toxic materials are involved, except for those cases where discharge to atmosphere is impossible or decidedly impracticable. Where air is recirculated, its contamination must not exceed the established maximum allowable concentrations listed in Chapter 8. Usual requirements are a fraction, often  $\frac{1}{2}$  to  $\frac{1}{4}$ , of this standard, depending on: regulation involved, air quantities recirculated in relation to the cubical content of working space, and the presence of other exhaust systems discharging to the atmosphere.

Cleaning requirements for the utilization of cleaned gases are dependent on the process and are generally of the highest order (usually comparable to atmospheric air cleanliness).

Regardless of standards it is good practice to install the most effective collection equipment available in the light of practical operation features, installation, and equipment costs. This is warranted because the required degree of cleaning is increasing continually.

### FACTORS AFFECTING SELECTION

Selection of an industrial air cleaner for a given application requires an evaluation of the following 5 considerations:

1. Concentration, particle size, and size distribution of the contaminant.

2. Degree of cleaning required.
3. Conditions of air or gas stream with reference to temperature, moisture content, and chemical composition.
4. Characteristics of the contaminant, corrosiveness, solubility, adhesion, or packing, and its specific gravity, surface, and shape.
5. Methods of disposal or salvage that meet the conditions imposed by material, process, or plant location.

In view of the range of these variables, all available test data, application experience, and manufacturers' performance data should be considered.

### TYPES AND APPLICATION

There are a number of principles involved in the operation of industrial air and gas cleaners. They are illustrated by the following types of cleaners:

1. *Inertial Separators* (Gravitational or inertial force principle): Baffle Chambers, Centrifugal Collectors.
2. *Scrubbers and other Wet Collectors*: Air Washers, Wet Filters or Packed Towers, Spray Towers, Centrifugal or Inertial Scrubbers, Venturi Scrubbers.
3. *Filters*: Fabric Filters, Ultra or Absolute Filters.
4. *Electrostatic Precipitators*.
5. *Absorbers, Absorbers, and Combustion Devices*.

Units employing these principles may apply them singly or in combination. The important characteristics of any unit are: its collection efficiency, resistance to air or gas flow (power requirements), ability to maintain specified air or gas flow during its operating cycle, and maintenance requirements.

In relation to industrial air cleaners, efficiency of collection is generally presented on a basis of weight removal. In many instances, collection efficiency is expressed in terms of weight removal in specific particle size ranges. Occasionally efficiencies are given in terms of visibility or photometric evaluation. Under other circumstances efficiencies are stated by particle count. For most process recovery problems and air pollution control, the weight basis has been adequate. When loss of visibility is the major problem, light opacity measurements may be required.

From a hygienic viewpoint where air is to be recirculated, only the contaminant concentration in the recirculated air stream, rather than the correction efficiency, should be considered.

Correlation between the various efficiencies is poor due to the wide variation in particle size, size distribution, and shape.

Resistance or pressure drop through any given collector is related to the operating principle, and varies about as follows: low resistance collectors—up to 2 in. water; medium resistance collectors—2 to 8 in. water; high resistance collectors—8 to 25 in. water.

In mechanical centrifugal collectors of the wet or dry type (power driven impellers or rotors) resistance alone is not of significance since these devices are also air movers and therefore the factor of paramount importance is the overall power consumption of the unit. This is also true of certain types of wet collectors which require auxiliary pumping power.

The ability of any unit to maintain specified air or gas flow during its operating cycle is also a function of its operating principle. For example,

inertial collectors of the simple and centrifugal type are able to maintain constant resistance regardless of concentration and particle size. However, adhesive materials may collect at the entry, throughout the unit, and at the exit, and thus cause a reduction in air flow and serious maintenance problems. With the exception of packed towers and wet filters, wet collectors operate at constant resistance throughout their operating cycles. However they may also be adversely affected by adhesive or corrosive materials. Wet filters or packed towers will eventually become clogged because of retention of inert dusts. Units employing fabric or other filter media will have resistance influenced by the concentration, particle size, shape and packing characteristics of the aerosol. Their overall resistance during the operating cycle may increase gradually over a known or determined period. Auxiliary cleaning devices such as separate compartments, alternately shaken, reverse air flow, or reverse jet air flow may maintain constant or nearly constant resistance or insure only small fluctuations in air or gas flow. Electrostatic precipitators have the outstanding characteristic of maintaining a constant air flow with an accompanying low resistance. Adsorbers behave similarly to packed towers in that they provide constant resistance until the voids become seriously plugged with inert dusts. This generally requires a matter of several months on normal applications.

It has been found that inertial separators require the least maintenance. Simple wet collectors rank next in this respect. Complex wet collectors and fabric arrestors require maintenance on a definitely scheduled basis. Electrostatic precipitators require the usual maintenance connected with high voltage equipment and may vary widely. The maintenance of adsorber type units is minimal and is based primarily on the amount of inert material encountered.

### INERTIAL SEPARATORS

There are many types in this group. These range from simple settling chambers utilizing gravitational forces, to complex centrifugal devices using abrupt directional changes or motor driven rotors. They all have the desirable features of constant resistance during their operating cycle and do not require any special construction for temperatures under 750 F. Usually they require less maintenance than other types of collectors.

On the basis of their important characteristics inertial separators may be classified according to Table 1.

### SCRUBBERS AND OTHER WET COLLECTORS

In these collectors many methods are used to wet the contaminant and remove it from the air stream. A number of wet collectors are similar in design to dry collectors with the addition of sprays or liquid contactors. The mechanism of separation in wet collectors depends on inertial forces such as impaction and impingement, and in some cases, diffusion.

Wet collectors do not require any special construction for high temperatures. They are suitable for use on mixed contaminants such as gases and solid or liquid particles. The collection of dust in a wetted form eliminates a secondary dust problem in disposal of collected material. Protection against corrosion and freezing may be necessary and disposal of waste liquids may become a problem. With the exception of the packed



towers and wetted filters they all have a constant resistance during their operation.

On the basis of their important characteristics wet collectors may be classified according to Table 2.

### FILTERS

Filters for industrial air and gas cleaning consist primarily of cloth dust collectors and the ultra or absolute type of filter.

Cloth dust collectors are generally constructed in the form of housings with cloth envelopes drawn over wire screen frames or with vertical cloth

TABLE 1. INERTIAL SEPARATOR CHARACTERISTICS.

|                              | EFFICIENCY PARTICLE SIZE RANGE IN MICRONS |               |               | RESISTANCE (PRESSURE DROP) | DESCRIPTION AND REMARKS                                                                                                                                                                                                      |
|------------------------------|-------------------------------------------|---------------|---------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                              | >100                                      | 100-10        | <10           |                            |                                                                                                                                                                                                                              |
| Settling and baffle chambers | Medium                                    | Low           | Low           | Low                        | A large chamber to reduce velocity to permit settling. Auxiliary baffles are sometimes used to improve performance. Requires large space.                                                                                    |
| Large diameter cyclones      | High                                      | Medium to Low | Low           | Low                        | Considered as single body over 3 ft in diameter. Gases and material must be dry. Air-tight dust bins or continuous removal of material must be provided. Space requirements moderate.                                        |
| Refined design centrifugals  | High                                      | High          | Medium to low | Medium                     | Available as multiple small diameter tubes, scroll shaped bodies, and multiple louvers. Gases and material must be dry. Air-tight dust bins or continuous removal of material must be provided. Space requirements moderate. |
| Integral rotor type          | High                                      | High          | Medium to low | See remarks                | Rotor acts as air mover and separating element. Usually limited to dry granular materials and dry gases. Low space requirements. No external pressure loss involved but power requirements are higher than usual exhauster.  |
| Slotted scroll fan           | High                                      | Medium to low | Low           | See remarks                | Separation takes place in fan scroll. No external loss involved but power requirements are higher than usual exhauster.                                                                                                      |

bags or tubes. Cloth filters depend to a great extent on the accumulated dust layer for their effectiveness. Their basic or initial efficiency depends upon the type of fabric employed; felted media such as wool gives higher initial removal than woven fabrics. The increase in resistance to air flow, resulting from the accumulated dust layer, is related to rate of flow, concentration, and characteristics of the contaminant. Removal of the collected material is accomplished through periodic shaking by single mechanisms or combinations of them employing rapping, or through reversal of air flow, or by means of high velocity reverse air jets. With shaking or rapping, air flow is not constant and filtering velocities are usually held under 6 fpm. With reverse jets or reverse air flow, substantially constant air flow is maintained and filtering velocities are generally higher (up to 35 fpm). Filtering velocities in all fabric collectors are highly dependent upon the aerosol, fume, or dust being collected.

The ultra or absolute type of filter<sup>8</sup> may consist of pleated cellulose as-

TABLE 2. CHARACTERISTICS OF WET COLLECTORS

|                                   | EFFICIENCY                     |      |                | RESISTANCE IN WATER  | WATER RATE IN GALLONS PER 1000 Cu Ft Gas | MAINTENANCE | DESCRIPTION AND REMARKS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------|--------------------------------|------|----------------|----------------------|------------------------------------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                   | PARTICLE SIZE RANGE IN MICRONS | >10  | 10-1           | <1                   |                                          |             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Air washers                       | High                           | High | Medium         | Low                  | 5-15                                     | Medium      | Composed of one or more banks of low pressure sprays and flooded eliminator plates. Space requirements are large. Water is usually recirculated.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Wet filters                       | High                           | High | Medium         | Low (less than 1)    | 3-8                                      | Medium      | Composed of one or more banks of low pressure sprays flooding packed cells of glass or other fibers. Space requirements are large. Limited to low loadings of solid particles.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Packed towers                     | High                           | High | Medium         | High                 | 5-10                                     | High        | Composed of granular or ceramic packing. Space requirements large. Generally limited to gas absorption.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Spray towers                      | High                           | High | Medium         | Low                  | 5-10                                     | Low         | Usually a vertical chamber equipped with low pressure water sprays at the top or along the walls. Baffle plates may be provided for contacting. Space requirements medium. Usually applied for hot gases.                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Centrifugal or inertial scrubbers | High                           | High | Medium to high | Medium (see remarks) | 1/4-40                                   | See remarks | This classification includes most of the commercial wet collectors. They may utilize singly or in combination, low or high pressure sprays, wetted plates, rotating members, liquid gas contact by induction or centrifugal action.                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Venturi scrubber                  | High                           | High | High           | High (12-25)         | 5-10                                     | Medium      | Some of these units (disintegrators) have high overall power requirements for driving the rotor while others have high power consumption for raising water pressures for spray nozzles. Maintenance varies from low to high depending on component parts. Simple gas liquid contact units would be classified as low. Units having rotating members may vary from medium to high depending on the type of service. Consists of a simple venturi with low pressure sprays at throat followed by cyclonic type separator. Space requirements are low. Unit functions independent of grain loadings. High velocity at venturi throat may cause erosion problems. |



bestos paper, deep sand beds, composite glass wool layers, compressed glass fiber in the form of paper or batts and resin wool. The use of this type of filter is limited to concentrations in the range of outdoor air where very high efficiencies, greater than 99.95 percent are required.

Fabric filters are not suitable for high temperatures, above 300 F, acid mists or vapors, or mixed contaminants such as wet corrosive gases and solid or liquid particles. Cotton fabrics are limited to 180 F, whereas wool is limited to temperatures under 200 F. A wide variety of natural and synthetic filter medias is available for various temperature and corrosion conditions but caution must be exercised relative to rupture, high temperatures, and corrosive gases. When properly selected, efficiencies are often high enough to permit recirculation of air except, possibly, when handling toxic contaminants.

TABLE 3. CHARACTERISTICS OF FABRIC FILTERS

| TABLE 3. CHARACTERISTICS OF FILTERS                               |                                |         |                     |                        |                              |                                    |
|-------------------------------------------------------------------|--------------------------------|---------|---------------------|------------------------|------------------------------|------------------------------------|
|                                                                   | EFFICIENCY                     |         |                     | RESISTANCE<br>IN WATER | FILTERING<br>VELOCITY<br>fpm | MAINTENANCE                        |
|                                                                   | PARTICLE SIZE RANGE IN MICRONS |         |                     |                        |                              |                                    |
|                                                                   | >10                            | 10 TO 1 | <1                  |                        |                              |                                    |
| Cloth collector<br>(shaken or<br>rapped) <sup>a</sup>             | High                           | High    | Moderate to<br>high | Medium                 | 1-6                          | Medium to<br>high<br>(periodic)    |
| Cloth collectors<br>(reverse air or<br>jet cleaning) <sup>b</sup> | High                           | High    | Moderate to<br>high | Medium to<br>high      | 10-35                        | Medium to low                      |
| Absolute type <sup>c</sup>                                        | High                           | High    | High                | Medium                 | 3-14                         | None (see<br>remarks) <sup>a</sup> |

<sup>a</sup> Space requirements large. Requires scheduled cleaning.

<sup>b</sup> Space requirements medium. Cleaning constant during operating cycle. Added horsepower used for reverse jet action.

<sup>c</sup> Space requirement small. Requires replacement of unit when predetermined resistance is attained. Ordinary cleaning not possible.

On the basis of their important characteristics, fabric filters may be classified according to Table 3.

### ELECTROSTATIC PRECIPITATORS

Electrostatic precipitators for industrial air and gas cleaning differ materially from the low voltage designs described in Part I of this chapter, although the principles of operation are similar. For industrial concentrations, it is obvious that more severe demands are made upon methods of cleaning the collector, disposal of collected material, and servicing practices. Low voltage cleaners for industrial loadings to date do not have sufficient inherent dust holding capacity. One exception in the field of exhaust systems is that of the oil mist collector, which functions satisfactorily on a liquid aerosol with the conventional low voltage type (2 stage) electrostatic precipitator.

Industrial precipitators employ an assembly of parallel collector electrodes of various constructions, including corrugated plate, rod curtains, or perforated plate. Air flow is usually horizontal, although special construction may permit vertical air flow. High voltage collectors were made in the form of vertical pipes, and are used for high operating pressures and for wet collector designs where water continuously flows downward inside

the pipe walls of the collector electrode. The negative discharge electrodes or rods are accurately centered between the usual 9 in. collector electrode spacing, the latter being of positive charge. Precipitation occurs in a single stage wherein ionization and collection are carried on simultaneously throughout the unit, and depend on high potentials of 25,000 to 75,000 volts. The high voltage direct current is supplied by either mechanical or electronic rectifiers.

High efficiencies are obtained by allowing suitable time for contact in the collector zone, and by proper ratio of air flow velocity to that of transverse velocity of the negatively charged particles toward the positive charged collector plates.

Air velocities vary from 240 fpm to 480 fpm with a constant pressure drop of less than  $\frac{1}{2}$  in. water. Since the maximum efficiency is obtained with the finer particles at low concentrations, and the precipitation is not effective for large particles, inertial separators are frequently used in series with these units.

Attention should be directed to the prohibition of air recirculation to occupied spaces. High voltage cleaning equipment produces ozone and nitrogen oxides in excessive quantities. The major source of maintenance usually will be in conjunction with the high voltage rectifying equipment rather than the collector. Although usually used for elevated temperature work, unless the gases are pre-conditioned, temperatures in excess of 700 F should be avoided.

Collector electrode cleaning is accomplished by a rapping device, either electrical or pneumatic, without interrupting operation. The dry plate surfaces release the dust into hoppers below the plates. Some wet cleaning methods are also used.

Electronic precipitators require large spaces, maintenance may vary widely, and initial costs are high. Efficiency is a function of the aerosol encountered and usually ranges above 90 per cent.

### ABSORBERS, ADSORBERS, AND COMBUSTION DEVICES

One of the important problems in industrial air and gas cleaning is the removal of soluble, insoluble, or combustible gases and vapors from fluid streams before their discharge to the atmosphere. These contaminants may create problems which are distinct from the particulate removal discussed previously. It has been pointed out that scrubbers and other wet collectors may remove gases and particulate matter from contaminated air streams. However, the units described are intended primarily for particulate removal with the exception of the spray or packed towers or wet cell devices.

Absorption devices are intended primarily for the removal of readily soluble gases which can be removed by simple absorbing agents such as water or alkali; for example, the removal of hydrochloric acid gas by a caustic spray.

Adsorption apparatus is intended primarily for removal of organic vapors in either high concentration (solvent recovery) or low concentration (odor removal). The first process is usually carried on as a matter of economic recovery. In the second process, the concentration of the contaminant must be low enough so that the adsorbent will have a reasonable life before replacement or reactivation.

Combustion, either total or catalytic, may be used to destroy organic

compounds, either gaseous or particulate, which create odor problems. The use of catalysts to reduce the temperature needed for combustion is comparatively recent in this field. In some instances the heat of combustion may be recovered for utilization. The temperature necessary for destruction of compounds varies with the nature of the contaminant. However, partial combustion may alter the compound to render it innocuous. The temperature required for complete destruction is usually above 1100 F. Catalysts may only require heating to 500 F or may operate without heating if the gas temperature is above 500 F.

#### Absorbers

These may consist of spray chambers, packed towers, or wet cell washers through which an absorbing agent is recirculated. The gases collected may be converted to insoluble salts or usable acids and other compounds. The performance of these devices depends upon several factors such as the solubility of the gas, its vapor pressure, its rate of reaction with the absorbent, the velocity through the collector, area of the absorbing surface either as spray droplets or wetted media. These are generally designed for the specific purpose intended. They usually are intended to collect over 95 percent of the contaminant. Resistance depends upon the particular design and ranges from 1 to 10 in. of water in most installations. Their resistance during their operating interval is constant unless serious plugging of packing occurs. Spray units are seldom affected by plugging. Packed absorption devices require a precleaner to remove particulates if long trouble-free service is desired. Maintenance of spray nozzles is a function of the degree of atomization used and of conditions encountered, such as purity of spray liquids.

Protection against corrosion and freezing may be necessary and disposal of waste liquids may create secondary problems.

#### Adsorbers

These units consist of a chamber filled with a granular adsorbent. The adsorbent may be activated charcoal, silica gel, alumina and other treated solids. Activated charcoal is the most common and has the highest retention per unit weight for organic solvents. Performance of adsorbent beds depends upon their thickness, velocity of the gas passing, mesh size (surface area) of adsorbent and temperature of the vapor being removed. They can be designed to obtain almost complete removal of organic vapors and some inorganic gases. They may be reactivated by the use of steam or heat. Resistance depends upon the adsorbent mesh size, depth and velocity. It may range from less than one inch of water to several inches of mercury.

Adsorbent beds are usually limited, because of their cost, to applications where recovery may be economically feasible. Removal of particulate matter by use of precleaners is necessary if significant loadings are involved as the adsorbent voids are readily plugged. They are not suitable for high temperature conditions. Silica gel and alumina exhibit a strong preference for water vapor whereas charcoal does not.

#### Combustion Devices

This group of industrial air cleaners entails the use of high temperatures or catalysis combined with some elevation in temperature to destroy or decompose organic and some inorganic gases which create obnoxious odors.

The devices are divided into those in which combustion is obtained by use of liquid or gaseous fuels and the secondary air for combustion is provided by the contaminated air. In essence, the simplest form involves passing the contaminated air through the combustion chamber of a boiler or fire box. Special fire boxes or brick checkerwork may also be employed. Catalytic devices consist of noble metal packed into frames in the form of ribbons or screens or may be ceramic granules coated with noble metal catalysts. The frames or packing are placed in a housing over which the gas stream to be decontaminated is passed. The contaminants break down and are reduced to elemental gases of an innocuous nature. Catalysts reduce the amount of heat necessary but may become contaminated by sulfur or other elements.

The performance of a combustion device is dependent upon the retention period of the contaminant in the high temperature zone. Removal or destruction is thus dependent on velocity and surface area of the heat transfer device. If properly designed, obnoxious odors are removed.

The resistance of the direct combustion unit is negligible since it is an integral part of the fuel combustion system. Catalytic devices behave in a manner comparable to packed beds or filters except that they are not plugged by organic particulates but may be affected by inorganic solids.

Maintenance of these types of units is essentially dependent upon the contaminants encountered. The direct combustion system requires little care other than that required by ordinary fuel burning equipment. Catalytic units become contaminated slowly and will require removal for reactivation at certain intervals depending upon the application.

Economic factors may limit the use of direct combustion methods unless there is a demand for the heat generated. They may best be applied to processes employing combustion. Catalytic units require temperatures of at least 500 F and consequently it may be necessary to preheat the contaminated air to this value.

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## CHAPTER 35

### SPRAY APPARATUS

Air Washers, Humidification with Air Washers, Dehumidification and Cooling with Air Washers, Well and Water Main Temperatures, Apparatus for Direct Humidification, Unit Humidifiers, Water-Cooling Towers, Water Use and Conservation, Rivers and Lakes, Spray Cooling Ponds, Atmospheric and Mechanical Draft Cooling Towers, Mechanics of Atmospheric Water-Cooling, Design Conditions, Water-Cooling Tower Design, Selection of Water-Cooling Towers, Operation and Maintenance

AIR humidification is effected by the vaporization of water, and always requires heat from some source. This heat may be added to the water prior to the time vaporization occurs, or it may be secured by a transformation of sensible heat of the air being humidified to latent heat as the vapor is added to the air. The thermodynamics of the process are discussed in Chapter 3. The removal of moisture from air may, or may not, involve the removal of heat from the air-vapor mixture. With spray equipment, dehumidification of air always necessitates the removal of heat.

#### AIR WASHERS

An air washer consists essentially of a chamber or casing in which is provided a spray nozzle system, a tank at the bottom of the chamber for collecting the spray water as it falls, and an eliminator section at the leaving end of the chamber for removal of drops of entrained moisture from the delivered air. Air is drawn through the casing of the washer, where it comes into intimate contact with the spray water. A heat transfer takes place between the air and water, resulting in either humidification or dehumidification of the air, depending upon the method of operation and the relative temperatures of air and spray water.

To prevent backlash of spray ahead of the washer chamber, and to aid in more uniform air distribution, inlet diffusion plates or eliminator baffles, where necessary, are provided in the air entrance end of the air washer. Inlet diffusion plates are used when the air flow and water spray are in the same direction; eliminator baffles of special design are used where one or more of the water sprays opposes the air flow. At the outlet end of the washer suitable flooded eliminator plates are used. These plates, for the removal of entrained moisture, usually cause four to six changes in direction of the air flow.

Figs. 1 and 2 show the essential construction features of conventional air washers. Intimate contact between the air and the water is secured (1) by breaking the water into fine drops; (2) by passing the air over surfaces continuously wetted by water; or (3) by a combination of the two.

The wetted surfaces in an air washer may be of fiber glass, metal or scrubber plate construction. Scrubber plate types of washers are generally used to wash reclaimable products from the air, and are composed of several baffle type plates located across the air stream. Water is supplied at the top of the washer to spray over these plates. In the case of the fiber glass or metal surfaces, the water spray is usually rather coarse and at

low pressure. In many cases these sprays are set at an angle with the air flow. Air washers of this type not only perform necessary heat transfer functions, but also are effective removers of dust and dirt from the air stream.

Essential requirements in the air washer operation are: uniform distribution of the air across the chamber section; moderate air velocity of from 250 to 600 fpm in the washer chamber; an adequate amount of spray water broken up into fine droplets throughout the air stream, at pressures of from 15 to 30 psig; sufficient length of travel through the water

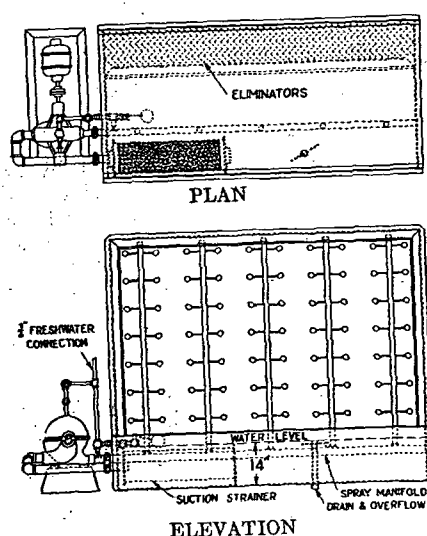


FIG. 1. TYPICAL SINGLE-BANK AIR WASHER

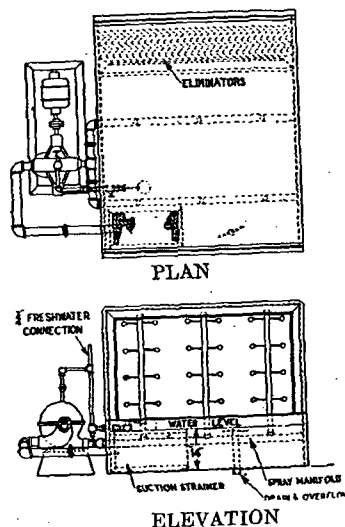


FIG. 2. TYPICAL TWO-BANK AIR WASHER

spray and wetted surfaces; and the elimination of entrained moisture from the outlet air.

Expected performances, physical size, length, number of sprays, etc., vary greatly, depending upon the functions of the installation. In general, the width and height of an air washer are dictated by the space available. Washers of nearly equal height and width are desirable from an air flow and economic standpoint, although not necessary. The length of washers varies considerably. A space of approximately 2½ ft between spray banks is used, and the first and last banks of sprays are located about 1 ft to 1½ ft from the entering or leaving end of the washer. In addition, air washers are very often furnished with cooling coils or heating coils within the washer chamber, and the use of these coils affects the overall length of the washer.

Where increase of overall heat transfer between the air and water is required, multistage washers are used. These washers are equivalent to a number of washers in series, and the water is often pumped from one stage to the other where conditions permit.

The resistance to air flow through an air washer varies with the type of eliminator and wetted surfaces, number of banks of spray and their

direction, air velocity, size and type of other resistances such as cooling and heating coils, and other factors such as air density. Resistances vary from as low as ¼ in. to higher than 1 in. water column, and it is therefore necessary that the manufacturer be consulted in regard to the resistance of any particular washer design involved.

### HUMIDIFICATION WITH AIR WASHERS

Air humidification can be accomplished in three ways with an air washer. These are: (1) use of recirculated spray water without prior treatment of the air; (2) preheating the air and washing it with recirculated spray water; and (3) using heated spray water. In any air washing installation the air should not enter the washer with a dry-bulb temperature less than 35 F in order to eliminate danger of freezing the spray water.

*Method 1.* Except for the small amount of energy added from outside by the recirculating pump in the form of shaft work, and for the small amount of heat leak from outside into the apparatus, including the pump and its connecting piping, the process would be strictly adiabatic. Evaporation from the liquid spray would therefore be expected to bring the air immediately in contact with it to saturation adiabatically; and, since the liquid is recirculated, its temperature would be expected to adjust to the thermodynamic wet-bulb temperature of the entering air.

It does not follow from the foregoing reasoning that the whole air stream is brought to complete saturation, but merely that its state point should move along a line of constant thermodynamic wet-bulb temperature as explained in Chapter 3. The extent to which the final temperature approaches the thermodynamic wet-bulb temperature of the entering air, or the extent to which complete saturation is approached, is conveniently expressed by a ratio known as *humidifying effectiveness* or *saturating effectiveness*, and is defined as

$$e_h = \frac{t_1 - t_2}{t_1 - t'} \quad (1)$$

where

$e_h$  = humidifying effectiveness, percent.

$t_1$  = dry-bulb temperature of the entering air, Fahrenheit degrees.

$t_2$  = dry-bulb temperature of the leaving air, Fahrenheit degrees.

$t'$  = thermodynamic wet-bulb temperature of the entering air, Fahrenheit degrees.

The following may be taken as representative humidifying or saturating effectiveness of an air washer for the conditions stated:

|                                          |               |
|------------------------------------------|---------------|
| 1 bank—downstream.....                   | 60-70 percent |
| 1 bank—upstream.....                     | 65-75 percent |
| 2 banks—downstream.....                  | 85-90 percent |
| 2 banks—1 upstream and 1 downstream..... | 90-95 percent |
| 2 banks—upstream.....                    | 90-95 percent |

The humidifying or saturating effectiveness of a washer is dependent upon the essential items of design mentioned under Air Washers. Other conditions being the same, low velocity of air flow is more conducive to higher humidification effectiveness.

*Method 2.* The preheating of the air increases both the dry- and wet-bulb temperatures, lowers the relative humidity, but does not alter the humidity ratio (pound water vapor per pound dry air). At a higher wet-

TABLE 1. AVERAGE MAXIMUM WATER MAIN TEMPERATURES\*

| STATE  | CITY           | TEMP. F. | STATE | CITY           | TEMP. F. | STATE         | CITY           | TEMP. F. |
|--------|----------------|----------|-------|----------------|----------|---------------|----------------|----------|
| Ala.   | Birmingham     | 84       | Mass. | Boston         | 80       | Ore.          | Tulsa          | 88       |
| Ark.   | Mobile         | 80       |       | Cambridge      | 70       |               | Eugene         | 60       |
| Ariz.  | Little Rock    | 83       |       | Fall River     | 76       |               | Portland       | 65       |
|        | Phoenix        | 82       |       | Lowell         | 50       | Pa.           | Altoona        | 74       |
| Calif. | Pasadena       | 80       |       | Lynn           | 68       |               | Erie           | 75       |
|        | Anaheim        | 60       |       | New Bedford    | 70       |               | Johnstown      | 74       |
|        | Berkeley       | 69       |       | Salem          | 68       |               | McKeesport     | 82       |
|        | Fresno         | 80       |       | Worcester      | 77       |               | Philadelphia   | 85       |
|        | Fullerton      | 75       | Mich. | Detroit        | 70       | R. I.         | Pittsburgh     | 86       |
|        | Glendale       | 68       |       | Grand Rapids   | 84       | S. C.         | Providence     | 68       |
|        | Los Angeles    | 80       |       | Highland Park  | 77       |               | Charleston     | 83       |
|        | Oakland        | 70       |       | Jackson        | 56       |               | Greenville     | 81       |
|        | Pasadena       | 82       |       | Kalamazoo      | 53       | S. D.         | Spartanburg    | 78       |
|        | Pomona         | 75       |       | Lansing        | 64       | Tenn.         | Rapid City     | 65       |
|        | Riverside      | 78       |       | Saginaw        | 62       |               | Chattanooga    | 84       |
|        | Sacramento     | 72       | Minn. | Duluth         | 55       |               | Knoxville      | 90       |
|        | San Bernardino | 65       |       | Minneapolis    | 85       |               | Memphis        | 85       |
|        | San Diego      | 84       |       | St. Paul       | 80       |               | Nashville      | 90       |
|        | San Francisco  | 71       | Mo.   | Jefferson City | 82       | Texas         | Amarillo       | 70       |
|        | Whittier       | 75       |       | Kansas City    | 84       |               | Austin         | 90       |
| Colo.  | Denver         | 75       |       | Springfield    | 82       |               | Beaumont       | 86       |
| Conn.  | Bridgeport     | 66       |       | St. Joseph     | 84       |               | Dallas         | 88       |
|        | Hartford       | 73       |       | St. Louis      | 85       |               | El Paso        | 85       |
|        | New Haven      | 76       |       | Springfield    | 74       |               | Fort Worth     | 85       |
|        | Waterbury      | 72       | Nebr. | Lincoln        | 70       |               | Galveston      | 90       |
| D. C.  | Washington     | 84       |       | Omaha          | 85       |               | Houston        | 83       |
| Del.   | Wilmington     | 83       |       | Reno           | 70       |               | Port Arthur    | 83       |
| Fla.   | Jacksonville   | 86       | Nev.  | Manchester     | 76       |               | San Antonio    | 78       |
|        | Miami          | 82       | N. H. | Jersey City    | 63       |               | Wichita Falls  | 85       |
|        | Tampa          | 77       | N. J. | Newark         | 75       | Utah          | Logan          | 44       |
| Ga.    | Atlanta        | 85       |       | Paterson       | 78       |               | Salt Lake City | 55       |
|        | Macon          | 80       |       | Trenton        | 79       | Va.           | Fredericksburg | 73       |
| Idaho  | Boise          | 60       |       | Albany         | 68       |               | Lynchburg      | 73       |
| Ill.   | Chicago        | 78       | N. Y. | Buffalo        | 78       |               | Norfolk        | 80       |
|        | Cicero         | 76       |       | Jamaica        | 56       | Wash.         | Richmond       | 85       |
|        | Evanston       | 73       |       | Mt. Vernon     | 74       |               | Olympia        | 58       |
|        | Moline         | 83       |       | New Rochelle   | 75       |               | Seattle        | 62       |
|        | Peoria         | 67       |       | New York       | 72       |               | Spokane        | 51       |
|        | Rockford       | 82       |       | Rochester      | 70       | W. Va.        | Tacoma         | 57       |
|        | Springfield    | 88       |       | Schenectady    | 60       |               | Charleston     | 78       |
| Ind.   | Evansville     | 75       |       | Syracuse       | 74       |               | Huntington     | 78       |
|        | Gary           | 84       |       | Utica          | 69       | Wis.          | Wheeling       | 54       |
|        | Indianapolis   | 84       |       | Yonkers        | 70       |               | LaCrosse       | 58       |
|        | South Bend     | 61       | N. C. | Asheville      | 74       |               | Madison        | 58       |
|        | Terre Haute    | 82       |       | Charlotte      | 85       |               | Milwaukee      | 75       |
| Iowa   | Cedar Rapids   | 78       |       | Raleigh        | 92       |               | Racine         | 68       |
|        | Des Moines     | 77       |       | Winston-Salem  | 82       |               |                |          |
|        | Sioux City     | 67       | N. M. | Albuquerque    | 65       | PROV-<br>INCE |                |          |
| Kans.  | Concordia      | 86       | Ohio  | Akron          | 76       |               |                |          |
|        | Kansas City    | 88       |       | Canton         | 50       |               |                |          |
|        | Topeka         | 88       |       | Cincinnati     | 84       | Alta.         | Calgary        | 64       |
|        | Wichita        | 72       |       | Cleveland      | 77       | B. C.         | Vancouver      | 80       |
| Ky.    | Louisville     | 85       |       | Columbus       | 84       |               | London         | 50       |
| La.    | Baton Rouge    | 85       |       | Dayton         | 60       | Ont.          | Toronto        | 63       |
|        | New Orleans    | 90       |       | Lakewood       | 82       |               | Charlottetown  | 48       |
|        | Shreveport     | 88       |       | Springfield    | 72       | P.E.I.        | Montreal       | 78       |
| Me.    | Augusta        | 60       |       | Toledo         | 83       | Que.          | Quebec         | 68       |
| Md.    | Baltimore      | 75       | Okla. | Oklahoma City  | 82       |               |                |          |

\* These averages taken from various city water main locations, with some actual values slightly higher and some lower than values shown. Some values were supplied by H. E. Degler, Marley Company. Some were obtained from City Water Department records. The highest values given by the various authorities are usually those listed.

bulb temperature, but the same humidity ratio, more water can be absorbed per pound of dry air in passing through the washer, assuming that the humidifying effectiveness of the washer is not adversely affected by operation at the higher wet-bulb temperature. The analysis of the process occurring in the washer itself is the same as that explained under Method 1. The final desired conditions are secured by adjusting the amount of preheating to give the required wet-bulb temperature at entrance to the washer.

Method 3. Even if heat is added to the spray water, the mixing occurring in the washer itself may still be regarded as adiabatic. The state

point of the mixture should move in a direction determined by the specific enthalpy of the heated spray as explained in Chapter 3. It is possible, by elevating the water temperature, to raise the air temperature, both dry-bulb and wet-bulb, above the dry-bulb temperature of the entering air.

In each of the methods, 1, 2 or 3, the air leaving the air washer may require reheating to produce in the conditioned space the required dry-bulb temperature and relative humidity.

### DEHUMIDIFICATION AND COOLING WITH AIR WASHERS

Cooling of the wet-bulb temperature of an air vapor mixture can be accomplished by an air washer if the temperature of the spray water is lower than the wet-bulb temperature of the air. Moisture removal is obtained when the spray water temperature is lower than the dew-point of the entering air. In these cases the final dry-bulb temperature and relative humidity of the leaving air are dependent upon the design factors of the air washer.

Both sensible and latent heat are removed in the process of dehumidification by cold spray water. Abstraction of sensible heat occurs during the entire time that the air is in contact with the spray medium. Latent heat removal takes place as condensation occurs. Therefore, the lower the spray temperature, the greater the amount of moisture removal per pound of dry air, all other conditions remaining the same.

Washers with two or more banks of spray are usually selected for dehumidifying installations, whether for comfort or industrial installations. Generally such air washers cool the air to within one or two degrees (Fahrenheit) of the leaving spray water temperature; this differential will increase somewhat when the difference between the entering wet-bulb and leaving dew-point is relatively large.

Where a limited supply of cold water is available, multiple stage washers may be used to great advantage. In such washers the cool water is pumped through the multiple spray systems in series and counterflow to the air flow. Such an arrangement brings the delivery air in contact with the coldest water, securing a maximum amount of cooling and saving water.

When using cold well water or water from city water mains, care should be used to secure accurate data on the water temperatures. Table 1 lists some approximate water main averages which may be used as a guide, but they should be verified from local records. This is particularly true with city water main temperatures. In the case of well water temperatures, Fig. 3 shows the approximate temperatures of water to be expected from wells at depths of 30 to 60 ft.

Air washers for dehumidifying and cooling usually have separate recirculating pumps. These pumps deliver a mixture of cold and recirculated water under the control of a three-way valve. The valve may be actuated either by a thermostat in the washer outlet, or by a humidity or other controller in the space being conditioned.

Air washers for dehumidifying are very often furnished with direct expansion or water cooling coils within the washer space, in which case water for the washer sprays is entirely recirculated.

### APPARATUS FOR DIRECT HUMIDIFICATION

Humidifiers may be divided into two general types which are, according to the method of operation: (1) indirect, such as the air washer, which

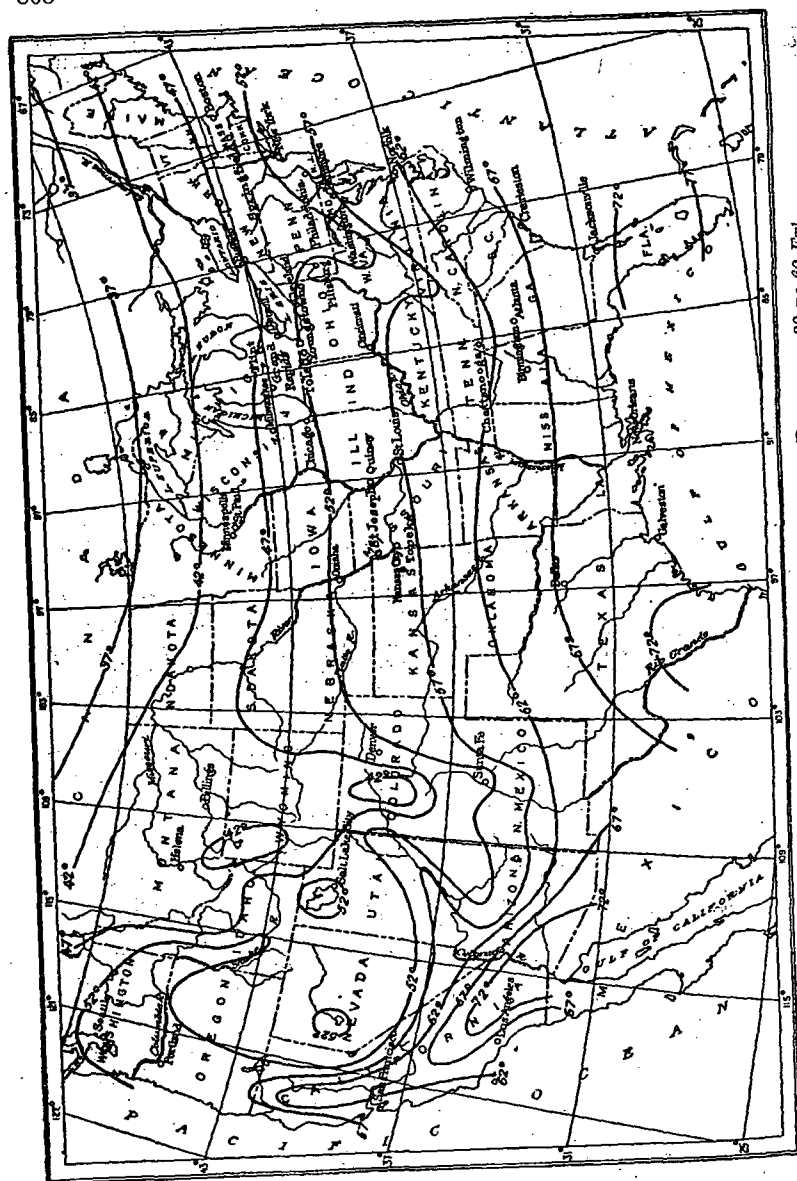


FIG. 3. APPROXIMATE WELL WATER TEMPERATURES AT DEPTHS OF 30 TO 60 FT.

introduces moistened air; and (2) direct, which sprays moisture into the room or introduces moisture by means of steam jets.

As in the cases of humidification by use of an air washer, the heat necessary for the vaporization of the moisture added to the air by direct humidification is secured either from heat stored in the spray water or by a trans-

formation of sensible to latent heat in the air humidified. In the latter case, the enthalpy of the air remains constant, but the dry-bulb temperature of the air is reduced.

Direct humidification is usually preferable where high relative humidities must be maintained, but where there is little cooling or ventilation required. In comfort air conditioning, where both humidification and ventilation are required, the indirect humidifier is preferable. In industrial applications, where the cooling or ventilation load is large and where very high relative humidities must be maintained, a combined system employing both direct and indirect humidifiers is sometimes used.

### Spray Generation

Spray generation is obtained by (1) atomization, (2) impact, (3) hydraulic separation, and (4) mechanical separation.

*Atomization* involves the use of a compressed air jet to reduce the water particles to a fine spray. With the *impact* method, a jet of water under pressure impinges directly on the end of a small round wire. Where *hydraulic separation* is employed, a jet of water enters a cylindrical chamber and escapes through an axial port with a rapid rotation which causes it immediately to separate in a fine cone-shaped spray. In the *mechanical separation* process, water is thrown by centrifugal force from the surface of a rapidly revolving disc and separates into particles sufficiently small to be utilized in certain types of mechanical humidifiers.

### Spray Distribution

Spray distribution is obtained by (1) air jet, (2) induction, and (3) fan propulsion.

The air jet which generates the spray in atomizers also carries the spray through a space sufficient for its distribution and evaporation, and this method of distribution is termed *air jet*. Where distribution is obtained by *induction*, the aspirating effect of an impact or centrifugal spray jet is utilized to induce a current of air to flow through a duct or casing, and this air current distributes the spray. *Fan propulsion* obviously consists of the utilization of fans to entrain and distribute the spray.

Industrial type direct humidifiers are commonly classified as (1) atomizing, (2) high-duty, (3) spray and (4) self-contained or centrifugal.

*Atomizing Humidifiers.* Several types of atomizing humidifiers employ nozzles placed within the room and rely upon compressed air to effect complete atomization of the water which is converted to vapor by the heat of the room air. Some of these nozzles depend upon an aspirating effect to draw the water into the nozzle and atomize it; others operate on a combined air and water pressure. It is usual for nozzles of the water pressure type to be controlled by a diaphragm valve actuated by the pressure of the atomizing air.

*High-Duty Humidifiers.* Water is supplied under high pressure (usually about 150 psi) through pipe lines from a centrally-located pumping unit. The spray-generating nozzle, which is of the impact type, is located in a cylindrical casing. A drainage pan provides for the collection and return of unevaporated water which flows through a return pipe to a filter tank, from which it is recirculated. A powerful air current is forced through the humidifier by means of a fan mounted above the unit.

The air enters from above, is drawn through the head, charged with moisture, and cooled. It then escapes from the opening below at a high



velocity in a complete and nearly horizontal circle. The spray is evaporated and the resulting vapor diffused. This distribution of fine spray over the maximum possible area promotes complete and rapid vaporization.

**Spray Humidifiers.** This type consists of an impact spray nozzle in a cylindrical casing with a drainage pan below it. The aspirating effect of the nozzle induces a moderate air current through the casing which distributes the entrained spray. The general method of circulating and returning the water is similar to that employed for high-duty humidifiers. A suitable pump and centrally-located filter tank are required.

**Self-Contained Humidifiers.** The self-contained or centrifugal humidifier has the ability to generate and distribute spray without the use of air compressors, pumps, or other auxiliaries. These may be used either singly or in groups. In large installations, where suitable connections are provided to permit the cleaning and servicing of individual units without affecting the room as a whole, group control of the water and power may be employed.

### UNIT HUMIDIFIERS

The term *unit humidifier* denotes an assembly of elements the principal function of which is to humidify. The essential element of a unit humidifier is an atomizer or evaporator. To this may be added a fan, a heater, outlet vanes or diffusers, and a housing to enclose the various parts.

Unit humidifiers fall into four general classifications, depending on the method of causing evaporation. These are as follows: (1) *Nozzle Type*, (2) *Rotary Type*, (3) *Cascade Type*, and (4) *Heater Type*.

In the *nozzle type* of humidifier water is sprayed into the air and evaporation is effected by adiabatic exchange of energy. Units of this type in simplest form, spray a fine mist of water directly into the air in a space. They are used to a great extent in the textile industry.

In the *rotary type* of humidifier the spray is created by rotating vanes or discs which throw the water by centrifugal force, and in so doing break it up into a fine mist. In all other respects, this type of humidifier is similar to the nozzle type. It has the advantage over the nozzle type of being less liable to become clogged.

In the *cascade type* the humidification takes place by water falling in sheets over a series of baffles or trays. This type is usually furnished with a fan, air heater, and air filter all enclosed in a housing.

In the *heater type* of humidifier the water is heated either to the boiling point or to a temperature at which the water vapor readily passes into the air stream. There are many variations of this type of humidifier. In the simplest form the heating element using steam, hot water, gas, oil, or electricity is placed in a pan or vessel of water, and the vapor passes from the surface of the water to the stream of air.

A modification of this type of humidifier is the combination of spray nozzle and heater type in which the water is sprayed over a hot surface and evaporated. It has the disadvantage of accumulating scale on the surfaces of the vessel or heating surface.

### WATER-COOLING TOWERS

The removal and dissipation of heat from a compressed refrigerant or from exhaust steam are important factors in the efficient operation of a refrigerating plant or an electric steam-generating station. This heat removal is generally accomplished by first transferring the heat of the gas

to cooling water in a heat exchanger. The water, if cheap or plentiful, may be wasted to the nearest sewer or open waterway, such as a river or lake. Where water usage is restricted or expensive, or where the available water contains dissolved salts which would form scale on the heat-exchange apparatus, it is necessary to recirculate the water, and to cool it, after each passage through the heat-exchanger, by contact with moving air in some type of water-cooling apparatus.

### Water Use and Conservation

Many communities have found that present water systems are not sufficiently large to satisfy the increasing demands of domestic and industrial users. The reasons for such shortages are primarily: (a) inadequate purification and water-distribution systems; (b) inadequate sanitary and storm-sewer disposal systems; or (c) inadequate sources of water.

Even when an adequate supply of water is available from the water mains or private wells, many cities do not have sufficient sanitary or storm sewer facilities to handle increasing demands. The sanitary systems are usually limited because of the capacity of the filtration plants, and therefore many cities restrict the use of the sanitary system to sewage.

### Rivers and Lakes

Until the year 1920, large generating stations were usually located on the banks of rivers, lakes, or artificial ponds. The removal and dissipation of the heat from the Diesel cylinder or the exhaust steam of a turbine was accomplished by taking in the circulating water at a considerable distance from the discharge, thus preventing mixing of the heated discharge with the inlet water. The use of water from streams for this purpose has the following disadvantages: the site may be far removed from the fuel source or from power consumers; water supply may limit plant expansion; municipal restrictions on use of water may hamper operation; costly intake structures with screens and sediment basins may be required; drastic flood or drouth conditions, the vagaries of most rivers, upstream pollution, scale-forming constituents, debris, sand, algae, and formation of troublesome ice may cause operating difficulties.

When lakes and cooling ponds have been used as a source of circulating water, the hot water is discharged close to the surface at the shore line. Natural air movement over the surface of the water causes evaporation over that area, thus carrying the heat away at a rate of about 4 Btu per (hr) (sq ft) (F deg temp difference between air and water). Increased density of the water due to loss of heat, causes the cooled water to sink to the bottom of the pond. The suction connection is therefore located as far below the surface as possible, and at as great a distance from the discharge as practicable. The area required by such cooling ponds is about 50 times that of a spray pond, or about 1000 times that of a water-cooling tower to dissipate the same quantity of heat and achieve equal operating costs. If the surfaces of such ponds were below the level of surrounding terrain, and the shore were wind-sheltered by trees or other vegetation, so that natural air movement across the surface of the water would be retarded, the use of a spray pond or water-cooling tower would be indicated.

### SPRAY COOLING PONDS

The spray pond consists of a water collecting basin, above which spray nozzles are located in an arrangement such as shown in Fig. 4 to spray



the water upwards into the air. Properly designed spray nozzles break the water into small drops, but not into a mist. Since the objective is to cool the pond water, the individual drops must be heavy enough to fall back into the pond and must not float away in the air. The water surface exposed to the air passing over the pond becomes the integrated area of all the small drops. The spray pond requires about one-fiftieth of the space required by the cooling pond to dissipate the same quantity of heat with equal results, due to four factors: (1) the speed with which the drops are propelled into the air and fall back into the water basin; (2) the increased wind velocity at a point above the surrounding obstruction; (3) the increased volume of air delivery due to the greater vertical cross-section of air permissible; and (4) the vastly increased area of contact between water and air.<sup>2</sup>

Spray pond effectiveness is increased by: (1) elevating the nozzles to a higher point above the surface of the water in the basin; (2) increasing the spacing between nozzles of any one capacity; (3) using smaller capacity

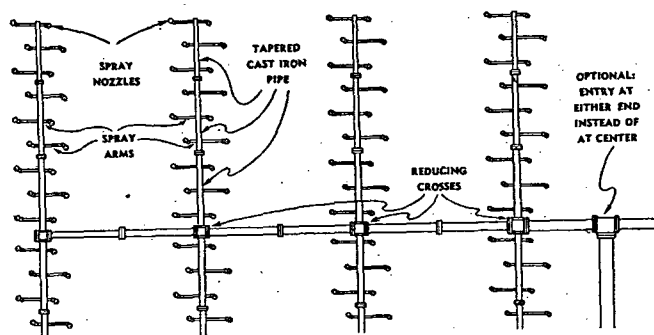


FIG. 4. TYPICAL NOZZLE ARRANGEMENT FOR A SPRAY POND

nozzles to decrease the concentration of water per unit area; and (4) using smaller nozzles and increasing the pressure to maintain the same concentration of water per unit area.

It is usual practice to locate the nozzles from 5 to 12 feet above the surface of the water (dependent also upon depth of water and curb level) with water supply at 5 to 7 psig pressure at the nozzles. Nozzles spray from 25 to 60 gpm each, and the nozzles are spaced so that the average water delivered to the surface varies from 0.1 gpm (small ponds) to 0.4 gpm (large ponds) per square foot. See Table 2 for additional spray pond design data. Best results are obtained by placing the nozzles in a long, relatively narrow area, located broadside to the wind.

Louver fences, to prevent the carrying of entrained water beyond the edge of a spray pond by the air on the leeward side, are required for all roof locations and for ground locations where space is restricted; the outer nozzles should be located at least 20 ft from the edge of the basin. Such fences up to 12 ft in height usually are constructed of horizontal overlapping louvers supported between vertical posts. The air, in passing between these louvers, tends to be freed of the larger drops of water. The louvers

also restrict the flow of air, particularly at the higher wind velocities, thus reducing the possibility of water being carried from the spray cloud. The height of an effective fence should be equal to the height of the spray cloud. Algae formations may be a nuisance in a spray pond. Such growths are minimized by the periodic addition of bromine, chlorine, chlorinated lime, copper sulfate, or various blends of chlorophenates (see Chapter 43).

The performance of a spray pond is limited because of space requirements and the probable high cost of piping and pumping. Water-cooling towers, however, allow the designer a wider range of performance within a given space because of the possibility of altering the smaller physical dimensions or varying the water concentration, measured in gallons per (minute) (square foot of tower area). In most cooling towers the water is broken up into drops many times, whereas with the spray pond it is broken up only once and, consequently, in the latter the rate of cooling diminishes rapidly as the temperature of the surface of the drop approaches the wet-bulb temperature of the ambient air.

TABLE 2. SPRAY POND DESIGN DATA  
Conventional Up-Spray System

|                                          | UNITS | STANDARD | MINIMUM | MAXIMUM |
|------------------------------------------|-------|----------|---------|---------|
| Water capacity per nozzle                | gpm   | 35 to 50 | 25      | 60      |
| Nozzles per 12 ft length of pipe         |       | 6        | 4       | 6       |
| Height of nozzles above water level      | ft    | 6        | 5       | 12      |
| Nozzle pressure                          | psig  | 6        | 5       | 7       |
| Size of nozzles and nozzle arms          | in.   | 2        | 1½      | 2       |
| Distance between spray lateral piping    | ft    | 25       | 13      | 38      |
| Distance nozzles from pond side unfenced | ft    | 25 to 35 | 20      | 50      |
| Distance nozzles from pond side fenced   | ft    | 15 to 20 | 15      | 25      |
| Height of louver fence                   | ft    | 12       | 12      | 12      |
| Depth pond basin                         | ft    | 4 to 5   | 2       | —       |
| Friction loss allowed per 100 ft pipe    | ft    | 1 to 3   | —       | —       |
| Design wind velocity                     | mph   | 5        | 3       | —       |

### ATMOSPHERIC COOLING TOWERS

*Spray-filled atmospheric cooling towers* are used for open-area installations because of their dependence upon the velocity and direction of the wind. Operation is not so limited as with spray ponds, but the design is generally based on a 3 mph wind, and the performance falls off rapidly as the ambient air velocity decreases. These towers require less basin area, less piping, and no more mechanical equipment than spray ponds, but these savings may be largely offset by the extra cost of the structure. The drift nuisance is similar to that of spray ponds. The word *tower* used in this connection is a misnomer, as the design simulates a narrow spray pond with length twice the width, or more, having elevated nozzles and a high louver fence. As usually built, the nozzles spray downward from the top of the structure, and the distance from the center of the nozzle system to the louvers on either side is not more than half the distance that the nozzles are elevated above the water-collecting basin. Heights range from 6 to 15 ft, with the total width of the structure usually not greater than the height. Loadings range from 0.6 to 1.5 gpm per sq ft of tower area, and hence require about one-fourth the area of an equivalent spray pond. As the louvers are wetted continuously, they add to the surface of water exposed to the cooling air. The spray-filled atmospheric tower is shown in Fig. 5.

Much of the atmospheric water cooling for refrigeration work during the past 30 years has been done with natural-draft deck type towers, also referred to as *atmospheric deck towers*, see Fig. 6. These towers consist of a sturdy wooden or steel frame 20 to 50 ft high and 8 to 16 ft wide, carrying open horizontal wooden latticework or *decks* at regular intervals from top to bottom. The hot water is distributed over the upper part of the structure by means of troughs, splash heads, or nozzles, and drops from deck to deck enroute to the basin. The purpose of the decks is primarily to arrest the fall of the water, to break and re-break it into drops so as to present the most efficient cooling surface to the air which is passing through the tower transversely to the decks. The wooden decks also add to the area of water surface exposed to the air, but since they offer resistance

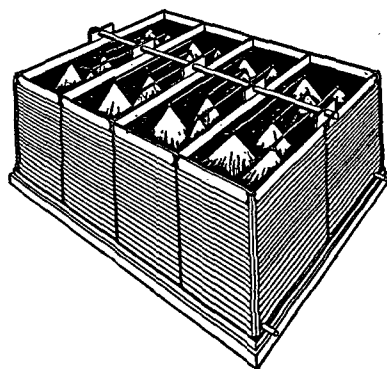


FIG. 5. SPRAY FILLED ATMOSPHERIC COOLING TOWER

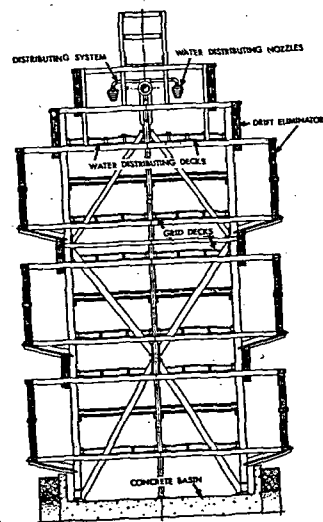


FIG. 6. ATMOSPHERIC DECK TOWER

to the flow of air, the number and arrangement of the decks depend upon basic tests and operating experience.

To prevent loss of water on the leeward side of the tower, wide louvers (drift eliminators) are attached at regular intervals from top to bottom; these louvers extend outward and upward at an angle of 45 to 50 deg. In most designs the top edge of each louver extends above the bottom edge of the one above. These louvers serve the same function as a louver fence around a spray pond, namely, to stop the water drops carried by the air beyond the open area of the tower, and to control the quantity of air permitted to pass through the tower.

The efficiency of a deck tower is improved primarily by increasing length or height, or both, within limits; the length and height increase the area of tower exposed to the wind. The improvement is not directly proportional to the change made in either case. Neither does a certain percentage

change of one dimension make an equal improvement in efficiency on two equal towers of different original lengths or heights. Since the range of efficiency varies through wide limits, it is impracticable to attempt to list data here on the area required per unit quantity of water. Improved efficiency, due to added height, is obtained at the expense of additional pumping head and increased weight per unit of area, whereas improvement gained by greater length or width will increase the area and, consequently, the foundation required.

Drift loss in a properly designed deck tower is considerably less than in the spray pond, but the drift nuisance may be considerable, and for this reason atmospheric deck towers are unsuitable for downtown building roofs, locations adjacent to buildings, or near expensive mechanical equipment in industrial plants. They must be located in an open area, broadside to the prevailing wind. They are inefficient with less than 3 mph wind velocity and with wind directions other than broadside. These towers are long and high in proportion to width, and must be securely anchored to prevent uplift or overturning during high winds. High pumping requirements (30 to 60 ft) and total dependence upon atmospheric caprice, especially wind (quantity and direction), are disadvantages.

Due to new uses and growth of demand in recent years, requirements for water-cooling equipment have become increasingly varied and exacting, necessitating refinements and specialized adaptations. The principal demand for large water-cooling systems in recent years has come from the petroleum industry and steam power plants. Refrigeration, air conditioning, and engine-jacket cooling service today employ a large percentage of the medium sized and small water-cooling towers installed.

### MECHANICAL DRAFT TOWERS

The mechanical draft tower consists usually of a vertical shell constructed of wood, metal, transite, or masonry. Water is distributed near the top, uniformly over the area, and falls to the collecting basin in the bottom, passing through air which is being circulated in the tower from bottom to top by forced or induced draft fans, or which is circulated horizontally in crossflow towers by induced draft fans.

In vertical towers the air passes counterflow to the water and is in contact with the hottest water just before leaving the tower; hence, a given quantity of air picks up more heat than the average equal quantity of air on natural draft equipment. This permits the water to be cooled with the least quantity of air required by any type of cooling equipment. As movement of air through the towers is obtained by power-consuming fans, it is essential that this air quantity and the draft loss be reduced to a minimum so as to secure low operating cost.

The inside of a mechanical draft tower may be spray filled, *i.e.*, the water surface is presented to the air by filling the entire inside of the structure with water droplets from the spray nozzles, or it may be packed with wood filling, over which the water cascades from top to bottom. In many cases, a combination of the spray-filled and wood-filled design is used.

The *forced draft* type of tower (Fig. 7), has the advantages of being suitable for corrosive waters, and having the fan mounted near the ground level on a rigid foundation where it is easily accessible.

The heated air leaves the top of a forced draft tower at a low velocity and may be subject to *recirculation* to the fan inlet, with consequent reduc-

tion in performance. This reduction could be as much as 20 percent under certain conditions. During cold weather, recirculation may cause ice formation on adjacent equipment and buildings, as well as in the tower fan ring, with possible resultant fan breakage. Fan sizes are limited to 12 ft or less, and therefore more fans, motors, starters, and wiring are needed than for induced draft towers. Induced draft towers, since fans and motors are not visible, are therefore somewhat more adaptable to architectural treatment.

In the *spray-filled mechanical draft tower*, the area presented to the air is the combined surface area of the small drops present in the tower at any one time. The net free cross-sectional area of the air spaces in a spray-filled tower is greater than that of the wood-filled tower for the same plan area. Before discharging to the atmosphere, the water-laden exhaust air passes through a drift eliminator to remove entrained moisture. This

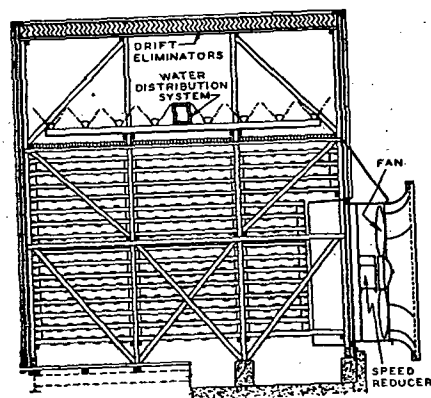


FIG. 7. FORCED DRAFT COOLING TOWER

type of tower is particularly applicable for installations in restricted areas where city ordinances require fire-proof construction.

In the wood-filled tower, lumber of various cross sections is laid horizontally across the space on as close centers, horizontally and vertically, as required, without introducing too great a resistance to air flow. The water is distributed over the top layer by means of spray nozzles, troughs, splash heads, or through evenly spaced nozzles located in the floor of an overhead open-type water distribution basin, and drops from piece to piece of the wood filling as it progresses downward. As the air moves upward or across the wood filling, the latter presents a large wetted surface, repeatedly breaks up the falling drops of water, and continuously provides new drop surfaces whose integrated areas are several times that of the wood-fill area.

The efficiency of a mechanical draft tower is improved by increasing the amount of filling, height, area, or air quantity. Increasing the height increases the length of time the air is in contact with the water, without affecting seriously the fan power required, but increases the pumping power. Increasing the area while maintaining constant fan power increases the air quantity somewhat and, because of lowered velocity, increases the time

this air is in contact with the water. The surface area of water in contact with the air is increased in both cases. Increasing the air quantity decreases the time the air is in contact with the water, but since a greater quantity of air is passing through, the average differential between the water temperature and wet-bulb temperature of the air is increased, and this speeds up the heat transfer rate. Increased air quantities are obtained only at the expense of increased fan power, which, for fans of the disc type, increases approximately as the cube of the air handled.

The performance of mechanical draft towers is independent of wind velocity; hence, it is possible to design them for more exacting performance.

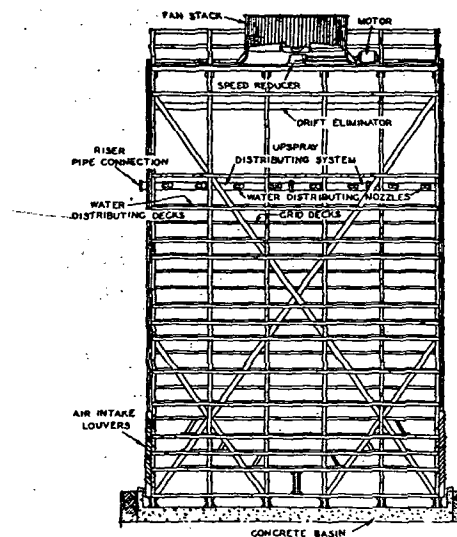


FIG. 8. COUNTERFLOW INDUCED DRAFT COOLING TOWER

They require less space and less piping than atmospheric deck towers, and the pumping head varies from 11 to 26 feet, depending upon the design. Overall plant economy, due to colder water temperature, usually more than offsets the additional operating expense and initial cost as compared with those of atmospheric towers.

The *counterflow* (conventional) type of *induced draft tower* has the fan located at the top, Fig. 8, to provide vertical air movement across the filling. Air is discharged upward at a high velocity to prevent recirculation. Another type, for small requirements, has the induced draft fan in one end (see Fig. 9) to provide horizontal flow.

Another induced draft tower, developed for the purpose of obtaining compactness, larger capacity, increased flexibility and improved performance, is the *crossflow* type. This type of tower employs multiple fans centered along the top, each fan drawing air through two cells paired to the suction chamber which is partitioned midway beneath the fans and fitted with *drift eliminators* that turn the air upward toward the fan outlet. This tower obtains a horizontal air movement as water falls in a cascade

of small drops over the filling and across the air stream with less resistance to air flow. The air travel is longer than with the conventional design.

Air velocities through mechanical draft towers vary from 250 to 400 fpm over the gross area of the structure. The air requirements are approximately 300 to 400 cfm of air per ton of mechanical refrigeration, and about 100 to 150 cfm of air per gallon of water passing through the tower. Cooling tower calculations are based upon the fact that mechanical refrigeration requires approximately 30 gallon-deg of cooling water per minute per ton of refrigeration. In atmospheric cooling towers, if 5 gpm were circulated, the water-cooling range would be 6 deg; with mechanical draft towers, 3 or 4 gpm are usually circulated for a desired water-cooling range of 10 or 7½ F. Some designs of mechanical draft towers are limited to 6 or 7 gpm per sq ft because of blanketing effect, while the capacity of the most efficient types ranges up to 9 or 10 gpm.

When an inside cooling tower is required, some adaptation of a spray filled or wood filled induced draft tower is often used, and occasionally an

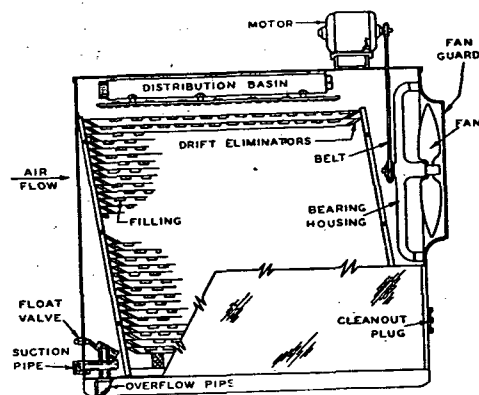


FIG. 9. SMALL HORIZONTAL INDUCED DRAFT COOLING TOWER FOR 3 TO 50-TON REFRIGERATING UNITS

air washer is converted to this service. In this type of application precautions must be taken to prevent the discharged air from short circuiting to the intake.

### MECHANICS OF ATMOSPHERIC WATER-COOLING

The heat exchange in atmospheric water-cooling equipment is accomplished partially by a transfer of sensible heat which raises the wet-bulb temperature of the moving air; but most of the cooling is due to an exchange of latent heat resulting from the evaporation of a small part of the water. If all of the water were cooled by evaporation, the rate of evaporation would be approximately one percent for each 10 deg of cooling. In practice, the loss of circulating water by evaporation will approximate 1 percent for 12 to 14 deg of actual cooling due to the additional amount of cooling by sensible heat transfer, and the rate of evaporation will vary from about 0.64 percent of the water circulated in the winter to 0.88 percent in the summer for a water-cooling range of 10 deg.

The lowest temperature to which water may be cooled in atmospheric

cooling equipment is the temperature of adiabatic saturation, which is at the wet-bulb temperature of the air. Performance is measured in terms of *approach* (5 to 10 F deg, with 7 F deg average) of the cooled water to the wet-bulb temperature of the ambient air when cooling the water through some desired range. The *water-cooling range* in some installations will vary from 10 to 12 F deg when a spray pond is used, and from 5 to 17 F deg (with 10 F deg average) for a mechanical draft cooling tower.

Heat absorption by the moving air in an atmospheric water-cooling tower continues as long as the wet-bulb temperature of the air is lower than the temperature of the water. The rate of heat transfer depends upon: (1) the area of water in contact with the air; (2) the relative velocity of the air and water during contact; (3) the difference between the wet-bulb temperature of the air and the initial temperature of the water; and (4) the time of contact of the air with the water. The rate of heat dissipation is also influenced by many other lesser factors<sup>2</sup> which further complicate the cooling tower design. Ultimate selection of water-cooling equipment for any specified service depends on overall economic considerations established from correlated performance data. As the enthalpy of the moving air increases, its wet-bulb temperature rises (see Chapter 3). Since it is impracticable to allow the air to be in contact with the water for a long enough time to permit the wet-bulb temperature of the moving air and the temperature of the water to reach equilibrium, atmospheric water-cooling equipment aims to circulate only enough air to cool the water to the desired temperature with least expenditure of power.

### DESIGN CONDITIONS FOR WATER-COOLING

The maximum wet-bulb (design) temperature at which the total quantity of circulating water must be cooled through a specified range by water-cooling equipment is never selected as the highest wet-bulb temperature ever known to have occurred for some locality, nor the average wet-bulb temperature over any period of time. The *maximum* basis would require cooling equipment several times larger than normal capacity, and the *average* basis would result, for a large part of the time, in higher condenser temperatures than those for which the plant was designed.

Accepted design practice for water-cooling towers, evaporative condensers, and spray ponds, is to use the maximum hourly outdoor dry-bulb temperature which will be exceeded no more than 2½ percent of the time for the months of June to September; also, to use the maximum hourly wet-bulb temperature which will be exceeded no more than 5 percent of the total hours for the same period. Tabulation of these data has not been completed. The limited portion of such data as are available is given in Table 2, Chapter 13 for airport weather stations; for other localities design dry-bulb and wet-bulb temperatures in use locally are tabulated as a guide to design temperatures. More complete summer weather data, statistics, charts, maps, and technical analysis have been prepared by Albright.<sup>4</sup>

Equipment for steam turbine condensers and internal combustion engines, is usually based upon somewhat lower design temperatures if peak loads occur at night or during winter months when outdoor temperatures are lower.

Knowing the hot water temperature and the wet-bulb temperature for which the equipment must be designed, the cold water temperature must be chosen to place the requirement within the effectiveness range of the

type of atmospheric water cooling apparatus to be used. This effectiveness is expressed as the percentage ratio of the actual cooling effect to the maximum possible cooling effect. Since the wet-bulb temperature of the entering air is the equilibrium temperature to which the water could be cooled, the effectiveness of water cooling apparatus can be indicated thus:

$$E_1 = \frac{(\text{hot water temperature} - \text{cold water temperature}) \times 100}{\text{hot water temperature} - \text{wet-bulb temperature of entering air}} \quad (2)$$

where

$E_1$  = water cooling effectiveness, percent.

Magnitudes of this effectiveness ratio will vary through wide limits in accordance with construction and conditions of operation. Values indicative of the commercial range of the effectiveness ratio are given in Table 3, although unusual designs may operate outside these ranges.

*Example 1:* A mechanical refrigeration installation requires 3 gpm of cooling water, per ton of refrigeration, with the hot-water temperature at 95 F and the cold-water at 84 F, with a design wet-bulb temperature of 78 F. Find the water-cooling effectiveness of a mechanical draft tower for the above conditions.

*Solution:* Substituting known conditions in Equation 2,

$$\text{Water-cooling effectiveness} = \frac{95 - 84}{95 - 78} \times 100 = 64.7 \text{ percent (typical).}$$

From a consideration of the factors which include the water-cooling range and the design wet-bulb temperature of the ambient air, the quantity of water required can be calculated from the amount of heat to be rejected. The average quantities of heat to be removed from various types of mechanical equipment that require cooling are listed in Table 4.

#### WATER-COOLING TOWER DESIGN

Because of the many variables<sup>3</sup> in water-cooling tower calculations and performance, it is difficult to provide simple handbook equations and tables whereby an engineer can readily select the type and size of unit for a definite requirement. Each manufacturer has a semi-confidential method of sizing a tower, based largely upon research and actual performance correlated with definite requirements; selection of water-cooling equipment for any specified service must ultimately depend upon overall considerations established from reliable design and performance data.

Some of the variables encountered in water-cooling tower work are: continuously changing air and water temperatures throughout the structure; varying moisture content, pressure, and volume of the moving air; caprice of the weather, ambient air changes in temperature, humidity, wind velocity and direction, and the amount of sunshine. Other less important physical properties of the air and water affecting tower performance are: density, specific heat, conductivity, viscosity, vapor pressure, surface tension, latent heat, coefficient of expansion, vapor diffusivity, emissivity, and molecular weight. The air velocity, overall and in different parts of the tower, and also the type of air movement provided by natural draft, forced draft, induced draft, counterflow, or crossflow design have an important effect on heat transfer. Different features of construction will produce dissimilar velocities of water, and will affect its distribution and diffusion as well as the size of drops, jets, sprays, and sheets. The pressure and elevation of the water supply system, as well as the adsorption

TABLE 3. EFFECTIVENESS OF WATER COOLING EQUIPMENT

| COOLING EQUIPMENT                 | WATER COOLING EFFECTIVENESS—PERCENT |          |         |
|-----------------------------------|-------------------------------------|----------|---------|
|                                   | Minimum                             | Typical  | Maximum |
| Spray Ponds.....                  | 30                                  | 40 to 50 | 60      |
| Spray Filled Atmospheric Towers.. | 40                                  | 45 to 55 | 60      |
| Atmospheric Deck Towers.....      | 50                                  | 50 to 60 | 90      |
| Mechanical Draft Towers.....      | 50                                  | 55 to 75 | 93      |

and interfacial surface tension of the wetted tower areas also affect distribution.

Dissolved gases and other impurities in the water influence the water-cooling process. Additional cooling tower variables affecting its performance include: location (ground, roof, nearby obstructions, wind orientation), dimensions, relative proportions (contour) of tower structure, materials, type and arrangement of interior surfaces; the louver and drift-eliminator designs as they facilitate the air flow to and from the tower; temperature of the structure at different points as influenced by the external and internal conditions. Other cooling tower factors to be considered are: loss of water by entrainment (drift loss), design and location of water-collecting basin, and surface evaporation therefrom; also the noise generated by the air, water, fan, and structure vibration.

Basically, a water-cooling tower is a heat exchanger in which heat flows from the water to the air (1) by a flow of sensible heat from the warm water to the cooler air, and (2) by an exchange of latent heat resulting from the evaporation of a small part of the circulating water to increase the humidity ratio of the air by a corresponding amount. The general principles involved are similar to those encountered in the processes of diffusion in absorption and extraction equipment.<sup>5,6</sup>

Details of the application of the process to water-cooling tower performance have been published by various authorities,<sup>7,8,9,10,11,12</sup> and those interested in the derivation of the various equations should refer to these references, as listed at the end of this chapter. The approach in each case is based on a heat balance in which the total heat given up by the water equals the total heat absorbed by the air. These derivations are also based on certain assumptions, viz: that the specific heat of water is unity at the temperatures encountered; that there is no loss in weight of the

TABLE 4. HEAT ABSORBED BY COOLING WATER

| MECHANICAL EQUIPMENT                        | BTU PER MIN<br>PER TON | BTU PER LB<br>OF STEAM | BTU PER<br>BHP-HR |
|---------------------------------------------|------------------------|------------------------|-------------------|
| Refrigeration Compressor.....               | 250                    | —                      | —                 |
| Refrigeration, Absorption System.....       | 550                    | —                      | —                 |
| Steam Turbine Condenser.....                | —                      | 1000                   | —                 |
| Steam Jet Refrigerating Condenser.....      | 550                    | 1100                   | —                 |
| Diesel Engine Jacket & Lube Oil:            |                        |                        |                   |
| Four-cycle, Supercharged.....               | —                      | —                      | 2600              |
| Four-cycle, Non-supercharged.....           | —                      | —                      | 3000              |
| Two-cycle, Crank-case Compressor.....       | —                      | —                      | 2000              |
| Two-cycle, Pump Scavenging, Large Unit..... | —                      | —                      | 2500              |
| Two-cycle, Pump Scavenging, High Speed..... | —                      | —                      | 2200              |
| Natural Gas Engine:                         |                        |                        |                   |
| Four-cycle.....                             | —                      | —                      | 4500              |
| Two-cycle.....                              | —                      | —                      | 4000              |

circulating water as a result of evaporation; that the water suspended in the tower is surrounded by a film of air which is saturated with water vapor and at the temperature of the water surrounded; and that the basic theory of cooling tower operation proposed by Lewis<sup>13</sup> and developed by Merkel<sup>14</sup> is applicable. This theory refers to the fact that the numerical value of the coefficient of sensible heat transfer, when divided by the numerical value of the coefficient of diffusion, equals the specific heat (at constant pressure) of air. The reader should observe that this relationship refers to the numerical values of three distinct constants, the units for each being different. The above relationship makes it possible to simplify the heat transfer equation by combining the two driving forces into one potential represented as the difference between the enthalpy of the air film (at water temperature) surrounding the water, and the enthalpy of the main air stream.

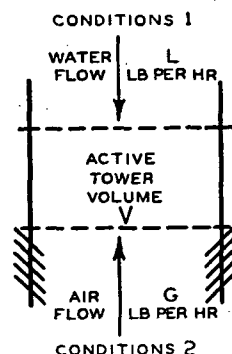


FIG. 10. OPERATIONS IN A TYPICAL WATER COOLING TOWER

### Tower Performance Factor

The operations taking place in a typical water-cooling tower are shown in Fig. 10. If the reduction in water flow rate, due to evaporation within the volume, is neglected, and the usual concepts of heat flow and mass heat transfer are applied, the equations typifying cooling tower operation are:

$$\frac{KaV}{G} = \int_2^1 \frac{dh}{h'' - h_a} \quad (3)$$

and

$$\frac{KaV}{L} = \int_2^1 \frac{d\theta}{h'' - h_a} \quad (4)$$

where

- $a$  = overall average wetted area (surface of water drops plus wetted tower surface), square feet per cubic foot of active tower volume.
- $G$  = weight rate of flow of air, pounds of dry air per hour.
- $h$  = enthalpy, Btu per pound of dry air.

### Spray Apparatus

- $h_a$  = enthalpy of air-vapor mixture, Btu per pound of dry air.
- $h''$  = enthalpy of saturated air-vapor mixture at water temperature, Btu per pound of dry air.
- $K$  = overall energy unit conductance, Btu per (hour) (square foot overall average wetted area) (Btu enthalpy difference per pound of dry air).
- $L$  = water rate, pounds per hour.
- $\theta$  = temperature of water in tower, Fahrenheit.
- $\theta_1$  = temperature of inlet water, Fahrenheit.
- $\theta_2$  = temperature of outlet water, Fahrenheit.
- $V$  = active tower volume, cubic feet.

Either term  $\frac{KaV}{G}$  or  $\frac{KaV}{L}$  may be called the *Tower Performance Factor* or *Number of Tower Units (NTU)*.

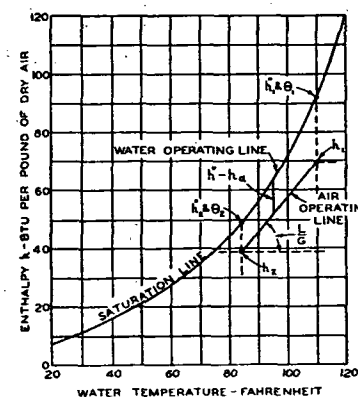


FIG. 11. TEMPERATURE-ENTHALPY DIAGRAM FOR AIR-WATER VAPOR MIXTURE SHOWING OPERATING LINES FOR EXAMPLE 2

These equations indicate that the rate of heat transfer from the water to the air depends primarily upon the enthalpy of the air, the latter being dependent only on the wet-bulb temperature of the air. This explains the common observation that cooling tower performance is independent of inlet dry-bulb air temperature, and that adiabatic conditions exist.

The integration of Equations 3 and 4 must be performed by mechanical or graphical means, because direct mathematical integration would be accurate only within narrow temperature limits. The temperature-enthalpy diagram in Fig. 11 represents the conditions for either of the above equations. The water is cooled from the temperature  $\theta_1$  to  $\theta_2$ , and the enthalpy of the air film surrounding it follows the saturation line  $h''$ . Air enters the tower at a wet-bulb temperature of  $t'_2$ , and an enthalpy of  $h_a2$ . It is heated to an outlet wet-bulb temperature of  $t'_1$ , with an enthalpy of  $h_a1$ . Since the heat rejected by the water equals the heat absorbed by the air, the heat absorbed per pound of air is a function of the pounds of water per pound of air going through the tower, and the slope of the air operating line is the  $L/G$  ratio.



**Example 2:** It is desired to cool 150,000 lb of water per hour (about 100 tons of mechanical refrigeration) from 110 to 84 F with 125,000 lb of dry air per hour, with a design wet-bulb air temperature of 75 F. These conditions could prevail with a steam-turbine driven centrifugal refrigeration compressor. Determine the *Tower Performance Factor*; show in tabular form the successive steps for this mechanical integration by selecting two-degree intervals of the water-temperature range.

**Solution:** The accompanying Table 5 shows the sequence of mechanical integration for the given water and air temperatures. The first column shows the water temperature  $\theta$  in increments of two degrees ( $\Delta\theta = 2$  F deg). Column 2 gives the enthalpies of the saturated air-vapor mixture at the water temperature, Btu per pound of dry air. The enthalpy of air,  $h_a$ , in column 3, has an original value of 38.61 Btu per lb corresponding to the 75 F entering wet-bulb temperature of the ambient air; this value of  $h_a$  increases in equal increments of  $1.2 \left(\frac{L}{G}\right)$  Btu per F deg, hence,

$\Delta h = \Delta\theta \times \frac{L}{G} = 2 \times \frac{150,000 \text{ lb}}{125,000 \text{ lb}} = 2.4$ . The potential for mass heat transfer is  $(h'' - h_a)$  as shown in column 4; this is frequently called the tower driving force potential. The values in column 5 for each increment are determined by dividing 2.4 Btu per F deg by the average value of  $(h'' - h_a)$ ; and column 6 is calculated in a similar manner, except that the increments are two degrees instead of 2.4 Btu.

TABLE 5. SEQUENCE OF MECHANICAL INTEGRATION TOWER PERFORMANCE FACTOR

| 1<br>WATER TEMP.<br>$\theta$ | 2<br>ENTHALPY OF<br>FILM<br>$h''$ | 3<br>ENTHALPY OF<br>AIR<br>$h_a$ | 4<br>ENTHALPY<br>DIFFERENCE<br>$(h'' - h_a)$ | 5<br>$\frac{\Delta h}{(h'' - h_a)}$<br>(avg.) | 6<br>$\frac{\Delta\theta}{(h'' - h_a)}$<br>(avg.) |
|------------------------------|-----------------------------------|----------------------------------|----------------------------------------------|-----------------------------------------------|---------------------------------------------------|
| 84                           | 48.22                             | 38.61                            | 9.61                                         | 0.249                                         | 0.208                                             |
| 86                           | 50.66                             | 41.01                            | 9.65                                         | 0.247                                         | 0.206                                             |
| 88                           | 53.23                             | 43.41                            | 9.82                                         | 0.241                                         | 0.201                                             |
| 90                           | 55.93                             | 45.81                            | 10.12                                        | 0.232                                         | 0.194                                             |
| 92                           | 58.78                             | 48.21                            | 10.57                                        | 0.221                                         | 0.184                                             |
| 94                           | 61.77                             | 50.61                            | 11.16                                        | 0.208                                         | 0.173                                             |
| 96                           | 64.92                             | 53.01                            | 11.91                                        | 0.194                                         | 0.162                                             |
| 98                           | 68.23                             | 55.41                            | 12.82                                        | 0.180                                         | 0.150                                             |
| 100                          | 71.73                             | 57.81                            | 13.92                                        | 0.165                                         | 0.137                                             |
| 102                          | 75.42                             | 60.21                            | 15.21                                        | 0.150                                         | 0.125                                             |
| 104                          | 79.31                             | 62.61                            | 16.70                                        | 0.137                                         | 0.114                                             |
| 106                          | 83.42                             | 65.01                            | 18.41                                        | 0.124                                         | 0.103                                             |
| 108                          | 87.76                             | 67.41                            | 20.35                                        | 0.112                                         | 0.093                                             |
| 110                          | 92.34                             | 69.81                            | 22.53                                        |                                               |                                                   |

Tower Performance Factor = 2.460 or 2.050

Hence, the mechanical integration for the above conditions gives two results:

$$\frac{KaV}{G} = \sum \frac{dh}{h'' - h_a} = 2.46, \text{ Tower Performance Factor}$$

and

$$\frac{KaV}{L} = \sum \frac{d\theta}{h'' - h_a} = 2.05, \text{ Tower Performance Factor}$$

The results obtained in *Example 2* are designated as the *Tower Performance Factor (TPF)* or the *Number of Tower Units (NTU)*; these figures represent correlated values that are directly proportional to the performance being considered. Similar calculations could be made for other quantities and temperatures of air and water. It should be noted that this factor is not related to the equipment doing the cooling, that any numerical value may represent an infinite number of possible performance conditions, that any cooling tower arrangement may give almost any performance under certain conditions. Also the mechanical integration

procedure used above applies only to counterflow apparatus. However, the same principles may be applied to crossflow atmospheric water-cooling towers, although the method is more involved.

The basic mathematical theory for water-cooling towers is now well established and recognized, but each manufacturer relies upon experimental results and practical experience with his own tower designs to establish a system for rating each unit that he builds. The problem of cooling tower design or selection is based on a knowledge of the characteristics of the equipment being considered. The *Tower Performance Factor* is a variable which is a function of the design; it also varies with the water loading and air velocity. Experimental data indicate that it varies with the heat load, although this variation may be due to deviations from the theoretical calculations which become more pronounced at the higher temperatures. The reference literature contains *Tower Performance Factors* which have been reported by various investigators, but the reader should be warned that the use of such factors, without a full understanding of the source, may lead to erroneous results.

### SELECTION OF WATER-COOLING TOWERS

The correct type and size of water-cooling equipment for a given service cannot be determined intelligently without considering the characteristics of the various types, together with the many correlated requirement factors. Very few installations are exactly alike in details of requirements, hence, conditions affecting performance and operation of the several types of water-cooling equipment vary widely because of the many diversified applications and wide-spread geographical locations.

Before the characteristics of a specific water-cooling apparatus can be judged desirable or undesirable for a given heat load and wet-bulb temperature, a survey should consider the importance of each of the following items: first cost including all necessary auxiliaries, area, height, weight, effect of wind velocity and direction, rigidity of structure to withstand high winds, safety, conformity to building codes, drift nuisance, make-up water requirements and cost of chemical treatment if needed, total power for pumping (plus fan operation in the case of mechanical draft), maintenance, available locations (with due thought to possible future expansion, wind restrictions, space cost, proximity and accessibility, etc.), appearance, the equipment's operating flexibility for the most economical conformance to varying loads or seasonal changes, and other considerations occurring with regard to a specific application.

For a definite heat-load dissipation, the type and size of a water-cooling tower is primarily affected by the following conditions:

1. Gallons per minute of cooling water.
2. Geographical location of the tower installation.
3. Wet-bulb design temperature of ambient air (see Table 2, Chapter 13).
4. Temperature of the hot water entering the tower at normal rating.
5. Temperature of the cold water leaving the tower at normal rating.
6. Ground, roof, or sub-structure installation.
7. Area available for cooling tower.
8. Proximity to other structures.
9. Surface of water exposed to each unit quantity of air.
10. Time of contact of the air with the water; this depends upon height (or length) of tower, and upon the relative velocity of air and water.



The selection of a proper water-cooling range depends upon: (1) type of service—refrigeration, internal-combustion engine, or steam condenser; (2) wet-bulb air temperature at which the equipment must operate; and (3) type of condenser or heat exchanger employed.

Because the design of an entire plant is usually affected by the quantity and temperature of the cooling water supply, plants should be designed for cooling water conditions which can be most efficiently attained. The first consideration is usually the limiting temperature of the plant. For example, if an ammonia compressor refrigerating plant is to be designed for 185 psig head pressure as a normal maximum, the limiting temperature of the ammonia in the condenser is 96 F. Should the ammonia temperature go above this figure, the head pressure will exceed 185 psig and the power consumption increase. To obtain this head pressure, the temperature of the circulating water leaving the condenser must always be less

TABLE 6. CONDENSER DESIGN DATA

| GAS                      | DESIRED PRESSURE IN CONDENSER | GAS TEMPERATURE IN CONDENSER, FAHRENHEIT | LEAVING HOT-WATER TEMPERATURE, FAHRENHEIT |                          |
|--------------------------|-------------------------------|------------------------------------------|-------------------------------------------|--------------------------|
|                          |                               |                                          | Best Condenser Design                     | Average Condenser Design |
| Steam.....               | 28 in. vacuum                 | 101.2                                    | 97                                        | 93                       |
| Steam.....               | 27 in. vacuum                 | 115.1                                    | 110                                       | 105                      |
| Steam.....               | 26 in. vacuum                 | 125.4                                    | 120                                       | 114                      |
| Ammonia.....             | 185 psi*                      | 96.0                                     | 92                                        | 88                       |
| Carbon dioxide.....      | 1030 psig*                    | 86.0                                     | 83                                        | 80                       |
| Methyl chloride.....     | 102 psig*                     | 100.0                                    | 96                                        | 92                       |
| Dichlorodifluoro-methane | 117 psig*                     | 100.0                                    | 96                                        | 93                       |
|                          | 126 psig*                     | 105.0                                    | 100                                       | 97                       |
|                          | 136 psig*                     | 110.0                                    | 104                                       | 101                      |

\* Head pressure.

than 96 F by an amount depending upon the size and design of the condenser, the quantity of water being circulated, and the refrigerating tonnage being produced. A condenser having a large surface per ton of refrigeration may be designed to operate satisfactorily with the leaving hot-water temperature within 3 or 4 deg of the ammonia temperature corresponding to the head pressure, while a small condenser may require a 10 deg difference.

Table 6 lists several gases with data for the temperatures and pressures for which commercial condensers are designed. Careful evaluation of costs of water and electrical power should be made before deciding to use city water for jacket water and condensers. Economy of operation generally indicates the use of either a water-cooling tower or an evaporative condenser for most refrigeration installations of five tons or more capacity. Refer to Chapter 37, for information on Evaporative Condensers. Internal-combustion engines have limiting hot water temperatures of 140 to 180 F for closed systems, and 110 to 130 F for open systems, depending upon the quality of the cooling water. The cooling of such fluids as milk or wort has variable requirements, and is usually accomplished in counter-flow heat-exchangers in which the leaving circulating water is at a much higher temperature than is the leaving fluid.

## OPERATION AND MAINTENANCE

**Water Treatment.** The amount of make-up water required by a cooling tower depends upon evaporation loss, drift loss, and blow-down. Evaporation losses average 0.80 percent of the water circulated for each 10 F deg range. Drift loss is the water carried out of the tower by the air currents in the form of droplets or mist. In properly designed induced draft towers this loss normally approximates one-tenth of one percent, and most cooling tower manufacturers will guarantee a drift loss not to exceed two-tenths of one percent. The amount of blow-down water wasted depends upon the hardness of the circulating water, type of water softening used and the amount of drift loss. Blow-down is normally controlled to maintain the concentration of soluble and scale-forming solids below the point where the formation of scale would occur or would be caused by corrosion.

Algae formations will plug nozzles and prevent proper distribution of the water over the tower filling. This growth may also collect on equipment served by the cooling tower, and thereby reduce the heat transfer rate. Algae should be held at a minimum or eliminated by use of bromine, chlorine, chlorinated lime, copper sulfate, or various blends of chlorophenates (see Chapter 43).

Although some scale-forming materials are found in practically all water, those which cause trouble in water-cooling systems are normally calcium and magnesium carbonates. Scale formation in equipment served also reduces heat transfer rates. Scale can be reduced materially or prevented by softening the make-up water with lime and soda ash, zeolite, or sulfuric acid, or by use of small amounts of sodium hexametaphosphate. Water softening or treatment requires close regulation and control by a competent chemist. Too high a concentration of soluble solids in cooling tower water may raise the temperature of the water leaving the tower, and may cause sludge deposits or corrosion in the system. Concentration of solids is normally controlled by either blowing down or by a continuous overflow to the sewer. Refer also to Chapter 43.

**Delignification.** The presence of sodium carbonate in the circulating water results in delignification of any wood with which water comes in contact. This chemical dissolves lignin which binds the wood fibers together and leaves the wood surface in a white fibrous condition. Prolonged exposure reduces the structural strength of the wood. Delignification first appears on parts of the tower that are alternately wet and dry, since evaporation at such points rapidly increases the concentration of dissolved solids. The presence of sodium carbonate in harmful amounts is generally indicated by a high pH of 9 to 11. The effect of the sodium carbonate may be neutralized by the use of sulfuric acid. It is desirable to have the pH value of the water at 7 to 7.5 (7.2 pH value is neutral for redwood).

**Two-speed Motors.** For readily adapting tower performance to temporary or seasonal decreases in heat load, and especially for winter operation, the use of two-speed motors (for fan drives) is recommended. The chief advantage is that when operated at half-speed, fans require only about 15 percent of the power used at full speed. Particularly in multi-fan towers, the ready flexibility provided by two-speed motors results in considerable savings, even though load reductions may sometimes call for only one or a few fans to be operated at half speed.

**Cold-weather Operation.** Extremely cold water normally does not in-

crease performance to any great extent, but increases operating hazards considerably. Water-cooling towers operated in sub-freezing weather are subject to ice formation on the louvers and the outer portion of the filling.

To prevent icing in cold-weather operation, the cold raw water (tower circulating water) temperature should be maintained as high as practicable, taking into consideration the effect upon the economy of the equipment served. One or more of the following procedures are recommended for induced draft towers: (a) run two-speed motors on low speed, or shut off some of the fans; (b) shut down some cells completely and put all of the water over the remaining cells; (c) reduce water flow to the tower and shut off some of the cells; (d) by-pass the cooling tower with part of the water and shut off some of the fans or cells of the tower.

If ice should form on the louvers and filling, one of the following methods of removal can be used: (a) reversing (for not more than 10 minutes) the rotation of the motor driving the fan and thus blowing the warm air out through the louvers; (b) shutting down fans on some sections temporarily, but not the water. When these cells have thawed out, use the same procedure on other cells.

Where intermittent operation of a system is employed, water in outside basins may cause considerable damage due to freezing. To prevent this, such basins are drained when out of service and therefore in some small roof installations a tank large enough to hold all the water in the system may be installed inside the building.

**Maintenance.** Well-maintained equipment provides the best operating results and the least overall maintenance cost. A regular schedule should be set up for the structural and mechanical upkeep of water-cooling towers. The life and continued utility of any cooling tower is directly dependent upon its inherent qualities, climatic environment, type of service, severity of operation, and general care and maintenance.

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## CHAPTER 36

### AIR HEATING AND COOLING COILS

Uses for Coils; Coil Construction and Arrangement: Steam Coils, Water Coils, Direct-Expansion Coils, Flow Arrangement, Applications; Coil Selection: Heating, Cooling and Dehumidifying Coils; Heat Transfer and Air Flow Resistance; Performance of Heating and Dry Cooling Coils; Overall Coefficient of Heat Transfer; Performance of Dehumidifying Coils; Determining Refrigeration Load

**COILS** described in this chapter are used for heating or cooling an air stream under forced convection. Surface coil equipment may be made up of a number of banks assembled in the field, or the entire assembly may be factory constructed. The applications of each type of coil are limited to the field within which it is rated. Other limitations are imposed by code-regulations, by proper choice of materials for the fluids used and the condition of the air handled, or by an economic analysis of the possible alternates on each installation.

### USES FOR COILS

For *heating service*, coils are used as tempering coils, preheaters, reheaters or booster heaters. The function of the coils is air heating only, but the apparatus assembly may include means for humidification and air cleaning. Steam or hot water are the usual heating media, although others are used in special cases, such as reheating by means of discharge gas from a refrigerating system.

Coils are used for *air cooling* with or without accompanying dehumidification. Examples of cooling applications without dehumidification are precooling coils using well water or other relatively high temperature water to reduce the load on the refrigerating machinery, or water cooled coils removing sensible heat in connection with chemical moisture-absorption apparatus. A major portion of coil equipment is designed to handle both sensible cooling and dehumidification. The assembly usually includes air cleaning means to protect the coil from accumulation of dirt, and to keep dust and foreign matter out of the conditioned space. Although cooling and dehumidification are the usual functions, cooling coils are additionally and purposely wetted to aid in air cleaning and odor absorption.

The usual cooling media used in surface coils are cold water or Group I (ASA Classification) refrigerants, but others are used in special cases. Brines are seldom required for the range of applications covered by this chapter, although there are cases where low entering air temperatures with large latent heat loads require a refrigerant temperature so low that use of water becomes impracticable. Sometimes, also, brine from an industrial system already installed is the only convenient source of refrigeration.

For combined cooling and dehumidifying, surface coils present an alternate to spray dehumidifiers. For many applications it is possible, by proper selection of apparatus, choice of air velocities, refrigerant temperatures, etc., to perform the same duty with either. In a few cases both sprays and coils are used. The coils may then be installed within the spray

chamber, either in series with the sprays or below them. In making the selection between spray and surface dehumidifiers, certain advantages of each should be considered. The fact that a spray dehumidifier is usually designed to deliver nearly saturated air, tends to simplify the control problem. In this case the dry-bulb temperature is also the dew point, and hence, a dew point control can be arranged by using a simple duct thermostat. Spray dehumidifiers have an advantage over unwetted coils of obtaining some air cleaning and odor absorption. On the other hand, coils make possible a closed and balanced cooling water circuit, obviating the unbalanced pumping head, the complication of water level control, and danger from possible floods incidental to multiple spray dehumidifiers, especially if located on different levels. The use of coils often makes it possible for the same surface to serve for summer cooling and winter heating by circulating cold water in the one season and hot water in the other, with consequent saving in apparatus and piping. Another advantage is that where the surface coil system can be used with direct expansion of refrigerant, it is comparatively low in initial and operating costs. For comfort conditioning applications, the regulations of the applicable national and local safety codes should be consulted by the design engineer.

#### COIL CONSTRUCTION AND ARRANGEMENT

Coils are basically of two types, those consisting of plain tubes or pipe, and those having *extended* surfaces. The former are little used for the applications covered by this chapter, but are often employed where conditions cause frost accumulation, and for cooling within spray dehumidifiers.

The heat transmission from air passing over a tube to a fluid flowing within it is impeded by three resistances. The first is that from the air to the surface of the tube and is usually called the outside surface resistance or air-film resistance. The second is the resistance to the conduction of heat through the metal itself. Finally there is another surface or film resistance to the flow of heat between the inside surface of the metal and the fluid in the tube. For the applications under consideration both the resistance of the metal wall to heat conduction, and the inside surface or film resistance are usually low as compared with the air-side surface resistance. Economy in space, weight and cost makes it advantageous to decrease the external surface resistance, where it is proportionately large, to approach that of the tube wall, and that from the tube to refrigerant. This may be accomplished by increasing the external surface by means of fins. Sometimes water spray is applied to the same type surface as would have been used without it. The overall heat transfer is not necessarily increased much, but the water spray may serve other purposes than to increase the flow of heat, such as air and coil cleaning.

In fin or *extended-surface* coils the external surface of the tubes is known as *primary*, and the fin surface is called *secondary*. The primary surface consists generally of round tubes or pipes which may be staggered, or in some cases placed in line with respect to the air flow. The staggered arrangement is usually preferred because it obtains a somewhat higher heat transfer value. Numerous types of fin arrangement are used, the most common of which are spiral, flat and flat-crinkled or corrugated, all as shown in Fig. 1. While the spiral fin surrounds each tube individually in all cases, the flat types may be continuous (including several rows of tubes), or they may be round or square, with individual fins for each tube. All of these, as well as other less common types, are in use, the selection for a particular installation being based on economic considerations, space re-

quirements and resistances of individual designs of coils. A most important factor in the performance of extended-surface coils is the bond between the fin and the tube. An intimate contact between the tube and the fin must be maintained permanently in order to assure a continuing rated performance after the heating units have been in service for a period of time. In some coils, fins are wound on the tubes under pressure, in order to upset the metal slightly at the fin root, and then are given a coating of solder while the fin and tube are still revolving, for the purpose of assuring a uniform coating of solder. In other types, the spiral fin may be knurled into a shallow groove on the exterior of the tube. The tube may be expanded after the fins are assembled, or the tube-hole flanges of a flat or corrugated fin may be made to override those in the preceding fin and so compress them upon the tube. There are also types of construction where the fin is formed out of the material of the tube itself.

For *heating coils*, materials most generally used are copper and aluminum. Steel is occasionally used where sodium or calcium chloride brine is circulated in the tubes. Aluminum fins on copper tubes are a common con-

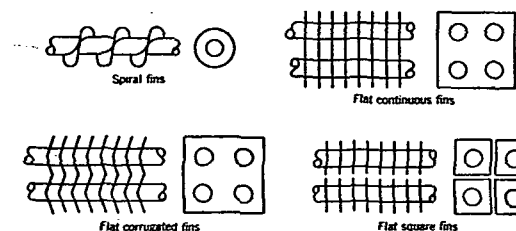


FIG. 1. TYPES OF FIN COIL ARRANGEMENT

struction. Generally speaking, brass does not serve as a satisfactory fin material because of corrosion difficulties. *Cooling coils* for water or for volatile refrigerants most frequently have copper fins and tubes, although aluminum fins on copper tubes are also used. There are many makes of heating and cooling coils of the light weight extended surface type for both heating and cooling with tubes commonly  $\frac{1}{2}$ ,  $\frac{3}{8}$ ,  $\frac{3}{4}$ , and 1 in. outside diameter, and with fins spaced three per inch up to eight per inch. The tube spacing generally varies from about  $1\frac{1}{2}$  to  $2\frac{1}{2}$  in. on centers, depending upon the width of individual fins and on other considerations of performance. Fin spacing should be chosen for the duty to be performed, with special attention being paid to possibility of lint accumulation and, especially in dehumidifying, the consideration of frost accumulation.

#### Steam Coils

For proper performance of steam heating coils, condensate and air must be continuously eliminated and the steam must be evenly distributed to the individual tubes. This distribution is usually accomplished by individual orifices in the tubes, by distributing plates and orifices in the steam header, or by perforated internal steam-distributing pipes extending into the individual tubes. The latter arrangement has the advantage of distributing the steam throughout the length of each tube, and is conducive to uniform temperature of delivered air. The tendency of condensate to freeze at the bottom of the coil with cold entering air and light heating

loads, is also minimized. This is especially valuable for outside air pre-heaters.

### Water Coils

The performance of water coils, for heating or cooling, depends on the elimination of air from the system and proper distribution of water. Air elimination is taken care of in the system piping as described in Chapter 22. To assure a pressure drop sufficient for adequate distribution, but at the same time to provide against excessive pumping head where large water quantities are handled, water coils are provided with various water circuit

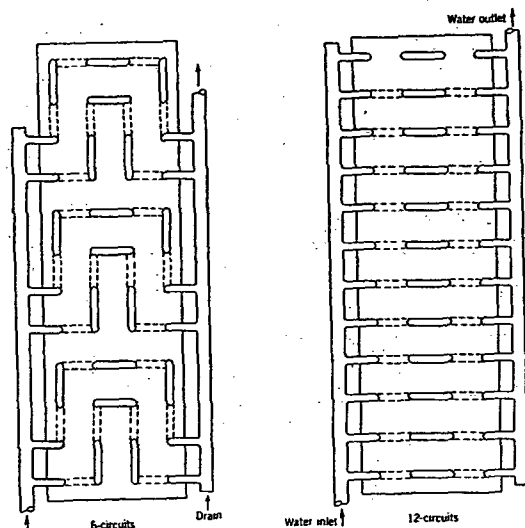


FIG. 2. VARIOUS WATER CIRCUIT ARRANGEMENTS

arrangements. For instance, a typical coil 18 tubes high and 6 tubes deep in the direction of air flow can be arranged for 6, 9, 18, 24, or 36 parallel water circuits, as conditions may require. Orifices in individual tubes are occasionally employed, but are usually unnecessary as the resistance of individual water circuits is generally sufficient to effect a satisfactory distribution. In precooling coils using well water, where there may be considerable sand and other foreign matter in the water, provision for cleaning of individual tubes is of advantage. It is important to arrange water coils for complete drainage (see Fig. 2). The drains are usually provided in the water piping at the coil header.

### Direct-Expansion Coils

Coils for volatile refrigerants present more complex problems of fluid distribution than do water, brine or steam. It is desirable that the coil be effectively and uniformly cooled throughout, and necessary that the compressor be protected from entrained, unevaporated refrigerant. There are two types, namely, flooded systems, and thermal expansion valve systems, as shown in Figs. 3 and 4. In a flooded coil, the circulation is similar to that in a water tube boiler. The liquid is maintained at the proper level by the action of a float regulator as shown in Fig. 3. The thermal expan-

sion valve system depends upon the thermal valve automatically feeding just as much liquid to the coils as is required to maintain the superheat at the coil suction outlet within predetermined limits, which vary from about 6 to 10 deg. The thermal valve arrangement is in common use for the type of coils covered by this chapter, while the flooded system is rarely used.

With the flooded system the refrigerant distribution through the tubes depends on properly selecting the length of the feeds, and the head of liquid imposed upon the liquid inlets. No auxiliary distributing devices are required. With the thermal valve system, there are two factors to consider. There must be, generally, more than one refrigerant feed through the coil per thermal valve to keep the pressure drop through the refrigerant circuit within practical limits, and to reduce the corresponding penalty in increased

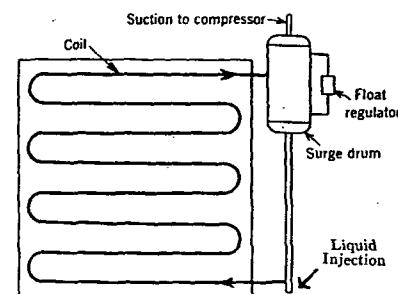


FIG. 3. DIRECT-EXPANSION COIL WITH FLOODED SYSTEM

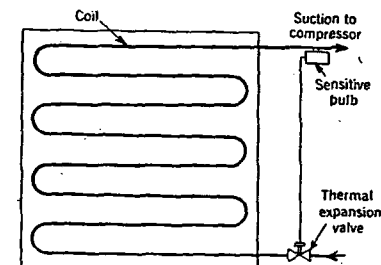


FIG. 4. DIRECT-EXPANSION COIL WITH THERMAL VALVE SYSTEM

evaporating temperature. At the same time the coil must be so arranged that the required suction superheat can be attained with a minimum sacrifice in the performance of the coil as a whole. It is general practice to attain this superheat within the coil itself, and not by the use of external heat exchangers or other auxiliary devices.

With thermal expansion valves it is advantageous to keep the pressure drop through the refrigerant feeds as low as possible. The feeds are laid out to expose each to the same mean temperature difference so that it handles the same refrigerating load. Here, a distributing means is imposed between valve and coil liquid inlets to divide the refrigerant equally among the feeds. Such a distributor must be effective for distributing both liquid and vapor, because the entering refrigerant is a mixture of the two. Fig. 5 shows three typical types of distributors. In distributor A the liquid and gas mixture from the thermal valve is led tangentially into a chamber. The coil feed connections extend outward radially at the top of this chamber. In distributor B the refrigerant is discharged at a high velocity through a central jet against the end plate, forming a uniform mixture of gas and liquid within the distributor, from which individual connections are led as shown. In type C the refrigerant enters at high velocity from the thermal valve and is discharged against the end plug in which the individual liquid feeds are closely arranged. These distributors can be used in either vertical or horizontal position. There are also other types of headers such as the centrifugal and weir type. The individual liquid connections from the distributor to the coil inlet are commonly made of small diameter tubing, and are all of the same length and diameter in order to impose the same friction between the distributor and the coil. Since the

thermal valves act in response to the superheat at the coil outlet, this superheat should be produced with the least possible sacrifice of active evaporating surface. Sometimes a single thermal valve is used per coil. In other cases, multiple valves are used, with the coil divided across the air flow or parallel to the air flow as shown in Fig. 6. The arrangement of Fig. 7 should be avoided, since it offers the disadvantage of unequal load on the two parallel circuits.

### Flow Arrangement

In all heat transfer processes, the relative directions of flow of the fluids influence the performance of the heat transfer surface. In air-heating and cooling coils, the air usually flows at right angles to the tubes. In a coil having only one row in the direction of air flow, the relative directions of

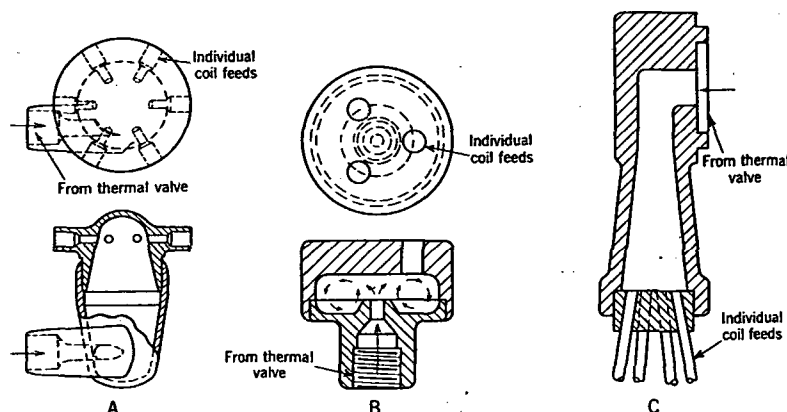


FIG. 5. TYPES OF REFRIGERANT FEED DISTRIBUTING HEADS

flow would all be at right angles. In coils having more than one row in the direction of air flow, the media in the tubes may be variously circuited as illustrated for water or steam coils in Fig. 8. It is the usual practice to designate a coil that is circuited and employed as in Fig. 8A as a *parallel flow* coil. Figs. 8B and 8C show the general arrangements that are termed *counter-flow* and *cross-flow* respectively. Cross flow is common in steam heating coils, the temperature within the tubes being substantially uniform, and the mean temperature difference the same whatever the direction of flow, relative to the air. The parallel and counter-flow arrangements as illustrated in Figs. 8A and 8B are common in brine or water coils, with the counter-flow arrangement being the preferred arrangement to secure the advantage of highest possible mean temperature difference. Most direct-expansion coils also follow the general scheme of counter flow but the circuiting requirements for proper loading sometimes result in a combination of the other flow arrangements with counter flow in the same coil. Cross flow is generally avoided in the volatile refrigerant coils because of the unequal loading of the parallel circuits.

### Applications

Heating coils in field-assembled banks are used for a number of purposes as described in Chapter 30. They may be arranged with the air flow

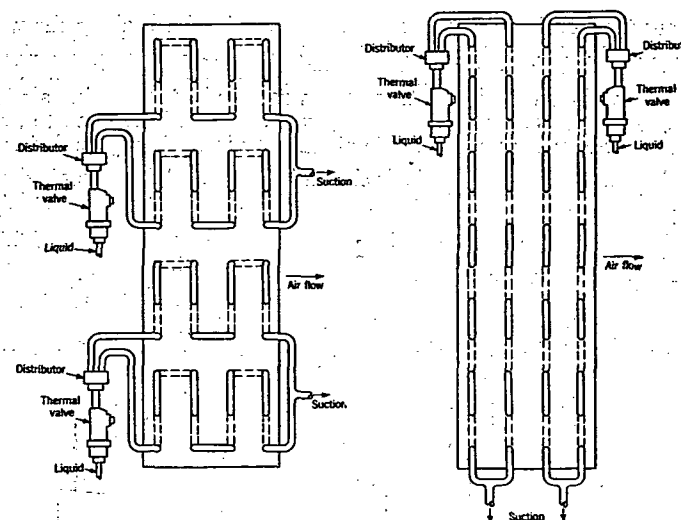


FIG. 6. ARRANGEMENT FOR FACE CONTROL

FIG. 7. ARRANGEMENT FOR DEPTH CONTROL

vertical or horizontal, although the latter is more common. For steam heating, the coils may be set with the tubes vertical or horizontal. In the latter case the coil should be sloped to provide for condensate drainage. Because of the multi-circuit feed arrangement and the necessity for avoiding air and water pockets, water heating coils are generally arranged with the tubes horizontal. Certain precautions must be taken against freezing. Where steam coils are used with entering air below freezing temperature, throttling the steam supply may cause freezing of the condensate in the bottom of the coil, if the tubes are of the variety not provided with internal distributing pipes or an equivalent arrangement.

There are coils available having inner distributing tubes, and having the supply and return headers cast in one piece. In this type of coil the condensate that forms in the outer tube has resulted from steam fed from

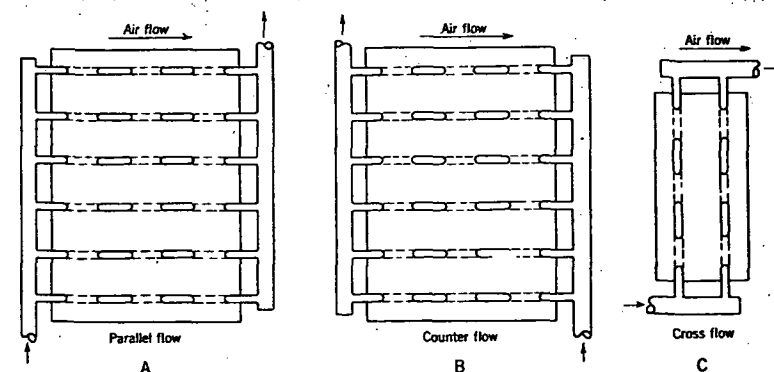


FIG. 8. FLOW OF MEDIA IN TUBES IN RELATION TO AIR FLOW

the inner tube orifices. This condensation flowing back along the warm inner tube is prevented from freezing. A wide range of modulation at very low temperatures without danger of freezing, is therefore obtained. As an added precaution, with both steam and water coils, the outside air inlet dampers are often closed automatically when the fan is stopped to avoid trouble caused by very cold outside air drifting in during off periods.

A typical arrangement of coils is shown in Fig. 9. All of the air should be filtered to prevent dirt, insects and foreign matter from accumulating on the coils. The cooling coil and humidifier must be provided with a drip pan to catch the condensate formed during the cooling cycle and the excess water from the humidifier. The drain connection should be on the downstream side of the coils, made of ample size (not less than 1½-in. pipe), provided with accessible clean-outs, a deep seal trap, and discharge to an indirect waste, so that there will be no possibility that sewer gas may enter

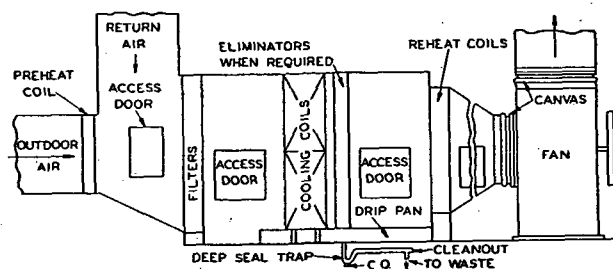


FIG. 9. TYPICAL ARRANGEMENT OF COOLING COILS IN A CENTRAL SYSTEM

the system. Precautions against freezing must be taken with the humidifier piping and drain connections.

Water coils and large steam coils are also subject to freezing. Cold outside air must be provided with tempering coils or mixing vanes. They must be installed to insure thorough mixing of the outside and return air to prevent this hazard.

Face and by-pass damper have proven to be satisfactory means of capacity reduction for cooling coils using non-volatile refrigerants. The use of such face and by-pass damper arrangements on volatile refrigerant coils poses difficult refrigerant control problems which are most severe when a change of setting at the thermostat imposes a rapid change in the dampers at the coils. On many installations, the coil bank is divided into 2, 3, or 4 sections and each section is connected to an individual compressor, or connected to a modulating compressor or compressors which will adjust to the load as each succeeding coil section is cut out by the thermostat.

The design features of the coil (fin spacing and type of fins, whether circular fins or plate) determine at what air velocity condensed moisture will be blown off the coil. Water blows off some coils below 400 fpm face velocity, while this does not occur on others at face velocities in excess of 500 fpm. Where there is a likelihood of water being blown off the coil face, eliminator plates should be placed on the down-stream side of the coil. Plate coils are most frequently installed without eliminator plates. When a number of coil sections are stacked one above another, there is a tendency for the condensate to be carried out into the air stream as it drips

from one coil to the next one. In such cases, drip troughs as are shown in Fig. 10 are used to collect the water and conduct it to the drain pan.

The enclosure around a coil or filter bank should be corrosion resistant and should have adequate access doors to provide for changing of air filters, cleaning of coils, adjusting expansion valves, oiling motors, etc.

Sometimes cooling and dehumidifying coils are sprayed with water to increase the rate of heat transfer and to provide leaving air approaching saturation. This arrangement requires a collecting tank and recirculating pump to maintain water circulation whenever the apparatus is in operation. Fig. 11 illustrates this arrangement with a bypass around the coil. This bypass is often used to facilitate thermostatic control. It is advantageous

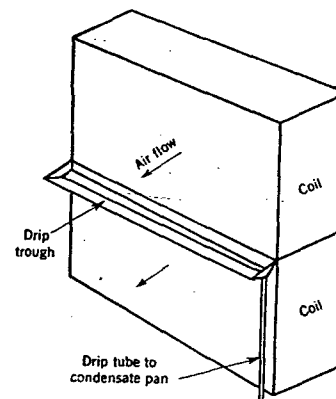


FIG. 10. COIL ARRANGED WITH DRIP TROUGH

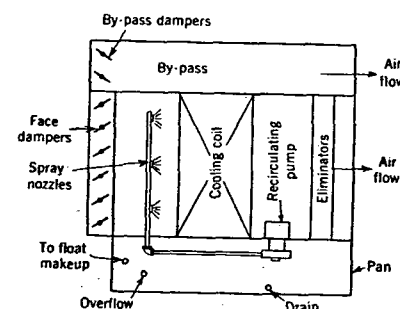


FIG. 11. RECIRCULATING SPRAY SYSTEM FOR CLEANING COILS

to direct only return air through the bypass rather than a mixture of return and outdoor air in order to hold the humidity ratio under thermostatic control.

Although both heating and cooling coils are made of sufficient strength to take up expansion and contraction arising within themselves, care should be taken to avoid imposing strains from the piping on the coil connections. (See Chapter 21.)

### COIL SELECTION

In the selection of a coil it is necessary to consider various factors:

1. The duty required: heating, cooling, dehumidifying, and the capacity required to maintain balance with other system components such as compressor equipment in the case of direct expansion coils.
2. Temperature of entering air—dry-bulb only if there is no dehumidification; dry- and wet-bulb if moisture is to be removed.
3. Available heating and cooling media.
4. Space and dimensional limitations.
5. Air quantity limitations.
6. Allowable resistances in air circuit and through tubes.
7. Allowable resistance between the inlet and the outlet of the coil tubing circuits.
8. Characteristics of individual coil designs.
9. Individual installation requirements, such as, for example, the type of automatic control to be used.

The duties required may be determined from information in Chapters 9,



11, 12, 13 and 30. There may, or may not, be a choice of cooling and heating media, as well as temperatures available, depending upon whether the installation is new or is in combination with present sources of heating or cooling. Space limitations are dictated by the requirements of individual cases. The air quantity is influenced by a number of considerations. The air quantity through heating coils is often made the same as that necessary to handle the summer cooling load. The air handled may be limited by the use of old ventilating ducts as the air distribution system or may be dictated by requirements for satisfactory air distribution or ventilation. The resistance through the air circuit influences the fan horsepower and speed. This resistance may be limited to allow the use of a given size of fan motor, or to keep the operating expense low, or it may be limited because of sound level requirements. The allowable friction through the water or brine circuit may be dictated by the head available from a given size of pump and pump motor. The performance of a surface heating or cooling coil depends upon correct choice of the original equipment, and upon proper application and maintenance.

Coil ratings are based on a uniform face velocity. Interference with uniform air flow through the coil will affect performance. Such air flow interference may be caused by air being brought in at odd angles or by inadvertent blocking of a portion of the coil face. To obtain rated performance it is necessary that the air quantity be adjusted on the job to that used in determining the coil selection, and that it be kept at this value. The most common causes of a reduction of air quantity are the fouling of the filters and collection of dirt in the coils. These difficulties can be avoided by proper design and regular servicing. There are a number of ways in which coils may be cleaned. A common method is to wash them with water. They can sometimes be brushed and cleaned with a vacuum cleaner. In bad cases of neglect, especially on restaurant jobs where grease and dirt have accumulated, it is sometimes necessary to remove the coils and wash off the accumulation with steam, compressed air and water, or hot water. The best practice, however, is to keep the filters serviced, and to inspect and wash the coils at regular intervals.

The proper selection of coils requires an understanding of the requirements of each case, and should be based on an economic analysis of the plant design as a whole. While no general rule can be established for the selection of heating or cooling coils, it is possible, however, to point out the limits of usual practice and to indicate the influence of the variables involved in the coil selection.

### Heating Coils

*Steam and hot water heating coils are usually rated within these limits:*

Air Face Velocity—200 to 1200 fpm, sometimes up to 1500 fpm.  
 Steam Pressure—2 to 200 psig, sometimes up to 350 psig.  
 Hot Water Temperature—150 to 225 F.  
 Water Velocity—2 to 6 fps.

Individual cases may deviate widely, but the tabulation given herewith will serve as a guide to usual *heating installation practice*:

Air Face Velocity—500 to 800 fpm face, 500 being a common figure.  
 Delivered Air Temperature—varies from about 72 F for ventilation only, to about 150 F for complete heating.  
 Steam Pressure—2 to 10 psig, 5 psig being common.  
 Hot Water Temperature—150 to 225 F.  
 Water Velocity—2 to 6 fps.

### Air Heating and Cooling Coils

*Water Quantity*—Based on about 20 deg temperature drop through a hot-water coil.

*Air Resistance*—The total resistance through heating coils is usually limited to from  $\frac{3}{8}$  to  $\frac{5}{8}$  in. of water for public buildings, to about 1 in. for factories.

The selection of heating coils is relatively simple as it involves dry-bulb temperatures and sensible heat only, without the complication of simultaneous latent heat loads, as in cooling coils. For a given duty, entering air temperature, and steam pressure, it is possible to select several arrangements of the same design of coil depending upon the relative importance of space, cross-sectional area, and air resistance.

### Cooling Coils

*Cooling and dehumidifying coils are usually rated within these limits:*

Entering Air Dry-Bulb—60 to 100 F.  
 Entering Air Wet-Bulb—50 to 80 F.  
 Air Face Velocities—300 to 800 fpm (sometimes as low as 200 and as high as 1200).  
 Volatile Refrigerant Temperatures—25 to 55 F, at coil suction outlet.  
 Water Temperatures—40 to 65 F.  
 Water Quantities—2 to 6 gpm per ton, or equivalent to a water temperature rise of from 4 to 12 deg.  
 Water Velocity—2 to 6 fps.

The ratio of total to sensible heat removed varies in practice from 1.00 to about 1.65, i.e., sensible heat is from 60 to 100 percent of total, depending on the application. (See Chapter 30.) Since required ratios may demand wide variations in air velocities, refrigerant temperatures, and coil depth, general rules as to their values may be misleading. On most comfort installations air face velocities between 400 and 600 fpm are frequent, 500 being a common value. Refrigerant temperatures ordinarily vary between 35 and 50 F where cooling is accompanied by dehumidification. Water velocities range from 2 to about 6 fps.

When no dehumidification is desired, for which condition the dew point of the entering air is equal to or lower than the cooling coil surface temperature, the coil selection is made on the basis of dry-bulb temperatures and sensible-heat transfer only, the same as with heating coils. It is possible also to choose various arrangements of face area, depth, air velocity, etc., for the same duty.

### Dehumidifying Coils

The performance of coils accomplishing both cooling and dehumidification is determined by a series of tests carried on under laboratory conditions. Coil ratings can be prepared from such laboratory test data to facilitate the selection of coils for cooling and dehumidifying duty. The coil capacity should be in balance with the capacity of related equipment, such as compressors, and the temperature of the circulating medium.

The selection of cooling coils for factory-assembled self-contained air conditioners is generally accomplished in conjunction with laboratory testing. The current industry standards call for ratings at 33.4 cfm per thousand Btu of cooling capacity and this is approximately 400 cfm per ton of refrigeration. The use of an entering air condition of 80 F dry bulb and 67 F wet bulb is representative of the entering air conditions actually encountered in many comfort operations because, while the indoor conditions are usually lower than 67 wet bulb, the introduction of outside air will usually bring the mixture of air to the cooling coil up to an approximation of the 67 wet bulb entering air condition at design conditions.

The selection of cooling coils for field assembled projects is usually ac-



completed by the use of coil rating tables. The practice of selecting coils from the load division indicated by the load calculation has worked out satisfactorily for the usual human comfort applications. Additional design precautions and refinements are being used for more exacting industrial applications and for improved results on all types of air conditioning in the more humid areas. One of these refinements is the use of a separate cooling coil to cool and dehumidify the ventilation air before admixture with recirculated air. This procedure takes care of one of the main sources of moisture in the usual application. Provision for reheat is required for some industrial applications, and is used for better results on very special commercial applications.

In checking the operating results obtained from cooling coils in various air conditioning installations, it is necessary to keep in mind the influence of the climatic conditions of the various areas encountered. The majority of problems are encountered at *light load* conditions when the cooling requirement is considerably less than at design conditions. In the hot dry climates, where the outside dew points are so constantly low that dehumidifying is not generally a problem, the *light load* condition does not pose any special problems. In the hot humid climates, where the outside dew points are generally high and close to the dry-bulb temperatures, the *light load* condition has a higher proportion of moisture and a correspondingly lower proportion of sensible heat. These climatic conditions result in higher dew points in the conditioned spaces during the *light load* conditions unless some of the special means for controlling the inside dew points are used. In the geographic locations where warm weather occurs with both high and low dew points, such as around the Great Lakes, the *light load* operating conditions with the higher percentage of moisture loading will be encountered less frequently and consistently than in the south coastal areas.

Care should be taken to avoid freezing at light loads. In general, freezing occurs when the coil surface temperature falls to 32 F. With usual coils for comfort installations, this does not occur unless the evaporating temperature at the coil outlet is about 20 to 25 F. The exact value depends on the design of the coil and the amount of loading. Although it is not customary to choose coil and condensing units to balance at low temperatures at peak loads, there is danger of this occurring when the load decreases. This is further aggravated if a by-pass is used so that less air is passed through the coil at light loads.

### HEAT TRANSFER AND AIR FLOW RESISTANCE

The transfer of heat between the heating or cooling medium and the air stream is influenced by several variables:

1. The temperature difference.
2. The design and surface arrangement of the coil.
3. The velocity and character of the air stream.
4. The velocity and character of the medium in the tubes.

The driving force is usually taken as the logarithmic mean temperature difference for heating or cooling without dehumidification. The rating of cooling coils for combined cooling and dehumidification is discussed later in this chapter. With volatile refrigerants there is often an appreciable pressure drop and corresponding change in evaporating temperature through the refrigerant circuit. The problem is further complicated by the fact that the refrigerant is evaporating in part of the circuit, and superheating in the remainder. In the case of volatile refrigerants, a cooling coil is tested and rated in conjunction with a specific distributing and liquid

metering device, and the capacities are stated for a given superheat condition of leaving vapor.

The design and surface arrangement of the coil include such items as materials, type, thickness, height, and spacing of the fins, and the ratio of this surface to that of the tube, the use of the staggered or in-line tube arrangement, and provisions to increase the air turbulence such as the use of corrugated as against flat fins. Staggered tubes increase the total heat transfer, as against the in-line arrangement, and corrugated fins may be more effective than flat. This design and surface arrangement has a large effect on the air film heat transfer resistance.

The velocity of the air usually considered is the coil *face* velocity. This bears a *varied relation to the actual velocity* over the surface, depending upon the individual coil design. As long as a fixed design of coil is under consideration face velocities may be used, but they may be unsatisfactory in comparing different designs, as it is the *actual surface velocity that is significant*. The air volume is often based on standard air at 70 F and a barometric pressure of 29.92 in. Hg.

At the same mass air velocity, varying performance can be obtained depending upon the turbulence of the air flow into the coil, and upon the uniformity of distribution of air over the coil face. The latter is very important in obtaining reliable test ratings, and in realizing rated performance in practical installations. The resistance through the coils will assist in distributing the air properly, but where the inlet duct connections are brought in at sharp angles to the coil face, the effect is frequently bad and there may even be reverse air currents through a portion of the coils. This reduces the capacity, but can be avoided by proper layout or by the use of vanes or baffles.

Heat transfer information on plain pipe coils has been developed and verified through many tests. In the case of finned coils, the heat transfer from the cooling or heating medium to the air stream is dependent on so many factors that reliable rating and performance information for any design of coil must be based upon actual tests of the specific coil. Mathematical comparisons of different designs of coils on a square foot of surface and face area basis may be misleading. The selection of finned coils should be made from curves or tables of coil performance prepared from a series of adequate and reliable tests. There are cases in which the engineer must extend available data or design for a single unique installation. For such purposes the following coil calculations will be useful.

### PERFORMANCE OF HEATING AND DRY COOLING COILS

The performance of heating and dry cooling coils depends in general upon:

1. The overall coefficient of heat transfer from the fluid within the coil to the air it heats or cools.
2. The mean temperature difference between the fluid within the coil and the air flowing over the coil.
3. The physical dimensions of the coil.

Thus, for any one definite operating condition, the heating or cooling capacity of a given coil is expressed by the following basic formula:

$$q_t = U \times (\Delta t_m) \times A \times N \quad (1)$$

where

$q_t$  = total heat transfer the coil, Btu per (hour) (square foot of coil face area).

$U$  = overall coefficient of heat transfer, Btu per (hour) (square foot of external coil surface) (Fahrenheit degree temperature difference between the fluid within the coil and the air flowing over the coil).

$\Delta t_m$  = mean temperature difference, Fahrenheit degrees, between the fluid within the coil and the air passing over it. (This is commonly taken as the logarithmic mean temperature difference).

$A$  = external surface area of the given coil, square feet per (square foot of coil face area) (row of coil depth).

$N$  = number of rows of coil depth.

### Overall Coefficient of Heat Transfer

While the overall coefficients of heat transfer for plain pipe coils have been defined by numerous tests within close limits, the verification of a plain coil design by a series of tests is an accepted commercial practice. The overall coefficients of heat transfer for finned coils should always be obtained from tests. The data from a series of tests may be used for purposes of extending coil data beyond test range but such data should later be verified by test.

Considering any coil, whether of bare pipe or of finned type, the overall heat transfer coefficient for a given size and design of coil can always be considered as a combined effect of three individual heat transfer coefficients, namely:

1. The film coefficient of heat transfer between air and the external surface of the coil, usually given in Btu per (hour) (square foot external surface) (Fahrenheit, degree mean temperature difference).

2. The conductivity of the coil material—tube wall, fins, ribs, etc., usually given in Btu per (hour) (square foot of surface) (Fahrenheit degree per inch).

3. The film coefficient of heat transfer between the internal surface of the coil and the fluid flowing within the coil, usually given in Btu per (hour) (square foot internal surface) (Fahrenheit degree mean temperature difference).

These three individual coefficients acting in series result in an overall coefficient of heat transfer in accordance with the basic laws given in Chapters 5 and 9. For a *bare pipe* coil the overall coefficient of heat transfer, whether for heating or for cooling (without dehumidification), can be expressed by a simplified basic formula as follows:

$$U = \frac{1}{\frac{R}{f_i} + \frac{L}{k} + \frac{1}{f_o}} \quad (2)$$

where

$U$  = overall coefficient of heat transfer, Btu per (hour) (square foot external surface) (Fahrenheit degree mean temperature difference between air and fluid within the coil).

$f_i$  = film coefficient of heat transfer between the internal surface of the coil and the fluid flowing within the coil, Btu per (hour) (square foot internal surface) (Fahrenheit degree mean temperature difference between that surface and the average fluid temperature).

$f_o$  = film coefficient of heat transfer between air and the external surface of the coil, Btu per (hour) (square foot external surface) (Fahrenheit degree mean temperature difference between the mass of air and the external surface).

$k$  = conductivity of material from which the bare pipe is constructed, Btu per (hour) (square foot) (Fahrenheit degree per inch thickness).

### Air Heating and Cooling Coils

$L$  = thickness of tube wall inches.

$R$  = ratio between external and internal surface of the bare tube, usually varying from 1.03 to 1.15 for the tube used in typical heating or cooling coils. This ratio  $R$  is inserted in the formula in order to place internal fluid coefficient of heat transfer on the basis of external surface.

Frequently, when pipe or tube walls are thin and of material having high conductivity (as is the case in construction of typical heating and cooling coils) the term  $L/k$  in Equation 2 becomes negligible and is generally disregarded. (The effect of the term  $L/k$  in typical bare pipe heating or cooling coils seldom exceeds 1 to 2 percent of the overall coefficient). Thus, in its simplest form, for bare pipe:

$$U = \frac{1}{\frac{R}{f_i} + \frac{1}{f_o}} \quad (3)$$

For finned coils the formula\* for the overall coefficient of heat transfer can be conveniently written:

$$U = \frac{1}{\frac{R}{f_i} + \frac{1}{\eta f_o}} \quad (4)$$

in which the term  $\eta$ , called the *fin efficiency*, is introduced to allow for the resistance to heat flow encountered in the fins.

The term  $R$ , in this case, is the ratio of *total* external surface to internal surface. For typical designs of finned coils for heating or cooling, this ratio varies from 10 to 30. Term  $R$  is again introduced to place the internal surface coefficient of heat transfer on a basis of external surface.

The performances of all heating and dry cooling coils are influenced by these same factors. But, when cooling coils operate wet or act as dehumidifying coils, the performance cannot be predicted on the basis of overall coefficients.

### PERFORMANCE OF DEHUMIDIFYING COILS

When the dew point of the air leaving a cooling coil is lower than the dew point of the air entering the coil, some moisture removal has been accomplished. A coil that normally accomplishes (or is designed to accomplish) moisture removal in addition to sensible heat cooling is termed a dehumidifying coil.

In most air conditioning processes, the air may be considered as a mixture of water vapor and the dry components. Both dry components and the water vapor enter an air conditioning coil at the same dry-bulb temperature; both the dry components and the water vapor lose sensible heat during the contact with the first portion of the cooling coil in the same manner as in a dry cooling coil. As the dry-bulb temperature of the mixture approaches the dew point of the water vapor components, moisture removal starts.

The psychrometric path of air through a cooling coil is generally agreed to follow a path similar to that shown in Fig. 12. When the dry-bulb

\* Rational Development and Rating of Extended Air Cooling Surface, by H. B. Pownall (*Refrigerating Engineering*, October, 1935, p. 211).

temperature of the air mixture in the coil falls below the entering dew-point temperature, moisture removal proceeds. The indications are that the lower the leaving dry-bulb temperature below the entering dew-point temperature, the less will be the difference between the leaving dry-bulb temperature and the leaving dew-point temperature.

The first portion of a cooling coil (in the direction of air flow) may function in the same manner as a dry cooling coil. Where the moisture removal starts, the cooling surfaces also continue the removal of sensible heat, thereby carrying the load due to both. As saturation is approached in the cooling coil, each degree of sensible cooling is approximately matched by a

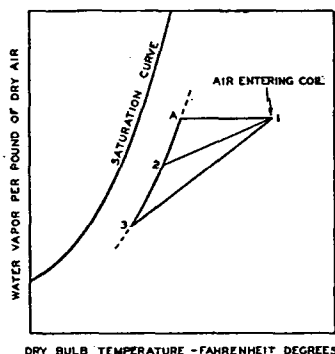


FIG. 12. PERFORMANCE OF DEHUMIDIFYING COIL

corresponding degree of dew point decrease. However, while the sensible heat removal from the dry air remains approximately constant per degree change, the amount of latent heat removal per degree of dew point change varies considerably because moisture content varies widely at different temperatures.

For example, the following tabulation compares the amount of moisture removal involved in a reduction of one degree of dew point from 60 to 59 F with the removal from 50 to 49 F:

| DEW POINT  | $W_s \times 10^3 \text{ lb/(lb)}$ | DEW POINT  | $W_s \times 10^3 \text{ lb/(lb)}$ |
|------------|-----------------------------------|------------|-----------------------------------|
| 60         | 11.080                            | 50         | 7.658                             |
| 59         | 10.690                            | 49         | 7.374                             |
| DIFFERENCE | 0.390                             | DIFFERENCE | 0.284                             |

The above values are given in Table 2, Chapter 3.

When cooling coils act as dehumidifying coils, the performance can be predicted accurately only from tests at a sufficient number of points to establish the definite performance characteristics of the coil under varying conditions of loading and of entering air. Dehumidifying coils employing volatile refrigerants are generally rated in conjunction with specific refrigerant distributing and flow control equipment. The combination of the coil with its refrigerant control equipment (such as distributor and expansion valve, and capillary tube or float valve) must be tested at both the higher and lower capacities of its rated range. The lower capacities

impose a test on the distributor to provide equal distribution and on the control to modulate without hunting at the lower capacities. The higher capacities result in a greater pressure drop through the coil system and a test of the maximum feeding capacity of the flow control device at various head pressures.

Most coil manufacturers have their own methods of producing performance rating tables from a suitable number of coil performance tests. Several such methods have been reported in the literature of the industry. A standard titled Standard Methods of Testing and Rating Forced-Circulation Air-Cooling and Air-Heating Coils has been completed by the Heating and Cooling Coil Manufacturers' Association and the Air-Conditioning and Refrigeration Institute.

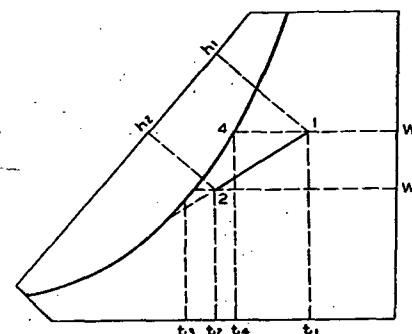


FIG. 13. PSYCHROMETRIC ARRANGEMENT OF COOLING COIL IN CENTRAL SYSTEM

### DETERMINING REFRIGERATION LOAD

The following determination of the refrigeration load shows a division of the true *sensible* and *latent* heat loss of the air, which is accurate within the limitations of the data. These divisions will not correspond to load determination obtained from approximate factors or constants.

The total refrigeration load  $q_t$  of a cooling and dehumidifying coil (or air washer) is indicated on Fig. 13 and consists of the following components:

1. The *sensible heat*  $q_s$  removed from the dry air and moisture in cooling from entering temperature  $t_1$  to leaving temperature  $t_2$ .
2. The *latent heat*  $q_e$  removed to condense the moisture at the dew-point temperature  $t_d$  of the entering air.
3. The heat of *subcooling*  $q_w$  removed from the condensate in cooling it from the condensing temperature  $t_c$  to the leaving condensate temperature  $t_3$ .

Items 1, 2, and 3 may be related by

$$q_t = q_s + q_e + q_w \quad (5)$$

If only the *total heat* value is desired, it may be computed by

$$q_t = (h_1 - h_2) - (W_1 - W_2)h_{w2} \quad (6)$$

where

$h_1$  and  $h_2$  = enthalpy at points 1 and 2 respectively.

$W_1$  and  $W_2$  = humidity ratio at points 1 and 2 respectively.  
 $h_{w2}$  = enthalpy of saturated liquid at the final temperature,  $t_2$ .

If a breakdown into *latent* and *sensible heat* components is desired, the following relations may be used:

The *latent heat* may be found from

$$q_e = (W_1 - W_2)h_{fg4} \quad (7)$$

where

$h_{fg4}$  = enthalpy at the condensing temperature,  $t_4$ .

The *sensible heat* may be shown to be

$$q_s + q_w = (h_1 - h_2) - (W_1 - W_2)h_{fg4} + (W_1 - W_2)(h_{w4} - h_{w2}) \quad (8)$$

where

$h_{fg4}$  = enthalpy at the condensing temperature,  $t_4$ .

$h_{w4}$  = enthalpy of saturated liquid at condensing temperature,  $t_4$ .

The last term in Equation 8 is the heat of *subcooling* the condensate from the condensing temperature  $t_4$  to its final temperature  $t_2$ . Then,

$$q_w = (W_1 - W_2)(h_{w4} - h_{w2}) \quad (9)$$

All values for solving the foregoing equations may be found on the ASHAE Psychrometric Chart and Tables 2 and 3 of Chapter 3.

**Example 1:** Air enters a coil at 90 F dry-bulb, 75 F wet-bulb; it leaves at 61 F dry-bulb, 58 F wet-bulb; leaving water is assumed to leave at a temperature between the leaving air dew point and coil surface temperature of 54 F. Find the total, latent, and sensible cooling loads on the coil.

**Solution:** From the ASHAE Psychrometric Chart, find the following:

$h_1 = 38.42$  Btu per lb of dry air.  $W_1 = 0.01525$  lb per lb of dry air.  
 $h_2 = 25.10$  Btu per lb of dry air.  $W_2 = 0.00960$  lb per lb of dry air.  
 $t_4 = 69$  F wet-bulb of entering air.

From Table 3, find:

$h_{w4} = 37.11$  Btu per lb.  $h_{fg4} = 1054.27$  Btu per lb.  
 $h_{w2} = 22.12$  Btu per lb.  $h_{g4} = 1091.34$  Btu per lb.

The total heat from Equation 6 is

$$q_t = (38.42 - 25.10) - (0.01525 - 0.00960) \times 22.12 = 13.32 - (0.00565 \times 22.12) = 13.32 - 0.12 = 13.20 \text{ Btu per lb dry air.}$$

The *latent heat* from Equation 7 is

$$q_e = 0.00565 \times 1054.27 = 5.96 \text{ Btu per lb of dry air.}$$

The *sensible heat* by difference, is

$$q_s + q_w = q_t - q_e = 13.20 - 5.96 = 7.24 \text{ Btu per lb of dry air.}$$

Or the *sensible heat* may be computed from Equation 8 as

$$\begin{aligned} q_s + q_w &= (38.42 - 25.10) - (0.00565 \times 1091.34) + 0.00565(37.11 - 22.12) \\ &= 13.32 - 6.16 + 0.00565 \times 14.99 \\ &= 13.32 - 6.16 + 0.08 = 7.24 \text{ Btu per lb of dry air.} \end{aligned}$$

The *sub-cooling* of the condensate as a part of the sensible heat is indicated by the last term of the equation, 0.08 Btu per lb of dry air.

## CHAPTER 37 REFRIGERATION

Refrigeration Theory: Definitions and Basic Concepts, Refrigerants, Vapor Compression Refrigeration Cycles, Clearance and Volumetric Efficiency, Complex Refrigeration Cycles, Air Cycle, Steam Jet, Absorption and Ice Systems, Heat Pump; Basic Refrigeration Equipment: Compression Machines, Condensers, Evaporators and Coolers; Refrigeration Controls, Piping and Accessories; Equipment Characteristics and Selection

WITH the increasing use of all-year comfort air conditioning installations, the importance of refrigeration to the air conditioning engineer has been greatly magnified. The details of equipment operation, maintenance and design remain problems for the refrigeration engineer, but the air conditioning engineer does retain a responsibility to the customer which requires on his part some knowledge of the different refrigeration cycles and the relative merits of each. In order to assist in meeting this need, the present chapter has been divided into four parts, the first covering the fundamental technical relationships which govern the selection and analysis of an operating cycle, the next two presenting brief discussions of basic refrigerating equipment and auxiliaries, and the last, information on selection criteria.

### REFRIGERATION THEORY

#### Definitions and Basic Concepts

The *ton of refrigeration* is a quantity unit which originated in the days when harvested ice was the principal source of summer cooling. By definition the *ton* is the cooling effect realized when one ton of 32 F ice melts to water at 32 F; since the latent heat of fusion of ice is 144 Btu per pound, the *ton* represents a unit cooling effect of  $144 \times 2,000 = 288,000$  Btu. In common practice the *ton* is usually considered a rate (rather than quantity) unit, and is taken as 288,000 Btu per day (24 hours), or 12,000 Btu per hour, or 200 Btu per minute. Thus for air conditioning calculations, the size of the requisite refrigeration machine, expressed in tons, can be obtained by dividing the heat gain of the structure, expressed in Btu per hour, by 12,000. In equation form:

$$H_t = (\text{Btu per hour heat gain}) \div 12,000 \quad (1)$$

where

$H_t$  = load in tons.

The *working substance*, or *refrigerant*, is the fluid which carries heat through the refrigeration cycle from the evaporator, where heat enters the refrigerant, to the condenser where the heat is discharged to some cooling medium. The great majority of modern refrigeration systems use a liquefiable vapor as the working substance. By altering the pressure of the refrigerant its boiling temperature is changed, allowing the material to *boil* in the evaporator at a temperature sufficiently lower than that of the conditioned space, to insure maintenance of an effective heat transfer rate from

the space (or in some cases from a secondary cooling fluid such as brine or cold water) to the refrigerant. The vapor formed in the evaporator is then raised in pressure (by a compressor, or by the absorber-generator combination of the absorption system) until its new boiling temperature exceeds the temperature of the available cooling medium. Under these conditions, heat transfer is established from the refrigerant vapor to the cooling medium with resultant condensation of the refrigerant. When condensed, the high-pressure liquid refrigerant is reduced in pressure and again allowed to boil in the evaporator.

In order to permit evaluation of the effectiveness with which any given cycle operates, some term is desirable which would be comparable to the *efficiency* that is used for heat engines. In refrigeration the desired effect is heat extraction, and the cost of achieving this extraction is the amount of energy which must be supplied as shaft work. Thus the ratio of refrigerating effect to the heat equivalent of the compressor work is used as a measure of effectiveness, and is defined as the coefficient of performance.

If the desired effect is the rejection of heat through the condenser instead of heat extraction through the evaporator, the refrigeration system is then termed a heat pump. In this case the coefficient of performance is the ratio of the heat rejected from the condenser to the heat equivalent of the compressor work. The coefficient of performance for the heat pump is greater than that for a system operating as a refrigerating machine, because all mechanical shaft work required to operate the compressor is dissipated as useful heat through the condenser.

The Carnot cycle, an ideal, thermodynamically reversible cycle consisting of an adiabatic expansion and an isothermal expansion, followed by an adiabatic compression and an isothermal compression to form a closed cycle, may be shown to be a measure of the maximum possible conversion of heat energy into mechanical energy. In its reversed form it is a measure of the maximum performance possible for any refrigeration cycle operating either as a refrigerator or as a heat pump. Although it cannot be applied in an actual machine because of the impossibility of obtaining complete reversibility, it is, nevertheless, extremely valuable as a criterion of inherent limitations. The coefficient of performance (CP) of a reversed Carnot cycle system operating as a refrigeration system is

$$(CP) = \frac{T_e}{T_c - T_e} \quad (2)$$

where

$T_e$  = evaporator temperature, Fahrenheit degrees, absolute.  
 $T_c$  = condenser temperature, Fahrenheit degrees, absolute.

With the ideal Carnot cycle operating as a heat pump, the coefficient of performance is

$$(CP) = \frac{T_c}{T_c - T_e} \quad (3)$$

The Carnot cycle coefficient of performance for both a refrigerating machine and a heat pump increases as the spread between the evaporator and the condenser temperatures decreases. In general, the same is true for an actual system operating as either a refrigerating machine or a heat pump.

### Refrigerants

A desirable refrigerant should possess chemical, physical, and thermodynamic properties which permit its efficient application in refrigerating systems. In addition, when the volume of the charge is large, there should be little or no danger to health or to property in case of its escape.

Thermodynamically, a material for use as a refrigerant should have a large latent heat of vaporization since it is this heat quantity—subject to minor variations—which constitutes the working effectiveness of the refrigerant. Further, since the work required to compress a vapor increases rapidly with the pressure ratio, the thermodynamic characteristics of the fluid should be such that the required low-to-high temperature range can be achieved with only a moderate change in ratio. A further consideration, from the standpoint of practical operating effectiveness, is that the suction pressure should not be below atmospheric (to prevent leakage of air into the refrigerant lines) nor should the condenser pressure be excessively high (to prevent need for extra-heavy construction). The specific volume-specific enthalpy relationship is also important because some materials would have such low density, when in vapor form, that impractical compressor displacements would be needed to handle the suction vapor.

Properties of refrigerants are usually given either in tabular or graphic form. In contrast to the temperature-entropy plotting which is used almost exclusively in steam-power work, refrigeration problems are usually referred to a pressure-enthalpy chart. The advantage of pressure-enthalpy plotting is that linear distances on the chart correspond to energy gains or losses, and the two types of processes, constant-pressure and constant-enthalpy, which occur most frequently in refrigeration cycles, can both be represented by straight vertical or horizontal lines. Figs. 1 and 2 present pressure enthalpy charts for dichlorodifluoromethane,  $\text{CCl}_2\text{F}_2$ , and monochlorodifluoromethane,  $\text{CHClF}_2$ , respectively. Although tabular arrangements of refrigerant properties require interpolation between values, they have the advantage of an accuracy greater than that obtainable from a chart. Tables 1, 2, and 3 give the thermodynamic properties of three of the more common refrigerants used in air conditioning installations: dichlorodifluoromethane, monochlorodifluoromethane and monofluorotrichloromethane,  $\text{CCl}_3\text{F}$ , the first two of these are commonly used in reciprocating compressors; the last refrigerant is used in centrifugal machines.

Referring to Table 1, the first column gives the range of saturation temperatures likely to occur in practice. The second column gives the saturation pressure expressed in pounds per square inch absolute corresponding to a given temperature, while the next six columns give the three fundamental specific properties, volume, enthalpy, and entropy, of the saturated liquid and saturated vapor, respectively. The last four columns give values of enthalpy and entropy for gases with 25 deg and with 50 deg of superheat; note particularly that the column heading 50 F *superheat* means, not that the gas is at a temperature of 50 F, but that its temperature exceeds by 50 deg the saturation temperature corresponding to its actual pressure. Thus,  $\text{CCl}_2\text{F}_2$  vapor at 38.0 psig and 91 F possesses 50 deg of superheat, since its saturation temperature corresponding to 52.7 psia is 41 F.

The tabular arrangements of refrigerant properties are literally for saturated or superheated materials only. In many cases, however, the engineer must work with sub-cooled liquids. With an accuracy sufficient for all practical purposes, the specific volume and the enthalpy of any sub-cooled

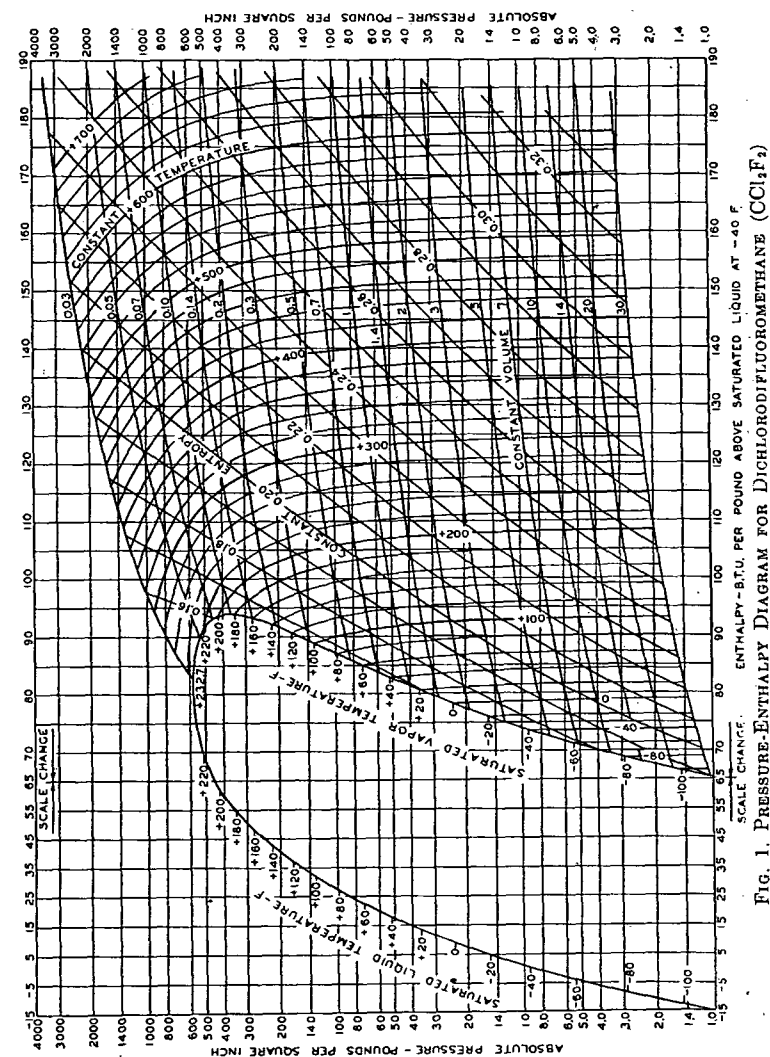


Fig. 1. PRESSURE-ENTHALPY DIAGRAM FOR DICHLORODIFLUOROMETHANE ( $\text{CCl}_2\text{F}_2$ )  
Temperature—F; Volume—Cu Ft per Lb; Enthalpy—Btu per Lb.

refrigerant can be taken as equal to the values read from the tables for a saturated liquid at the same temperature. Thus, if  $\text{CCl}_2\text{F}_2$  at 121 psia and 40 F is passing through a pipe, its volume and enthalpy can be determined from Table 1 as 0.0116 cu ft per pound and 17.0 Btu per pound.

Frequently it is necessary to determine the properties of a wet vapor or of a mixture of liquid with some added vapor, such as is found at discharge from an expansion valve. This can be done from the tables by noting that the specific enthalpy of the mixture must be equal to that of the saturated liquid, plus a fraction of the latent heat of vaporization equal to the fraction

TABLE 1. PROPERTIES OF DICHLORODIFLUOROMETHANE ( $\text{CCl}_2\text{F}_2$ )

| Sat. Temp. F | Abs. Press. Lb per Sq In. | VOLUME |       | ENTHALPY AND ENTROPY TAKEN FROM -40 F |       |         |         |                |         |                |         |
|--------------|---------------------------|--------|-------|---------------------------------------|-------|---------|---------|----------------|---------|----------------|---------|
|              |                           | Liquid | Vapor | Enthalpy                              |       | Entropy |         | 25 F Superheat |         | 50 F Superheat |         |
|              |                           |        |       | Liquid                                | Vapor | Liquid  | Vapor   | Enthalpy       | Entropy | Enthalpy       | Entropy |
| 0            | 23.87                     | 0.0110 | 1.637 | 8.25                                  | 78.21 | 0.01869 | 0.17091 | 81.71          | 0.17829 | 85.26          | 0.18547 |
| 2            | 24.89                     | 0.0110 | 1.574 | 8.67                                  | 78.44 | 0.01961 | 0.17075 | 81.94          | 0.17812 | 85.51          | 0.18529 |
| 4            | 25.96                     | 0.0111 | 1.514 | 9.10                                  | 78.67 | 0.02052 | 0.17060 | 82.17          | 0.17795 | 85.76          | 0.18511 |
| 5            | 26.51                     | 0.0111 | 1.485 | 9.32                                  | 78.79 | 0.02097 | 0.17052 | 82.29          | 0.17786 | 85.89          | 0.18502 |
| 6            | 27.05                     | 0.0111 | 1.457 | 9.53                                  | 78.90 | 0.02143 | 0.17045 | 82.41          | 0.17778 | 86.01          | 0.18494 |
| 8            | 28.18                     | 0.0111 | 1.403 | 9.96                                  | 79.13 | 0.02235 | 0.17030 | 82.66          | 0.17765 | 86.26          | 0.18477 |
| 10           | 29.35                     | 0.0112 | 1.351 | 10.39                                 | 79.36 | 0.02328 | 0.17015 | 82.90          | 0.17747 | 86.51          | 0.18460 |
| 12           | 30.56                     | 0.0112 | 1.301 | 10.82                                 | 79.59 | 0.02419 | 0.17001 | 83.14          | 0.17733 | 86.76          | 0.18444 |
| 14           | 31.80                     | 0.0112 | 1.253 | 11.26                                 | 79.82 | 0.02510 | 0.16987 | 83.38          | 0.17720 | 87.01          | 0.18429 |
| 16           | 33.08                     | 0.0112 | 1.207 | 11.70                                 | 80.05 | 0.02601 | 0.16974 | 83.61          | 0.17706 | 87.26          | 0.18413 |
| 18           | 34.40                     | 0.0113 | 1.163 | 12.12                                 | 80.27 | 0.02692 | 0.16961 | 83.85          | 0.17693 | 87.51          | 0.18397 |
| 20           | 35.75                     | 0.0113 | 1.121 | 12.55                                 | 80.49 | 0.02783 | 0.16949 | 84.09          | 0.17679 | 87.76          | 0.18382 |
| 22           | 37.15                     | 0.0113 | 1.081 | 13.00                                 | 80.72 | 0.02873 | 0.16938 | 84.32          | 0.17666 | 88.00          | 0.18369 |
| 24           | 38.58                     | 0.0113 | 1.043 | 13.44                                 | 80.95 | 0.02963 | 0.16926 | 84.55          | 0.17652 | 88.24          | 0.18355 |
| 26           | 40.07                     | 0.0114 | 1.007 | 13.88                                 | 81.17 | 0.03053 | 0.16913 | 84.79          | 0.17639 | 88.49          | 0.18342 |
| 28           | 41.59                     | 0.0114 | 0.973 | 14.32                                 | 81.39 | 0.03143 | 0.16900 | 85.02          | 0.17625 | 88.73          | 0.18328 |
| 30           | 43.16                     | 0.0115 | 0.939 | 14.76                                 | 81.61 | 0.03233 | 0.16887 | 85.25          | 0.17612 | 88.97          | 0.18315 |
| 32           | 44.77                     | 0.0115 | 0.908 | 15.21                                 | 81.83 | 0.03323 | 0.16876 | 85.48          | 0.17600 | 89.21          | 0.18303 |
| 34           | 46.42                     | 0.0115 | 0.877 | 15.65                                 | 82.05 | 0.03413 | 0.16865 | 85.71          | 0.17589 | 89.45          | 0.18291 |
| 36           | 48.13                     | 0.0116 | 0.848 | 16.10                                 | 82.27 | 0.03502 | 0.16854 | 85.95          | 0.17577 | 89.68          | 0.18280 |
| 38           | 49.88                     | 0.0116 | 0.819 | 16.55                                 | 82.49 | 0.03591 | 0.16843 | 86.18          | 0.17566 | 89.92          | 0.18268 |
| 39           | 50.78                     | 0.0116 | 0.806 | 16.77                                 | 82.60 | 0.03635 | 0.16838 | 86.29          | 0.17560 | 90.04          | 0.18262 |
| 40           | 51.68                     | 0.0116 | 0.792 | 17.00                                 | 82.71 | 0.03680 | 0.16833 | 86.41          | 0.17554 | 90.16          | 0.18256 |
| 41           | 52.70                     | 0.0116 | 0.779 | 17.23                                 | 82.82 | 0.03725 | 0.16828 | 86.52          | 0.17549 | 90.28          | 0.18251 |
| 42           | 53.51                     | 0.0116 | 0.767 | 17.46                                 | 82.93 | 0.03770 | 0.16823 | 86.64          | 0.17544 | 90.40          | 0.18245 |
| 44           | 55.40                     | 0.0117 | 0.742 | 17.91                                 | 83.15 | 0.03859 | 0.16813 | 86.86          | 0.17534 | 90.65          | 0.18235 |
| 46           | 57.35                     | 0.0117 | 0.718 | 18.36                                 | 83.36 | 0.03948 | 0.16803 | 87.09          | 0.17525 | 90.89          | 0.18224 |
| 48           | 59.35                     | 0.0117 | 0.695 | 18.82                                 | 83.57 | 0.04037 | 0.16794 | 87.31          | 0.17515 | 91.14          | 0.18214 |
| 50           | 61.39                     | 0.0118 | 0.673 | 19.27                                 | 83.78 | 0.04126 | 0.16785 | 87.54          | 0.17505 | 91.38          | 0.18203 |
| 52           | 63.49                     | 0.0118 | 0.652 | 19.72                                 | 83.99 | 0.04215 | 0.16776 | 87.76          | 0.17496 | 91.61          | 0.18193 |
| 54           | 65.63                     | 0.0118 | 0.632 | 20.18                                 | 84.20 | 0.04304 | 0.16767 | 87.98          | 0.17486 | 91.83          | 0.18184 |
| 56           | 67.84                     | 0.0119 | 0.612 | 20.64                                 | 84.41 | 0.04392 | 0.16758 | 88.20          | 0.17477 | 92.06          | 0.18174 |
| 58           | 70.10                     | 0.0119 | 0.593 | 21.11                                 | 84.62 | 0.04480 | 0.16749 | 88.42          | 0.17467 | 92.28          | 0.18165 |
| 60           | 72.41                     | 0.0119 | 0.575 | 21.57                                 | 84.82 | 0.04568 | 0.16741 | 88.64          | 0.17458 | 92.51          | 0.18155 |
| 62           | 74.77                     | 0.0120 | 0.557 | 22.03                                 | 85.02 | 0.04657 | 0.16733 | 88.86          | 0.17450 | 92.74          | 0.18147 |
| 64           | 77.20                     | 0.0120 | 0.540 | 22.49                                 | 85.22 | 0.04745 | 0.16725 | 89.07          | 0.17442 | 92.97          | 0.18139 |
| 66           | 79.67                     | 0.0120 | 0.524 | 22.95                                 | 85.42 | 0.04833 | 0.16717 | 89.29          | 0.17433 | 93.20          | 0.18130 |
| 68           | 82.24                     | 0.0121 | 0.508 | 23.42                                 | 85.62 | 0.04921 | 0.16709 | 89.50          | 0.17425 | 93.43          | 0.18122 |
| 70           | 84.82                     | 0.0121 | 0.493 | 23.90                                 | 85.82 | 0.05009 | 0.16701 | 89.72          | 0.17417 | 93.66          | 0.18114 |
| 72           | 87.50                     | 0.0121 | 0.479 | 24.37                                 | 86.02 | 0.05097 | 0.16693 | 89.93          | 0.17409 | 93.89          | 0.18106 |
| 74           | 90.20                     | 0.0122 | 0.464 | 24.84                                 | 86.22 | 0.05185 | 0.16685 | 90.14          | 0.17402 | 94.12          | 0.18098 |
| 76           | 93.00                     | 0.0122 | 0.451 | 25.32                                 | 86.42 | 0.05272 | 0.16677 | 90.36          | 0.17394 | 94.34          | 0.18091 |
| 78           | 95.85                     | 0.0123 | 0.438 | 25.80                                 | 86.61 | 0.05359 | 0.16669 | 90.57          | 0.17387 | 94.57          | 0.18083 |
| 80           | 98.76                     | 0.0123 | 0.425 | 26.28                                 | 86.80 | 0.05446 | 0.16662 | 90.78          | 0.17379 | 94.80          | 0.18075 |
| 82           | 101.70                    | 0.0123 | 0.413 | 26.76                                 | 86.99 | 0.05534 | 0.16655 | 90.98          | 0.17372 | 95.01          | 0.18068 |
| 84           | 104.8                     | 0.0124 | 0.401 | 27.24                                 | 87.18 | 0.05621 | 0.16648 | 91.18          | 0.17365 | 95.22          | 0.18061 |
| 86           | 107.9                     | 0.0124 | 0.389 | 27.72                                 | 87.37 | 0.05708 | 0.16640 | 91.37          | 0.17358 | 95.44          | 0.18054 |
| 88           | 111.1                     | 0.0124 | 0.378 | 28.21                                 | 87.56 | 0.05795 | 0.16632 | 91.57          | 0.17351 | 95.65          | 0.18047 |
| 90           | 114.3                     | 0.0125 | 0.368 | 28.70                                 | 87.74 | 0.05882 | 0.16624 | 91.77          | 0.17344 | 95.86          | 0.18040 |
| 92           | 117.7                     | 0.0125 | 0.357 | 29.19                                 | 87.92 | 0.05969 | 0.16616 | 91.97          | 0.17337 | 96.07          | 0.18033 |
| 94           | 121.0                     | 0.0126 | 0.347 | 29.68                                 | 88.10 | 0.06056 | 0.16608 | 92.16          | 0.17330 | 96.28          | 0.18026 |
| 96           | 124.5                     | 0.0126 | 0.338 | 30.18                                 | 88.28 | 0.06143 | 0.16600 | 92.36          | 0.17322 | 96.50          | 0.18018 |
| 98           | 128.0                     | 0.0126 | 0.328 | 30.67                                 | 88.45 | 0.06230 | 0.16592 | 92.55          | 0.17315 | 96.71          | 0.18011 |
| 100          | 131.6                     | 0.0127 | 0.319 | 31.16                                 | 88.62 | 0.06316 | 0.16584 | 92.75          | 0.17308 | 96.92          | 0.18004 |
| 102          | 135.3                     | 0.0127 | 0.310 | 31.65                                 | 88.79 | 0.06403 | 0.16576 | 92.93          | 0.17301 | 97.12          | 0.17998 |
| 104          | 139.0                     | 0.0128 | 0.302 | 32.15                                 | 88.95 | 0.06490 | 0.16568 | 93.11          | 0.17294 | 97.32          | 0.17993 |
| 106          | 142.8                     | 0.0128 | 0.293 | 32.65                                 | 89.11 | 0.06577 | 0.16560 | 93.30          | 0.17288 | 97.53          | 0.17987 |
| 108          | 146.8                     | 0.0129 | 0.285 | 33.15                                 | 89.27 | 0.06663 | 0.16551 | 93.48          | 0.17281 | 97.73          | 0.17982 |
| 110          | 150.7                     | 0.0129 | 0.277 | 33.65                                 | 89.43 | 0.06749 | 0.16542 | 93.66          | 0.17274 | 97.93          | 0.17976 |
| 112          | 154.8                     | 0.0130 | 0.269 | 34.15                                 | 89.58 | 0.06836 | 0.16533 | 93.82          | 0.17266 | 98.11          | 0.17969 |
| 114          | 158.9                     | 0.0130 | 0.262 | 34.65                                 | 89.73 | 0.06922 | 0.16524 | 93.98          | 0.17258 | 98.29          | 0.17961 |
| 116          | 163.1                     | 0.0131 | 0.254 | 35.15                                 | 89.87 | 0.07008 | 0.16515 | 94.15          | 0.17249 | 98.48          | 0.17954 |
| 118          | 167.4                     | 0.0131 | 0.247 | 35.65                                 | 90.01 | 0.07094 | 0.16505 | 94.31          | 0.17241 | 98.66          | 0.17946 |
| 120          | 171.8                     | 0.0132 | 0.240 | 36.16                                 | 90.15 | 0.07180 | 0.16495 | 94.47          | 0.17233 | 98.84          | 0.17939 |
| 122          | 176.2                     | 0.0132 | 0.233 | 36.66                                 | 90.28 | 0.07266 | 0.16484 | 94.63          | 0.17224 | 99.01          | 0.17931 |
| 124          | 180.8                     | 0.0133 | 0.227 | 37.16                                 | 90.40 | 0.07352 | 0.16473 | 94.78          | 0.17215 | 99.18          | 0.17922 |
| 126          | 185.4                     | 0.0133 | 0.220 | 37.67                                 | 90.52 | 0.07437 | 0.16462 | 94.94          | 0.17206 | 99.35          | 0.17914 |
| 128          | 190.1                     | 0.0134 | 0.214 | 38.18                                 | 90.64 | 0.07522 | 0.16450 | 95.09          | 0.17196 | 99.51          | 0.17906 |
| 130          | 194.9                     | 0.0134 | 0.208 | 38.69                                 | 90.76 | 0.07607 | 0.16438 | 95.25          | 0.17186 | 99.70          | 0.17897 |
| 132          | 199.8                     | 0.0135 | 0.202 | 39.19                                 | 90.86 | 0.07691 | 0.16425 | 95.41          | 0.17176 | 99.87          | 0.17889 |
| 134          | 204.8                     | 0.0135 | 0.196 | 39.70                                 | 90.96 | 0.07775 | 0.16411 | 95.56          | 0.17166 | 100.04         | 0.17881 |
| 136          | 209.9                     | 0.0136 | 0.191 | 40.21                                 | 91.06 | 0.07858 | 0.16396 | 95.72          | 0.17156 | 100.22         | 0.17873 |
| 138          | 215.0                     | 0.0137 | 0.185 | 40.72                                 | 91.15 | 0.07941 | 0.16380 | 95.87          | 0.17145 | 100.39         | 0.17864 |
| 140          | 220.2                     | 0.0138 | 0.180 | 41.24                                 | 91.24 | 0.08024 | 0.16363 | 96.03          | 0.17134 | 100.56         | 0.17856 |



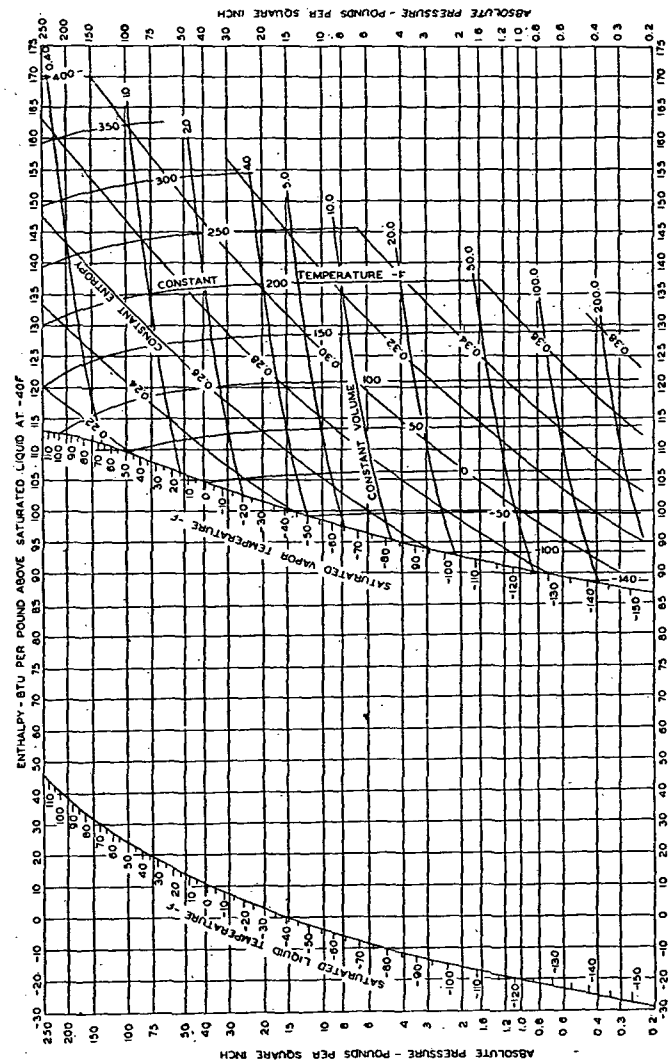


FIG. 2. PRESSURE-ENTHALPY DIAGRAM FOR MONOCHLORODIFLUOROMETHANE (CHClF<sub>2</sub>)  
Temperature—F; Volume—Cu Ft per Lb; Enthalpy—Btu per Lb (F deg).

of refrigerant which is present in vapor form. Consider, for example, CCl<sub>2</sub>F<sub>2</sub> with a quality (the percent in vapor form) of 30 percent; the enthalpy of this material would be equal to

$$h_m = h_l + 0.30 (h_v - h_l) \quad (4)$$

where

- $h_m$  = specific enthalpy of the mixture.
- $h_l$  = specific enthalpy of the liquid.
- $h_v$  = specific enthalpy of the saturated vapor.

TABLE 2. PROPERTIES OF MONOCHLORODIFLUOROMETHANE (CHClF<sub>2</sub>)

| SAT<br>TEMP<br>F | ABS<br>PRESS<br>LB PER<br>SQ IN. | VOLUME  |        | ENTHALPY AND ENTROPY TAKEN FROM -40 F |        |         |        |                     |              |                      |              |
|------------------|----------------------------------|---------|--------|---------------------------------------|--------|---------|--------|---------------------|--------------|----------------------|--------------|
|                  |                                  |         |        | ENTHALPY                              |        | ENTROPY |        | 50 DEG<br>SUPERHEAT |              | 100 DEG<br>SUPERHEAT |              |
|                  |                                  | Liquid  | Vapor  | Liquid                                | Vapor  | Liquid  | Vapor  | Enthalpy            | En-<br>tropy | Enthalpy             | En-<br>tropy |
| 0                | 38.79                            | 0.01192 | 1.373  | 10.63                                 | 105.02 | 0.0240  | 0.2293 | 112.35              | 0.2446       | 120.00               | 0.2590       |
| 2                | 40.43                            | 0.01195 | 1.320  | 11.17                                 | 105.24 | 0.0251  | 0.2289 | 112.59              | 0.2442       | 120.26               | 0.2586       |
| 4                | 42.14                            | 0.01198 | 1.270  | 11.70                                 | 105.45 | 0.0262  | 0.2285 | 112.83              | 0.2438       | 120.52               | 0.2581       |
| 6                | 43.91                            | 0.01201 | 1.246  | 11.97                                 | 105.56 | 0.0268  | 0.2283 | 112.95              | 0.2436       | 120.65               | 0.2579       |
| 8                | 45.74                            | 0.01205 | 1.175  | 12.23                                 | 105.66 | 0.0274  | 0.2280 | 113.07              | 0.2434       | 120.78               | 0.2577       |
| 10               | 47.63                            | 0.01208 | 1.130  | 12.76                                 | 105.87 | 0.0285  | 0.2276 | 113.31              | 0.2430       | 121.04               | 0.2572       |
| 12               | 49.58                            | 0.01211 | 1.088  | 13.29                                 | 106.08 | 0.0296  | 0.2272 | 113.55              | 0.2428       | 121.30               | 0.2568       |
| 14               | 51.59                            | 0.01215 | 1.048  | 13.82                                 | 106.29 | 0.0307  | 0.2268 | 113.79              | 0.2422       | 121.56               | 0.2564       |
| 16               | 53.68                            | 0.01218 | 1.009  | 14.36                                 | 106.50 | 0.0319  | 0.2264 | 114.02              | 0.2418       | 121.82               | 0.2560       |
| 18               | 55.79                            | 0.01222 | 0.9721 | 14.90                                 | 106.71 | 0.0330  | 0.2260 | 114.25              | 0.2414       | 122.08               | 0.2556       |
| 20               | 57.98                            | 0.01225 | 0.9369 | 15.44                                 | 106.92 | 0.0341  | 0.2257 | 114.48              | 0.2410       | 122.33               | 0.2552       |
| 22               | 60.23                            | 0.01229 | 0.9032 | 15.98                                 | 107.13 | 0.0352  | 0.2253 | 114.71              | 0.2406       | 122.59               | 0.2548       |
| 24               | 62.55                            | 0.01232 | 0.8707 | 16.52                                 | 107.33 | 0.0364  | 0.2249 | 114.94              | 0.2402       | 122.84               | 0.2544       |
| 26               | 64.94                            | 0.01236 | 0.8398 | 17.06                                 | 107.53 | 0.0375  | 0.2246 | 115.17              | 0.2398       | 123.10               | 0.2540       |
| 28               | 67.40                            | 0.01239 | 0.8100 | 17.61                                 | 107.73 | 0.0387  | 0.2242 | 115.40              | 0.2395       | 123.35               | 0.2537       |
| 30               | 69.93                            | 0.01243 | 0.7816 | 18.17                                 | 107.93 | 0.0398  | 0.2239 | 115.62              | 0.2391       | 123.60               | 0.2533       |
| 32               | 72.53                            | 0.01247 | 0.7543 | 18.74                                 | 108.13 | 0.0409  | 0.2235 | 115.84              | 0.2387       | 123.85               | 0.2529       |
| 34               | 75.21                            | 0.01250 | 0.7283 | 19.32                                 | 108.33 | 0.0421  | 0.2232 | 116.07              | 0.2383       | 124.10               | 0.2525       |
| 36               | 77.97                            | 0.01254 | 0.7032 | 19.90                                 | 108.52 | 0.0433  | 0.2228 | 116.29              | 0.2380       | 124.35               | 0.2522       |
| 38               | 80.81                            | 0.01258 | 0.6791 | 20.49                                 | 108.71 | 0.0445  | 0.2225 | 116.52              | 0.2376       | 124.59               | 0.2518       |
| 40               | 83.72                            | 0.01262 | 0.6559 | 21.09                                 | 108.90 | 0.0457  | 0.2222 | 116.74              | 0.2373       | 124.84               | 0.2515       |
| 42               | 86.69                            | 0.01266 | 0.6339 | 21.70                                 | 109.09 | 0.0469  | 0.2218 | 116.96              | 0.2369       | 125.08               | 0.2511       |
| 44               | 89.74                            | 0.01270 | 0.6126 | 22.29                                 | 109.27 | 0.0481  | 0.2215 | 117.18              | 0.2366       | 125.32               | 0.2508       |
| 46               | 92.88                            | 0.01274 | 0.5922 | 22.90                                 | 109.45 | 0.0493  | 0.2211 | 117.40              | 0.2363       | 125.56               | 0.2504       |
| 48               | 96.10                            | 0.01278 | 0.5726 | 23.50                                 | 109.63 | 0.0505  | 0.2208 | 117.61              | 0.2359       | 125.80               | 0.2501       |
| 50               | 99.40                            | 0.01282 | 0.5537 | 24.11                                 | 109.80 | 0.0516  | 0.2205 | 117.82              | 0.2356       | 126.04               | 0.2497       |
| 52               | 102.8                            | 0.01286 | 0.5355 | 24.73                                 | 109.98 | 0.0528  | 0.2201 | 118.02              | 0.2353       | 126.27               | 0.2494       |
| 54               | 106.2                            | 0.01290 | 0.5184 | 25.34                                 | 110.14 | 0.0540  | 0.2198 | 118.22              | 0.2350       | 126.50               | 0.2491       |
| 56               | 109.8                            | 0.01294 | 0.5014 | 25.95                                 | 110.30 | 0.0552  | 0.2194 | 118.42              | 0.2347       | 126.73               | 0.2488       |
| 58               | 113.5                            | 0.01299 | 0.4849 | 26.58                                 | 110.47 | 0.0564  | 0.2191 | 118.62              | 0.2343       | 126.96               | 0.2484       |
| 60               | 117.2                            | 0.01303 | 0.4695 | 27.22                                 | 110.63 | 0.0576  | 0.2188 | 118.82              | 0.2340       | 127.19               | 0.2481       |
| 62               | 121.0                            | 0.01307 | 0.4546 | 27.83                                 | 110.78 | 0.0588  | 0.2185 | 119.01              | 0.2337       | 127.42               | 0.2478       |
| 64               | 124.9                            | 0.01312 | 0.4403 | 28.46                                 | 110.93 | 0.0600  | 0.2181 | 119.21              | 0.2334       | 127.65               | 0.2475       |
| 66               | 128.9                            | 0.01316 | 0.4264 | 29.09                                 | 111.08 | 0.0612  | 0.2178 | 119.40              | 0.2331       | 127.87               | 0.2472       |
| 68               | 133.0                            | 0.01320 | 0.4129 | 29.72                                 | 111.22 | 0.0624  | 0.2175 | 119.59              | 0.2327       | 128.10               | 0.2469       |
| 70               | 137.2                            | 0.01325 | 0.4000 | 30.35                                 | 111.35 | 0.0636  | 0.2172 | 119.77              | 0.2324       | 128.32               | 0.2466       |
| 72               | 141.5                            | 0.01330 | 0.3875 | 30.99                                 | 111.49 | 0.0648  | 0.2168 | 119.96              | 0.2321       | 128.54               | 0.2463       |
| 74               | 145.9                            | 0.01334 | 0.3754 | 31.65                                 | 111.63 | 0.0661  | 0.2165 | 120.15              | 0.2318       | 128.76               | 0.2460       |
| 76               | 150.4                            | 0.01339 | 0.3638 | 32.29                                 | 111.75 | 0.0673  | 0.2162 | 120.32              | 0.2315       | 128.97               | 0.2457       |
| 78               | 155.0                            | 0.01344 | 0.3526 | 32.94                                 | 111.88 | 0.0684  | 0.2158 | 120.50              | 0.2312       | 129.19               | 0.2455       |
| 80               | 159.7                            | 0.01349 | 0.3417 | 33.61                                 | 112.01 | 0.0696  | 0.2155 | 120.67              | 0.2309       | 129.40               | 0.2452       |
| 82               | 164.5                            | 0.01353 | 0.3313 | 34.27                                 | 112.13 | 0.0708  | 0.2151 | 120.85              | 0.2306       | 129.61               | 0.2449       |
| 84               | 169.4                            | 0.01358 | 0.3212 | 34.92                                 | 112.24 | 0.0720  | 0.2148 | 121.02              | 0.2303       | 129.82               | 0.2446       |
| 86               | 174.5                            | 0.01363 | 0.3113 | 35.60                                 | 112.36 | 0.0732  | 0.2144 | 121.18              | 0.2300       | 130.02               | 0.2443       |
| 88               | 179.6                            | 0.01368 | 0.3019 | 36.28                                 | 112.47 | 0.0744  | 0.2140 | 121.34              | 0.2297       | 130.23               | 0.2441       |
| 90               | 184.8                            | 0.01374 | 0.2928 | 36.94                                 | 112.57 | 0.0756  | 0.2137 | 121.50              | 0.2294       | 130.43               | 0.2438       |
| 92               | 190.1                            | 0.01379 | 0.2841 | 37.61                                 | 112.67 | 0.0768  | 0.2133 | 121.66              | 0.2291       | 130.63               | 0.2435       |
| 94               | 195.6                            | 0.01384 | 0.2755 | 38.28                                 | 112.76 | 0.0780  | 0.2130 | 121.82              | 0.2288       | 130.83               | 0.2432       |
| 96               | 201.2                            | 0.01390 | 0.2672 | 38.97                                 | 112.85 | 0.0792  | 0.2126 | 121.97              | 0.2285       | 131.03               | 0.2429       |
| 98               | 206.8                            | 0.01396 | 0.2594 | 39.65                                 | 112.93 | 0.0803  | 0.2122 | 122.12              | 0.2282       | 131.23               | 0.2427       |
| 100              | 212.6                            | 0.01402 | 0.2517 | 40.32                                 | 113.00 | 0.0815  | 0.2119 | 122.26              | 0.2279       | 131.42               | 0.2424       |
| 102              | 218.5                            | 0.01408 | 0.2443 | 40.98                                 | 113.06 | 0.0827  | 0.2115 | 122.40              | 0.2276       | 131.61               | 0.2421       |
| 104              | 224.6                            | 0.01414 | 0.2370 | 41.65                                 | 113.12 | 0.0839  | 0.2111 | 122.53              | 0.2273       | 131.80               | 0.2418       |
| 106              | 230.7                            | 0.01420 | 0.2301 | 42.32                                 | 113.16 | 0.0851  | 0.2107 | 122.66              | 0.2270       | 131.99               | 0.2416       |
| 108              | 237.0                            | 0.01426 | 0.2233 | 42.98                                 | 113.20 | 0.0862  | 0.2104 | 122.79              | 0.2267       | 132.17               | 0.2413       |
| 110              | 243.4                            | 0.01433 | 0.2167 | 43.66                                 | 113.24 | 0.0874  | 0.2100 | 122.92              | 0.2264       | 132.35               | 0.2411       |
| 112              | 249.9                            | 0.01440 | 0.2104 | 44.35                                 | 113.29 | 0.0886  | 0.2096 | 123.04              | 0.2261       | 132.53               | 0.2408       |
| 114              | 256.6                            | 0.01447 | 0.2043 | 45.04                                 | 113.34 | 0.0898  | 0.2093 | 123.16              | 0.2258       | 132.71               | 0.2405       |
| 116              | 263.4                            | 0.01454 | 0.1983 | 45.74                                 | 113.38 | 0.0909  | 0.2089 | 123.28              | 0.2255       | 132.88               | 0.2403       |
| 118              | 270.3                            | 0.01461 | 0.1926 | 46.44                                 | 113.42 | 0.0921  | 0.2085 | 123.40              | 0.2253       | 133.05               | 0.2400       |
| 120              | 277.3                            | 0.01469 | 0.1871 | 47.14                                 | 113.46 | 0.0933  | 0.2081 | 123.51              | 0.2250       | 133.22               | 0.2398       |
|                  |                                  |         |        | 47.85                                 | 113.52 | 0.0945  | 0.2078 | 123.62              | 0.2247       | 133.39               | 0.2395       |

Data from Kinetic Chemicals, Inc., 1945.



TABLE 3. PROPERTIES OF MONOFLUOROTRICHLOROMETHANE (CCl<sub>3</sub>F)

| SAT.<br>TEMP.<br>F | ABS.<br>PRESS.<br>LB PER<br>SQ IN. | VOLUME  |        | ENTHALPY AND ENTROPY TAKEN FROM -40 F |       |         |        |                |              |                |              |
|--------------------|------------------------------------|---------|--------|---------------------------------------|-------|---------|--------|----------------|--------------|----------------|--------------|
|                    |                                    |         |        | Enthalpy                              |       | Entropy |        | 25 F Superheat |              | 50 F Superheat |              |
|                    |                                    | Liquid  | Vapor  | Liquid                                | Vapor | Liquid  | Vapor  | En-<br>thalpy  | En-<br>tropy | En-<br>thalpy  | En-<br>tropy |
| 0                  | 2.59                               | 0.01020 | 13.700 | 7.81                                  | 90.4  | 0.0178  | 0.1975 | 93.9           | 0.2049       | 97.4           | 0.2120       |
| 5                  | 2.96                               | 0.01024 | 12.100 | 8.81                                  | 91.2  | 0.0200  | 0.1974 | 94.7           | 0.2047       | 97.2           | 0.2117       |
| 10                 | 3.38                               | 0.01028 | 10.700 | 9.82                                  | 92.0  | 0.0222  | 0.1973 | 95.5           | 0.2045       | 99.0           | 0.2114       |
| 15                 | 3.85                               | 0.01032 | 9.530  | 10.80                                 | 92.8  | 0.0243  | 0.1971 | 96.3           | 0.2043       | 99.8           | 0.2111       |
| 20                 | 4.36                               | 0.01036 | 8.490  | 11.90                                 | 93.7  | 0.0264  | 0.1970 | 97.2           | 0.2041       | 100.7          | 0.2109       |
| 25                 | 4.94                               | 0.01040 | 7.580  | 12.90                                 | 94.5  | 0.0286  | 0.1969 | 98.0           | 0.2039       | 101.5          | 0.2107       |
| 30                 | 5.57                               | 0.01045 | 6.770  | 13.90                                 | 95.3  | 0.0307  | 0.1969 | 98.8           | 0.2038       | 102.3          | 0.2105       |
| 35                 | 6.27                               | 0.01049 | 6.080  | 14.90                                 | 96.1  | 0.0328  | 0.1968 | 99.6           | 0.2037       | 103.1          | 0.2103       |
| 40                 | 7.03                               | 0.01053 | 5.460  | 16.00                                 | 96.8  | 0.0349  | 0.1968 | 100.3          | 0.2036       | 103.8          | 0.2101       |
| 45                 | 7.88                               | 0.01057 | 4.920  | 17.00                                 | 97.6  | 0.0370  | 0.1967 | 101.1          | 0.2035       | 104.6          | 0.2099       |
| 50                 | 8.79                               | 0.01062 | 4.440  | 18.10                                 | 98.4  | 0.0391  | 0.1967 | 101.9          | 0.2034       | 105.4          | 0.2098       |
| 55                 | 9.80                               | 0.01066 | 4.020  | 19.10                                 | 99.2  | 0.0412  | 0.1967 | 102.7          | 0.2033       | 106.2          | 0.2097       |
| 60                 | 10.90                              | 0.01071 | 3.640  | 20.20                                 | 100.0 | 0.0432  | 0.1967 | 103.5          | 0.2033       | 107.0          | 0.2096       |
| 65                 | 12.10                              | 0.01076 | 3.300  | 21.30                                 | 100.8 | 0.0453  | 0.1967 | 104.3          | 0.2032       | 107.8          | 0.2094       |
| 70                 | 13.40                              | 0.01081 | 3.000  | 22.40                                 | 101.5 | 0.0473  | 0.1967 | 105.0          | 0.2032       | 108.5          | 0.2093       |
| 75                 | 14.80                              | 0.01086 | 2.740  | 23.50                                 | 102.2 | 0.0493  | 0.1967 | 105.7          | 0.2031       | 109.2          | 0.2092       |
| 80                 | 16.30                              | 0.01091 | 2.500  | 24.50                                 | 102.9 | 0.0513  | 0.1966 | 106.4          | 0.2030       | 109.9          | 0.2090       |
| 85                 | 17.90                              | 0.01096 | 2.280  | 25.80                                 | 103.6 | 0.0533  | 0.1966 | 107.1          | 0.2029       | 110.6          | 0.2089       |
| 90                 | 19.70                              | 0.01101 | 2.090  | 26.70                                 | 104.4 | 0.0553  | 0.1966 | 107.9          | 0.2028       | 111.4          | 0.2088       |
| 95                 | 21.60                              | 0.01106 | 1.918  | 27.80                                 | 105.1 | 0.0573  | 0.1966 | 108.6          | 0.2028       | 112.1          | 0.2087       |
| 100                | 23.60                              | 0.01111 | 1.761  | 28.90                                 | 105.7 | 0.0593  | 0.1965 | 109.2          | 0.2027       | 112.7          | 0.2085       |
| 105                | 25.90                              | 0.01116 | 1.620  | 30.10                                 | 106.4 | 0.0613  | 0.1965 | 109.9          | 0.2026       | 113.4          | 0.2084       |

Values of  $v_s$  and  $v_d$  for use in Equation 4 can be obtained directly or by calculation from the tables of properties of refrigerants.

By a reversal of this same procedure the tabular data can be used to determine the state of a mixture leaving an expansion valve. Consider a valve to which saturated liquid at pressure  $p_s$  is admitted, and a mixture of saturated liquid and vapor at pressure  $p_d$  is discharged. The quality of the material at discharge is then determined by making use of the fact that the expansion process is completely irreversible, is a throttling process, and hence, occurs without change in enthalpy. Thus, the enthalpy of the mixture,  $h_m$ , is equal to the enthalpy of the saturated liquid at the entrance state,  $h_{fs}$ , and can therefore be read from the table.

Thus,

$$h_{fs} = h_m = h_{vd} - (1 - x)(h_{vd} - h_{fd}) \quad (5)$$

or,

$$x = (h_m - h_{fd}) / (h_{vd} - h_{fd}) \quad (6)$$

where

$h_{fs}$  = enthalpy of saturated liquid at entrance to expansion valve.

$h_m$  = enthalpy of mixture.

$h_{vd}$  = enthalpy of saturated vapor at discharge.

$h_{fd}$  = enthalpy of liquid at discharge.

$x$  = proportion of liquid in the mixture, decimal.

### Vapor Compression Refrigeration Cycle

**Simple Cycle.** The refrigerant cycle is the series of state changes (which occur in the conditioning processes) needed to restore the refrigerant to a condition in which it will possess the ability to extract heat from the space to be cooled. For all compression-type systems the cycle consists of four processes: heat gain in the evaporator; pressure rise in the compressor;

heat loss in the condenser; pressure loss in the expansion valve. The compression process is accomplished at the expense of energy added to the compressor in the form of shaft work, and the expansion process could be carried out, if the economics of the system would permit, in an expanding engine with consequent release of energy as shaft work. In ordinary systems, however, the additional first cost and maintenance costs of an expanding engine so greatly exceed the advantage resulting from the work realized, that such engines are not used, and the pressure reduction is allowed to occur irreversibly in an expansion valve. Basically, then, a refrigeration cycle consists of two heat transfer processes and two pressure change processes, no work entering into the heat transfer processes and—in the simple cycle—no heat transfer occurring during the pressure-change processes.

The most common and least complicated type of refrigeration cycle is called the simple saturation cycle, and is shown diagrammatically in Fig. 3 and plotted upon pressure-enthalpy coordinates in Fig. 4. For this system,

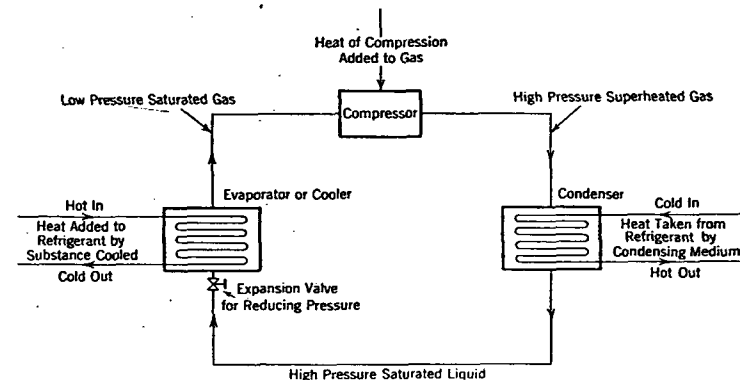


FIG. 3. MECHANICAL REFRIGERATION SYSTEM

saturated vapor flows without gain or loss of heat from the evaporator to the suction of the compressor. During passage through the compressor the energy added as shaft work goes entirely to increase the enthalpy of the refrigerant, and the compression process, which is assumed to occur irreversibly and without external heat transfer, is characterized by constant entropy. Thus, the state of the superheated vapor leaving the compressor can be determined from the tables of thermodynamic properties by noting the discharge pressure and fixing, also, the entropy of the saturated vapor at entrance to the compressor.

Superheated vapor from the compressor flows to the condenser where de-superheating and condensation take place. From the condenser the refrigerant flows to the expansion valve, undergoes a constant-enthalpy pressure reduction, and returns to the evaporator where it again removes a quantity of undesired heat. When the evaporator is arranged to permit direct cooling of room air by the refrigerant, the system is said to be of the *direct expansion* type, while a system in which the evaporating refrigerant cools water or brine, which in turn cools the air, is said to be *indirect*. Although many differences exist between most actual systems and that of the simple saturation cycle, this latter is, nonetheless, of great value in that it provides an extremely simple method of rapidly achieving an approximate

analysis of probable power requirements, compressor size, etc. Further, the equations used in analysis of a simple saturation cycle form the basis of the more complex treatments required for compound refrigeration cycles. For these reasons a typical simple saturation problem will be worked in detail.

**Example 1:** A simple saturation cycle carries a 7 ton load when operating between suction and discharge pressure of 52.7 psia and 121 psia with dichlorodifluoromethane,  $\text{CCl}_2\text{F}_2$ , as the refrigerant. Determine: (a) the cooling effect provided by each pound of refrigerant; (b) the refrigerant circulating rate; (c) the horsepower required; (d) the quantity of heat to be dissipated from the condenser; (e) the required condenser cooling water, in gallons per minute, if temperature rise of water passing through the condenser is 8 deg; (f) the bore and stroke of a double acting cylinder (neglecting the effect of the piston rod) if speed of compressor is 500 revolutions per minute; (g) coefficient of performance.

**Solution:** (a) Saturated liquid  $\text{CCl}_2\text{F}_2$  at 121 psia leaves the condenser and enters the expansion valve. The enthalpy of this material (from Table 1) is 29.68 Btu per pound, and this must also be its enthalpy at entrance to the evaporator. Leaving the evaporator as a saturated vapor at 52.7 psia, its enthalpy is 82.82, so the refrigerating effect must be  $82.82 - 29.68 = 53.14$  Btu per pound.

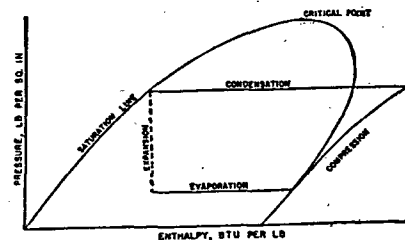


FIG. 4. PRESSURE-ENTHALPY DIAGRAM FOR SIMPLE SATURATION CYCLE

(b) The refrigerant circulating rate is equal to the total heat to be picked up in unit time, divided by the pick-up per pound of refrigerant or,

$$W_r = (7 \text{ ton} \times 200) + 53.14 = 26.3 \text{ lb per minute.}$$

(c) The horsepower required is equal to the increase in energy of the refrigerant passing through the compressor (expressed in Btu per minute) divided by the conversion factor 42.42, which is the number of Btu per minute corresponding to 1 hp,

$$(\text{hp}) = W_r (h_d - h_{vs}) \div 42.42 \quad (7)$$

where

hp = horsepower.

$W_r$  = refrigerant circulating rate in pounds per minute.

$h_d$  = enthalpy of vapor at condition of discharge from compressor.

$h_{vs}$  = enthalpy of saturated vapor entering compressor.

$W_r$  is known from (b) and  $h_{vs}$  is the enthalpy of refrigerant as it enters the compressor in a saturated vapor state at 52.7 psia; thus  $h_{vs} = 82.82$ .

In order to determine  $h_d$ , the state of the refrigerant must first be determined at the compressor discharge. At the known suction state the entropy (from Table 1 for saturated vapor at 52.7 psia) is 0.16828 and, since the compression is assumed to occur isentropically, it therefore follows that the discharge stage must have the same entropy at 121 psia. From the table the entropy of vapor superheated 25 deg is

## Refrigeration

0.17330, so the superheat,  $t_{sd}$ , possessed by the actual gas discharged from this compressor can be obtained by interpolation as;

$$\frac{t_{sd}}{25} = \frac{0.16828 - 0.16608}{0.17330 - 0.16608}$$

from which  $t_{sd} = 7.6$  deg.

As the saturation temperature at 121 psia is 94 F the actual temperature,  $t_d$ , of the vapor leaving the compressor is,  $t_d = 94 + t_{sd} = 94 + 7.6 = 101.6$  F. By the same kind of interpolation the enthalpy of the discharged vapor can be determined from the enthalpies given for vapor superheated 25 F and for saturated vapor,

$$\frac{(h_d - 88.10)}{(92.16 - 88.10)} = \frac{(0.16828 - 0.16608)}{(0.17330 - 0.16608)}$$

from which,  $h_d = 89.34$  Btu per pound.

Then substituting in Equation 7,

$$(\text{hp}) = 26.3 (89.34 - 82.82) \div 42.42 = 4.03.$$

(d) The rate of heat loss from the condenser,  $Q_c$ , must be equal to the sum of the energies picked up by the refrigerant in the evaporator and the compressor,

$Q_c = 53.14 + (89.34 - 82.82) = 53.14 + 6.52 = 59.66$  Btu per pound or  $26.3 \times 59.66 = 1569$  Btu per minute. This same figure can, of course, be determined more directly by subtraction of the enthalpy of liquid leaving the condenser from the enthalpy of superheated vapor going into it, thus,

$$Q_c = 26.3 (89.34 - 29.68) = 1569 \text{ Btu per minute.}$$

(e) The cooling water rate (based on a gallon as 8.34 lb) is  $1569 \div (8 \times 8.34) = 23.5$  gpm.

(f) The compressor size is fixed by the volume of gas which must be drawn into the machine per unit time. Saturated vapor at 52.7 psia has a specific volume, from Table 1, of 0.779 cu ft per pound, hence  $26.3 \times 0.779 = 20.49$  cu ft of gas must be handled. Assuming a volumetric efficiency of 90 percent, the compressor must then displace  $20.49 \div 0.9 = 22.8$  cu ft. The speed is given as 500 rpm and, as the unit is known to be double-acting, the displacement is therefore  $(22.8 \times 1728) \div (2 \times 500) = 39.4$  cu in. If the unit were designed so that bore  $d$  and stroke were the same,

$$(\pi d^3) \div 4 = 39.4 \quad d = 3.69 \text{ in.}$$

$$(g) (\text{CP}) = (h_{vs} - h_{lc}) \div (h_d - h_{vs})$$

$$= (82.82 - 29.68) \div (89.34 - 82.82) = 8.17$$

where  $h_{lc}$  is the specific enthalpy of liquid at discharge from the condenser.

The coefficient of performance of *Example 1* may be compared with that of an ideal system operating on the Carnot cycle between the same temperature limits. Then  $T_s = 501$  F (which is  $41$  F +  $460$ ) and  $T_c = 554$  F (which is  $94$  F +  $460$ ) and,

$$(\text{CP}) = \frac{501}{554 - 501} = 9.6$$

The actual cycle is therefore  $8.17 \div 9.6$  or 85 percent as effective as a Carnot cycle between the same temperature limits.

## Influence of Suction Pressure

Brief consideration of the analytical procedure used in discussion of the simple saturation cycle will bring out the need for maintaining the suction pressure on any refrigeration system as high as the load will permit. As the suction pressure increases, for fixed discharge pressure, the enthalpy

of refrigerant entering the evaporator remains unchanged, but the leaving enthalpy increases and, hence, the refrigerating effect increases. Further, compressor energy input is reduced not merely because of the greater enthalpy of the gas at suction, but also because of a reduction in the enthalpy of the superheated gas at discharge. Since the refrigerating effect is greater and the work less, it is obvious that there will be a substantial gain in the coefficient of the performance.

The actual value of suction pressure on any system is obviously determined by the required temperature which must be maintained in the conditioned space. For a direct expansion system the evaporator can be held at a temperature not much less than that of the conditioned enclosure, except in cases where lower temperatures may be needed in order to establish a desired ratio of dehumidifying to cooling load. When dehumidification requirements dictate the use of unusually low evaporator temperatures, the increased operating cost should properly be charged against the dehumidification rather than the sensible cooling.

#### Influence of Discharge Pressure

In contrast to the suction pressure, the compressor discharge pressure should be kept as low as operating conditions will allow. This pressure must be high enough to provide a saturation temperature of refrigerant within the condenser which is greater than the exit temperature of the cooling water. The discharge pressure therefore is a direct function of the temperature of the cooling fluid, and will automatically rise whenever the temperature of cooling water (or air) rises; it will also rise when the flow rate of the cooling medium is decreased.

Increase in discharge pressure (for fixed suction pressure) raises the enthalpy of the gas leaving the compressor; hence, increases the work of compression. Further, as the enthalpy of saturated liquid leaving the condenser increases with pressure, the refrigerating effect must decrease. Thus the effect of such a pressure rise is to require more work per pound of refrigerant handled, and at the same time to necessitate an increase in the refrigerant flow rate.

#### Influence of Water Jacket

The preceding discussion has, in every case, assumed isentropic compression. Where exact performance data are not available, this assumption is a desirable one since it leads to a conservatively large determination of the power required. In most actual systems, the compression process departs from isentropic due to irreversible heat transfers which occur between the vapor in the cylinder and the cylinder wall, and also because of intentional heat dissipation from the outside of the cylinder walls to the surroundings, or to a cooling fluid passing through a water jacket around the cylinder. Compressor cooling is highly desirable as a method of reducing power consumption.

#### Influence of Superheating and Subcooling

The most common departure from conditions of the simple saturation cycle is that resulting from admission of superheated vapor to the compressor. Thermodynamically, superheat is undesirable because the enthalpy increase required to compress a vapor through a given pressure range increases with superheat. Further, superheated vapor leaving an evaporator is usually an indication that the suction pressure is lower than

necessary. Under practical operating conditions, however, superheat is almost universally used as a means of assuring complete vaporization of the refrigerant going to the compressor. With modern compressors operating at high speed, and with relatively small clearance space, it is particularly necessary to avoid admission through the suction valves of liquid refrigerant.

Another common departure of actual systems from the simple saturation cycle occurs because of subcooling of refrigerant in the condenser. Thermodynamically, such subcooling is advantageous since it increases the refrigerating effect without affecting the unit energy requirements of the compressor. Further, it can be shown that for a fixed ratio of condenser cooling water to refrigerant circulating rate, the total compressor power requirements will be greater when operating at simple saturation than when operating with maximum sub-cooling. What is even more surprising is that condenser pressure may be lower for the sub-cooling cycle than for the saturation cycle. This condition results from the fact that,

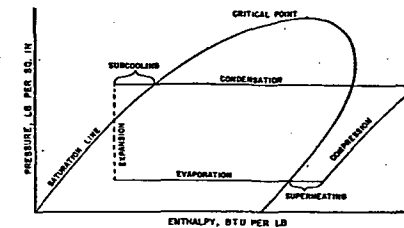


FIG. 5. PRESSURE-ENTHALPY DIAGRAM FOR REFRIGERATION CYCLE WITH SUBCOOLING AND SUPERHEATING

for the same capacity on a heavily loaded condenser, the refrigerant flow rate is less when there is sub-cooling.

Because of the advantages attendant upon the use of sub-cooling, many methods are in use for obtaining some sub-cooling effect outside of the condenser. One common procedure is to use the cold vapor leaving the evaporator to cool the liquid flowing from condenser to expansion valve.

Another somewhat unusual sub-cooling cycle allows cold refrigerant from the downstream side of the expansion valve to cool liquid refrigerant from the condenser down to the evaporator temperature. Fig. 5 shows the pressure-enthalpy diagram for a typical refrigeration cycle operating with both sub-cooling of the refrigerant from the condenser and superheating of the refrigerant leaving the evaporator.

#### Clearance and Volumetric Efficiency

*Clearance*, like displacement, is a characteristic—usually fixed—of a given compressor. In some cases clearance pockets are provided which place within the operator's control the ability to alter the clearance of the machine, but most moderate size compressors are built with fixed clearance. By definition, the clearance is the percentage of the volume swept by the piston, which is represented by spaces in the end of the cylinder (including valve spaces, etc.) when the piston is at the end of its stroke.

Because of the trapping of high pressure vapor in the clearance space, and its subsequent re-expansion, the suction valves of the compressor

do not open until the piston has completed part of its stroke. Hence, the volume of fresh vapor introduced into the compressor per stroke is less than the volume swept by the piston. The ratio of actual volume of fresh gas to swept volume is, by definition, the clearance volumetric efficiency, CVE. In equation form,

$$(CVE) = 100 - V_c \left[ \frac{v_s}{v_d} - 1 \right] \quad (8)$$

where

CVE = clearance volumetric efficiency.

$V_c$  = clearance, percent of volume swept by piston, which is contained in spaces at end of cylinder when piston is at end of stroke (clearance includes valve spaces, etc.).

$v_s$  = specific volume of gas at compressor inlet.

$v_d$  = specific volume of gas at compressor discharge.

Values of  $v_s$  and  $v_d$  can be obtained directly or by calculation from the tables of properties of refrigerants.

In addition to clearance, there are several other factors which tend to reduce the volumetric efficiency. The suction gases from the evaporator are heated and expanded upon contact with the hot cylinder walls during the suction stroke. This results in a reduction of the actual charge drawn into the cylinder. Wire-drawing through the suction and discharge valves reduces the suction pressure in the cylinder below that in the evaporator, and increases the discharge pressure above that in the condenser. Leakage of gases around the pistons also decreases the volumetric efficiency. The total volumetric efficiency (TVE) includes all of these factors and is reliably obtained only by laboratory measurements. It is too difficult to predict the effects of these factors to any degree of accuracy comparable to actual tests.

### Complex Refrigeration Cycles

The preceding sections have dealt only with refrigeration systems in which there is but one evaporator; compression is accomplished through but a single stage, and expansion proceeds through a single expansion valve. In large systems or in low temperature systems in which the compression ratio is high, the compression process can be carried out in stages, with the refrigerant passing through several cylinders arranged for operation in series. The thermodynamic advantage of such compound compression arises from the fact that intercoolers can be placed between the stages of compression to extract heat from the vapor, and thereby cause the overall compression process to approach more closely the ideal condition of isothermal compression. Essentially, such intercoolers serve the same purpose as a cooling jacket, but with greater effectiveness because of the more satisfactory heat transfer conditions.

In the simple saturation cycle the saturated liquid entering the expansion valve commences to vaporize as soon as its pressure starts to drop. The vapor produced during the expansion process has no further use, in terms of refrigerating effect, since it has already picked up its latent heat of vaporization as a result of heat which it has extracted from the unvaporized residue. Thus the instant such vapor forms, its usefulness is at an end, and to allow such material to undergo a further drop in pressure is uneconomical. With compound compression, there is at least one intermediate pressure

at which flash vapor can be extracted. In such cases several expansion valves can be utilized with all of the refrigerant from the condenser passed through a first expansion valve to the higher suction pressure, and the flash vapor then extracted and returned to the condenser through the high compression stage. The remaining refrigerant can then pass through a second expansion valve where the pressure is dropped to that corresponding to the low-pressure evaporator. The number of expansion valves is limited by the number of stages of compression.

Further cycle complications may arise if more than one evaporator is to be operated with a single compressor, and particularly, if the pressures in these evaporators are to differ. The most common solution is to operate the compressor at the suction pressure of the lowest pressure evaporator, and to equip all other evaporators with back-pressure regulating valves or throttling devices between the evaporator and the compressor suction.

### The Air Cycle System

Fundamentally, the air cycle<sup>1</sup> is essentially the same as the vapor cycle. Compression is accomplished by a reciprocating or centrifugal compressor, and, since there is no change of phase of the refrigerant upon expansion, an *air cooler* replaces the condenser, and a *refrigerator*, the evaporator. Although some cooling would result from the expansion of the gas through an ordinary expansion valve, a much greater drop in air temperature is accomplished if the expansion is controlled to approach the isentropic by replacing the valve with an expansion engine or turbine. Furthermore, the work recovered by such an expansion engine can be utilized to supply part of the work of compression or to drive other devices.

### The Steam Jet System

The *steam jet* system, under certain circumstances, is desirable for use in air conditioning.<sup>2</sup> Steam supplies directly the power used for compressing the refrigerant, thus eliminating the losses connected with other methods of supplying energy. As the compression ratio between the evaporator and condenser under normal circumstances is large, the mechanical efficiency of the equipment is somewhat lower than that of the positive mechanical type compressor. The condensing water requirements are considerably greater, as both the refrigerant and the impelling steam must be condensed.

The steam jet system functions on the principle that water under high vacuum will vaporize at low temperatures. Steam jet boosters or compressors of the type commonly used in power plants for various processes, will produce the necessary low absolute pressure to cause evaporation of the water.

A diagrammatic representation of a typical steam ejector water cooling system is shown in Fig. 6. The figures correspond to an average representative system. The water to be cooled enters the evaporator and is cooled to a temperature corresponding to the vacuum maintained. Because of the high vacuum, a small amount of the water introduced in the evaporator is flashed into steam. As this requires heat, and the only source of heat is the rest of the water in the evaporator tank, this other water is almost instantly cooled to a temperature corresponding to the boiling point determined by the vacuum maintained. The amount of water flashed into steam is a small percentage of the total water circulated through the evaporator, amounting to approximately 11 lb per (hr) (ton)

of refrigeration developed. The remainder of the water at the desired low temperature is pumped out of the evaporator and used at the point where it is required.

The ejector compresses the vapor which has been flashed in the evaporator, plus any entrained air taken from the circulated water, to a somewhat higher absolute pressure. The vapor and air mix with the impelling steam on the discharge side of the jet, and the total mixture then passes from the ejector into the condenser.

The slight amount of air which may be entrained in the cooled water is removed by a small secondary ejector which raises the pressure sufficiently so that the air can be discharged to the atmosphere. A secondary condenser is then necessary to condense the steam in the secondary jet.

While a single booster of smaller than 15 tons capacity is difficult to build, steam jet vacuum cooling units have been built for as small as 5 to 6 tons capacity. They can readily be built for steam pressures of from

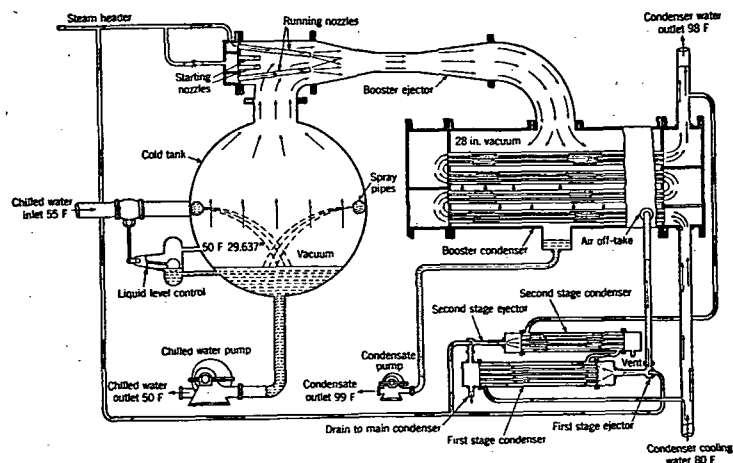


FIG. 6. DIAGRAMMATIC ARRANGEMENT OF STEAM JET VACUUM COOLING UNIT

5 to 200 psig, and condenser water temperatures as high as 90 F. The steam consumption in pounds per hour per ton of refrigeration increases rapidly as the booster steam pressure is lowered. For example, the lowering of the booster steam pressure from 200 to 90 psig results in an increase in steam consumption of approximately 5 percent, whereas a further decrease in booster steam pressure to 10 psig increases the steam consumption by approximately 72 percent over that required at 200 psig.

The capacity of a steam jet system is usually controlled by controlling the number of boosters in use since the unit usually has several boosters operating on the same evaporator. Usually one booster is automatically controlled, whereas the others are manually operated. The capacity is dependent, as for all compressors, upon the evaporator temperature, or in other words, the suction pressure. For example, the capacity is lowered approximately 17 percent if the evaporator or chilled water temperature is lowered from 50 to 45 F. The capacity therefore can be controlled to some extent by regulating the evaporator temperature.

### The Absorption System

The absorption and compression refrigeration cycles differ only with respect to the method of compression. Each cycle requires a condenser, expansion valve, and evaporator, but the absorption cycle utilizes three major equipments in place of the mechanical compressor; these equipments are the *absorber*, the *pump*, and the *generator*. Vapor from the evaporator is absorbed by a low temperature absorbent fluid which is then pumped to the generator where heat is supplied to boil off the refrigerant. The absorbent is now cooled and readmitted, through a pressure-reducing valve, to the absorber.

In addition to the three primary equipments of the absorption cycle it is necessary to provide auxiliary equipment, usually an analyzer and a rectifier, to remove from the refrigerant leaving the generator, insofar as is possible, the absorbent which vaporizes and leaves the generator with the refrigerant. Removal of this material is of great importance to effective operation of the system, since even a small concentration of absorbent

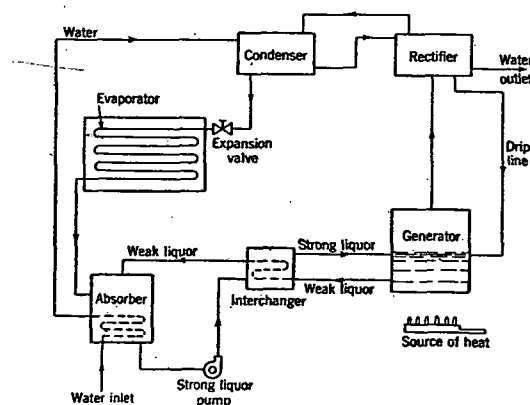


FIG. 7. CLOSED ABSORPTION SYSTEM

in the refrigerant will suffice to reduce greatly the evaporator pressure required for maintenance of a given evaporator temperature. Thermodynamic analysis of absorption cycles is relatively complex, and requires the use either of tables or graphs showing the equilibrium relationships and thermodynamic properties of the refrigerant-absorbent combination. Data of this kind are given in the first book in the bibliography. A discussion of various absorbents is given in the sixth book. Thermodynamically, the effectiveness of a refrigerant-absorbent combination increases directly with its negative deviation from Raoult's Law.

Fig. 7 shows a typical absorption cycle flow diagram. Cooling water first goes through the absorber (where it extracts the heat of absorption which is liberated by the refrigerant vapor as it goes into solution), then through the condenser, and finally through the rectifier. Refrigerant from the evaporator enters the absorber where it goes into solution in the absorbent; the high concentration solution is then pumped to the generator where heat is supplied; the refrigerant (with some absorbent vapor) leaves for the rectifier and the warm low concentration solution is returned to

the absorber. In the rectifier selective condensation occurs, the concentration of the absorbent in the condensate being much greater than its concentration in the entering vapor mixture; rectifier condensate is dripped back to the generator.

The ratio of refrigerating effect to heat input (the performance ratio or commonly used efficiency measure of absorption machines) is only 40 to 45 percent with the ordinary ammonia absorption system and, aside from the inherent disadvantages involved in the use of a toxic and explosive refrigerant, this is not sufficiently high to make it competitive with other types of systems when used in air conditioning applications. Therefore, recently, several absorption systems using hygroscopic brines of salts such as lithium chloride or lithium bromide<sup>3</sup> (solids in the pure state) as absorbents and water as the refrigerant have been developed. Such systems are limited to higher temperature applications but, thermodynamically, have

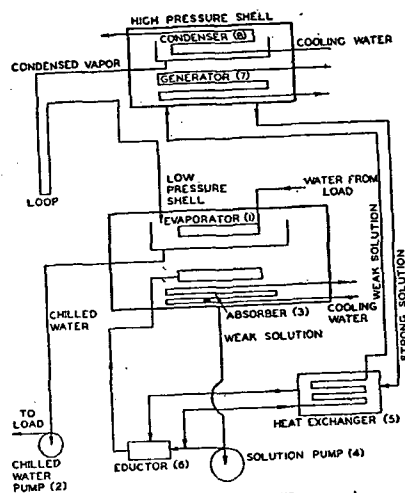


FIG. 8. DIAGRAM OF LITHIUM BROMIDE WATER ABSORPTION SYSTEM

the advantages of a refrigerant with a high latent heat of vaporization and nonvolatile absorbents with a large negative deviation from Raoult's Law. None of the absorbent is carried off with the refrigerant from the generator and the performance ratio ranges as high as 75 percent. Both the refrigerant and the absorbent are non-toxic and non-explosive and the performance ratio does not vary greatly between 20 percent of capacity and full load. This increased efficiency places operating costs in competition with other forms of refrigeration in many high temperature applications such as air conditioning.

One form of lithium-bromide-water absorption system is shown schematically in Fig. 8 with the generator and condenser shown located in a high pressure shell and the evaporator and absorber in a low pressure shell. The water to be cooled flows to the evaporator 1 from the load where a small portion of it is flashed into vapor thus cooling the remaining water which is then returned by pump 2 to the load. The pressure in the low side shell and, therefore, the temperature of the water passing through the shell is controlled by the temperature and concentration of the lithium

bromide brine sprayed over absorber coil 3. The water vapor flashed in the evaporator chamber is absorbed by the strong salt solution to form a weak solution which drains from the low pressure chamber and passes through solution pump 4. From pump 4 a portion of the weak brine is delivered through the heat exchanger 5 to the high pressure shell and the remainder is mixed with the strong solution through eductor 6 and delivered back to the low pressure shell. Heat applied at the generator 7 boils off the water vapor earlier condensed in the absorber and returns the brine to its original concentration. The condenser 8, also located in the high pressure shell, liquifies the water boiled off by the generator and this condensate is returned through a liquid loop to the evaporator. The re-concentrated solution is returned from the high pressure shell through the heat exchanger 5 to the eductor 6 where it is mixed with a portion of the weak solution and pumped to the absorber with the mixture at a still relatively high concentration.

### Ice Systems

Cold water systems using ice as the cooling agent have been installed in some theaters, restaurants, funeral homes, churches and other places where short hours of operation and high peaks of cooling demand make this type of system desirable. A comparatively small quantity of ice in the water cooling tank of such a system can release refrigeration at a relatively rapid rate. For instance, neighborhood theaters having a peak demand of 1,200,000 Btu per hr (100 tons refrigeration) have found 8 ton capacity ice bunkers satisfactory.

In operation, the water in the air conditioning system is circulated over ice placed in an insulated box, and is cooled to the 38 or 40 deg range or higher, if desired. This cold water is pumped from the ice bunker to air cooling coils or spray type air washers. The blowers, coils, air washer or air handling sections are the same as those parts in any system employing cold water as a refrigerant.

The ice water cooler or ice bunker is usually built at the installation in a location where it can easily be iced. It can be constructed of any desired material such as concrete, steel, or wood with an adequate amount of insulation to save the ice from one period of use to the next. The basic requirement is that the tank be durable and water-tight.

The temperature of the water is controlled at a predetermined point by a thermostat in the supply line. If the temperature drops too low, a part of the return water is by-passed directly to the sump and is not cooled over the ice. In the larger systems it is customary to install an overflow control which, as the ice melts, discards the excess water through an economizer coil, the surface of which is large in relation to the flow so that the water is warmed to 60 F or more as it is discharged from the system.

In an attempt to lower initial equipment cost and operating expense, or increase the refrigeration capacity of an existing air conditioning system, storage refrigeration has been utilized in a few applications. Some of the methods which have been adopted include the storage of refrigeration in the form of chilled water, chilled brine, ice on evaporator coils<sup>4</sup> and the accumulation of thin sheets of ice on copper plates in a steel tank.<sup>5</sup> If the peak load factor is low as compared with a long period of operation, such as in a restaurant, or if the hours of operation are short but the usage factor high, as in a church, then it is possible to consider storage refrigeration. This method of accumulating refrigeration frequently makes it possible to use low cost off-peak electric power. Power costs may also be reduced by



TABLE 4. HEAT PUMP HEAT SOURCES AND SINKS

| HEAT SOURCE                                                                                                | AIR                                                                                                                                                                                                                            | CITY WATER                                                                                                                                                               | WELL WATER                                                                                                                                                               | SURFACE WATER                                                   | WASTE WATER                                                                                                         | EARTH                                                                                                                                                                                                                                                                  | SOLAR                                                                                                                                                                                                                                                                                                                                                                                                               |
|------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Source Classification<br>Stability as Heat<br>Sink<br>Availability<br>(Location)<br>Availability<br>(Time) | Primary<br>Good<br>Universal<br>Continuous                                                                                                                                                                                     | Primary or auxiliary<br>Good<br>Cities<br>Continuous—except<br>local shortages                                                                                           | Primary<br>Good<br>Uncertain<br>Continuous—unless<br>well runs dry                                                                                                       | Primary<br>Good<br>Rare<br>Continuous                           | Primary or auxiliary<br>Variable with source<br>Limited<br>Variable                                                 | Primary or auxiliary<br>Usually poor<br>Extensive<br>Continuous, tempera-<br>ture level drops<br>from a maximum as<br>heat is removed, slowly<br>rises when pump is<br>inoperative<br>High, usually less than<br>the cost of drilling a<br>well<br>Relatively moderate | Auxiliary<br>None<br>Universal<br>Intermittent<br>Unreliable,<br>except over<br>extended<br>time<br>Unexplored<br>Unexplored<br>Unexplored as<br>auxiliary for<br>reducing oper-<br>ating cost<br>Excellent<br>Extreme<br>Practically<br>available<br>Probably<br>bulky<br>Fair<br>Air, earth,<br>water<br>Probably will<br>require heat<br>storage equip-<br>ment at either<br>evaporator<br>or condenser<br>side. |
| Expense (Original)                                                                                         | Low, less than earth<br>and water sources ex-<br>cept city                                                                                                                                                                     | Usually lowest                                                                                                                                                           | High, result of drilling<br>well                                                                                                                                         | Low                                                             | Variable                                                                                                            |                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Expense (Operating)                                                                                        | Relatively low                                                                                                                                                                                                                 | High, usually prohibi-<br>tive                                                                                                                                           | Low to moderate                                                                                                                                                          | Relatively low                                                  | Relatively low                                                                                                      |                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Temperature<br>(Level)                                                                                     | Favorable 75-95% of<br>time in most of U. S.                                                                                                                                                                                   | Usually satisfactory                                                                                                                                                     | Satisfactory                                                                                                                                                             | Satisfactory                                                    | Usually good                                                                                                        | Initially good—drops<br>with time and rate<br>of heat withdrawal<br>Large—less than for<br>air, however<br>Inadequate                                                                                                                                                  | Excellent                                                                                                                                                                                                                                                                                                                                                                                                           |
| Temperature<br>(Variation)                                                                                 | Extreme                                                                                                                                                                                                                        | Variable with loca-<br>tion (10 to 25 F. Deg)                                                                                                                            | Small                                                                                                                                                                    | Moderate                                                        | Usually moderate                                                                                                    |                                                                                                                                                                                                                                                                        | Extreme                                                                                                                                                                                                                                                                                                                                                                                                             |
| Design Information                                                                                         | Inadequate                                                                                                                                                                                                                     | Usually adequate                                                                                                                                                         | Usually adequate                                                                                                                                                         | Usually ade-<br>quate                                           | Adequate if source is<br>constant in supply and<br>variable (usually<br>moderate)                                   |                                                                                                                                                                                                                                                                        | Practically<br>available                                                                                                                                                                                                                                                                                                                                                                                            |
| Size of Equipment                                                                                          | Particularly bulky                                                                                                                                                                                                             | Moderate                                                                                                                                                                 | Moderate (except well)                                                                                                                                                   | Moderate                                                        | Variable (usually<br>moderate)                                                                                      | Moderate (except<br>ground coils)<br>Fair                                                                                                                                                                                                                              | Probably<br>bulky<br>Fair                                                                                                                                                                                                                                                                                                                                                                                           |
| Adaptability to<br>Mass Production<br>Sources it may<br>Augment                                            | Excellent, can be factory<br>assembled and tested                                                                                                                                                                              | Excellent                                                                                                                                                                | Excellent, (except well)                                                                                                                                                 | Excellent                                                       | Poor                                                                                                                | Air, water<br>Limited by local geol-<br>ogy and climate. In-<br>stallation costs diffi-<br>cult to estimate. Re-<br>quires considerable<br>ground area, may<br>damage lawns, gar-<br>dens.                                                                             | Air, earth,<br>water<br>Probably will<br>require heat<br>storage equip-<br>ment at either<br>evaporator<br>or condenser<br>side.                                                                                                                                                                                                                                                                                    |
| Special Problems                                                                                           | Least heat available<br>at demand great.<br>Coils may become<br>frozen requiring extra<br>capacity, alternate<br>source, or standby<br>heat. May require<br>duct work. Variable<br>air temperature makes<br>control difficult. | Scale on coils. Local<br>use restrictions dur-<br>ing shortages. Dis-<br>posal. Water tem-<br>perature may be-<br>come too low to per-<br>mit further heat re-<br>moval. | Corrosion, scale may<br>form on heat trans-<br>fer surfaces. Disposal.<br>Water location, tem-<br>perature, composi-<br>tion, usually un-<br>known. Well may<br>run dry. | Water may cause<br>scale, corro-<br>sion, and algae<br>fouling. | Usually scale forming or<br>corrosive. Often very<br>limited application,<br>hence requires indi-<br>vidual design. |                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                     |

installing a smaller refrigeration plant, augmented by a storage system, and by operating it for longer periods.

### The Heat Pump

It has been almost 100 years since Prof. William Thomson (Lord Kelvin) first proposed the use of a compressor as a "warming engine" and as a means of heating buildings to replace equipment for direct burning of fuels. Several early working models were constructed, but the device has remained essentially of laboratory interest until the last 20 years.

Although frequently referred to incorrectly as the reverse cycle system, the heat pump cycle is identical with the ordinary refrigeration cycle, and differs only in the sense that the desired effect is rejection of the heat from the condenser rather than absorption of heat in the evaporator. A discussion of the coefficient of performance for the heat pump is found earlier in this chapter.

The first actual residential heat pump installation was probably made in Scotland in 1927 and since that time, a number of commercial and residential systems have been made in this country. Both progress and growth of interest have been particularly rapid in recent years and, consequently, at the present time there are several hundred residential installations and probably a greater number of commercial systems. However, much research is needed before the residential heat pump installation can successfully emerge to compete economically and with equal reliability with the more common forms of heating and fuels.

From an analysis of the equation for the coefficient of performance, it is evident that the economical adaption of the heat pump as a practical means of heating, requires that the temperature of the source from which the heat is extracted be as high as possible, and that the temperature of the sink to which the heat is rejected for heating purposes, be as low as possible. Thus, with a small temperature spread between the evaporator and the condenser, six or more times as much heat may be obtained theoretically (and three to five times practically) as the heat equivalent of the work necessary to operate the system. There are a number of limitations, however, the most serious of which is the lack of ready availability of a practical source of heat.

One of the major problems in the development of the heat pump involves research on, and the compilation of reliable design data for, the various heat sources and sinks available. The four principal potential sources of heat are air, water, earth, and solar energy. Of these, the first three are primary sources of heat which may be used alone. The fourth, solar energy, while of tremendous potentiality, will probably be developed in most localities as auxiliary to the other three. In addition, there are other minor sources such as process waste heat, sewage, etc., which may be used under special circumstance.

There are also a number of industrial applications of heat pumps, for purposes other than space heating, which are practical largely through economic considerations of the particular process involved. Table 4 presents a summary of the advantages and disadvantages of each of these major heat sources.

By reference to Table 4, it will be seen that, to date, the most satisfactory heat sources are air, water, and earth, and that air and water are the most satisfactory heat sinks. There are, therefore, six possible combinations of source and sink in application: air to air, air to water, water to air, water to water, earth to air, and earth to water. In addition, it should be recog-



nized that heat storage devices may be used with any of these systems involving either a single or a dual heat source. One promising possibility involves the utilization of a storage pit or cistern operating upon a heat of fusion cycle and supplied by supplementary heat from air or solar sources. Heat of fusion may, for example, also be utilized with city water and sewage disposal to increase the practicability of these sources.

When heat is to be obtained from a ground coil it should be emphasized that, in general, the heat extracted must be replaced by heat from the sun, received by radiation to the ground or by heat carried into the ground by rain.

Combinations of heat sources, such as air and water, air and ground, air and solar energy, or ground and solar energy, may also be used and will frequently improve the coefficient of performance over an entire heating season; but they will probably result in considerably greater initial cost.

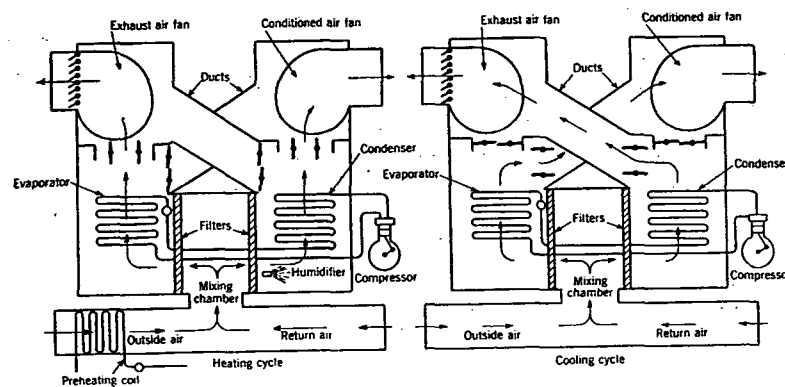


FIG. 9. SCHEMATIC OPERATION OF REVERSED CYCLE CONDITIONING SYSTEM

A typical arrangement of a heat pump system with air as the heat source is shown in Fig. 9.

Both water and air are practical media to which the condenser heat may be rejected; but the generation of steam requires too high a condenser temperature. Practical operation, therefore, dictates that the heat pump be used in conjunction with either an air or water heating system with actual distribution of the heat to the rooms through either air ducts, convection radiators, or panels.

In general, it is believed that the future of this device is very promising, and it is recognized that there are a number of practical and economical systems in operation at the present time. However, design data for the majority of types of systems are inadequate, and it is therefore recommended that the enthusiasm and the interest which have greeted the emergence of the heat pump from the category of a scientific toy to one of practical application, should be tempered with caution, since it will probably be several years before proper development and design information will enable the widespread satisfactory application of the heat pump. It is for this reason that no design information is presented at this time in THE GUIDE. A wealth of literature concerning individual installations is available, and reference to the many articles which have appeared

in current technical magazines should form sufficient information for those interested in the development of this type of heating.

## BASIC REFRIGERATION EQUIPMENT

### Compression Refrigeration Machines

Compression of the refrigerant gas drawn from the evaporator may be accomplished by one of several means. Positive displacement may be used as in the reciprocating, rotary or gear types of compressors; centrifugal force may be applied as in the centrifugal compressor; an ejector may be used as in the steam jet refrigeration cycle; or absorption of a low pressure refrigerant gas in a secondary fluid, followed by the absorbent's release upon application of heat, may be utilized. A detailed discussion of the equipment required for each of these types of systems is beyond the scope of this chapter. For a more comprehensive treatment, reference may be made to the bibliography. The present discussion is limited to positive displacement reciprocating compressors, rotary compressors and centrifugal compressors.

### Reciprocating Compressors

Reciprocating compressors may be classified according to (a) cylinder design, (b) compressor drive, (c) valves, and (d) lubrication and cooling.

**Cylinder Design.** Cylinder design may vary as to number, arrangement, and action (i.e., single-acting or double-acting). Single-acting compressors usually have their cylinders arranged vertically, radially, or in a V or W shaped arrangement. Double-acting compressors, with refrigerant gas drawn in, and compressed on both the head and crank ends of the cylinder, are usually arranged horizontally. Reciprocating units are available with from one to sixteen cylinders with the V, W, or radial arrangements best adapted to the greatest numbers. The present trend is toward higher operating speeds with a low displacement per cylinder, together with an increase in the number of cylinders. Whereas the original reciprocating compressors were slow speed (50 to 55 rpm) steam driven devices, modern electric motor-driven compressors range up to 3500 rpm. Cylinder heads are usually bolted tight to the cylinders, but in some large compressors where there is danger of wet compression or of foreign materials entering the compressor space, a secondary head known as a safety head, may be seated at the end of the cylinder and held in position with heavy springs. Normally, this head remains stationary, but excessive pressures in the clearance space are relieved by movement of the safety head, and thus prevent damage to the cylinder.

**Compressor Drives.** Reciprocating compressors may be subdivided on the basis of source of motive power, and whether they are open or hermetic. Practically all modern compressors are electric motor-driven, although a few large, steam-driven compressors are still being installed where steam forms the most economical source of energy. In a few cases, as with truck transportation, the compressor may be driven by an internal-combustion engine.

The division of compressors into open or closed types is dependent upon whether the motive power is received from an external source, or whether the motor is direct drive and sealed within the housing. In the open type, power is received from an external source with one end of the compressor crankshaft extending through the crankcase, and usually V-belt driven. The point of emergence of the shaft from the crankcase forms a weak point of refrigerant leakage, and is most frequently sealed with a bellows type crankshaft seal. Horizontal double-acting compressors operate with a sliding piston rod, moving back and forth through a stuffing box. If the motor is direct-drive and enclosed within the compressor housing, the compressor is classified as closed or hermetic. This eliminates the necessity of any shaft seal, and not only prevents refrigerant leakage at this point, but reduces operating noise. One disadvantage is the inaccessibility of moving parts for repairs, but lubrication is greatly simplified since both the motor and compressor operate in a sealed space with the lubricating oil.

**Compressor Valves.** All refrigeration compressor valves are dependent for their

operation upon a difference in pressure between the inside of the cylinder and the suction or discharge line. Although mechanically-operated valves might have some advantage, they have proved unsatisfactory because each change in the evaporator or condenser operating pressures requires a change of valve setting. The pressure differentials required for operation of the valves depend upon the valve design and the compressor speed. The suction and discharge valves may be arranged with both located in the compressor head, or with the suction valve on the top of the piston and the discharge valve in the compressor head (uniflow arrangement). The valves themselves are usually classified as either poppet, ring-plate or flexing.

**Lubrication and Cooling.** Lubrication of modern compressors is accomplished by either splash lubrication or forced lubrication. The latter is used on large compressors, while simple splash lubrication is used in the smaller units.

Large compressors are usually water cooled with the water jacket either cooling the cylinder walls, or both the cylinder walls and the compressor head. Small compressors are either water cooled or air cooled with extended finned surfaces cast on

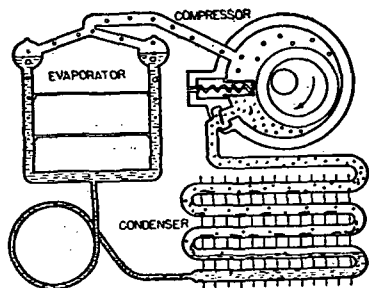


FIG. 10. DIAGRAMMATIC VIEW OF ROTARY COMPRESSOR WITH FLOODED EVAPORATOR AND CAPILLARY TUBE

the exterior of the cylinder. In a few cases small compressors may be found in which there is no attempt to add any purposive cooling other than through non-finned surfaces to the lower temperature air.

Water cooling is more effective than air cooling, but even under the best conditions cylinder cooling removes only a portion of the superheat in the refrigerant gas. This removal of heat from the cylinder results in some decrease in the work of compression, as well as reduction in condenser load.

### Rotary Compressors

In recent years rotary compressors, usually hermetically sealed, have become quite popular for fractional tonnage applications and are being designed in increasingly larger sizes. Of the various designs attempted, the single blade rotary compressor, shown diagrammatically in Fig. 10, is the most popular. An eccentric driven rotor revolves within a housing in which the suction and discharge passages are separated by means of a sealing blade. When the rotating eccentric first passes this blade and the suction opening, the compressor suction space is very small. As the eccentric rotates, this crescent-shaped space becomes increasingly larger, thereby drawing in a charge of suction gas. When the eccentric again passes the blade, the gas charge is cut off from the suction inlet, compressed, and discharged from the compressor. Such rotary compressors are quiet in operation and reasonably free from vibration. In common with other types of hermetically sealed units, they have the advantages of comparatively low loss of refrigerant and sealed-in lubrication.

### Centrifugal Compressors

*Centrifugal compressors* are used with very low pressure refrigerants; usually both evaporator and condenser work below atmospheric pressure. Water and monofluorotrichloromethane ( $\text{CCl}_3\text{F}$ ) are the refrigerants commonly used in centrifugal machines.

Compression of the refrigerant is accomplished by means of centrifugal force; therefore, this type of compressor is inherently suitable for large volumes of refrigerant at low pressure differentials. Two or more stages are usually required and high speeds are necessary to obtain good efficiency.

The evaporator is usually constructed as an integral part of the centrifugal type condensing unit, to chill water which is then circulated to the

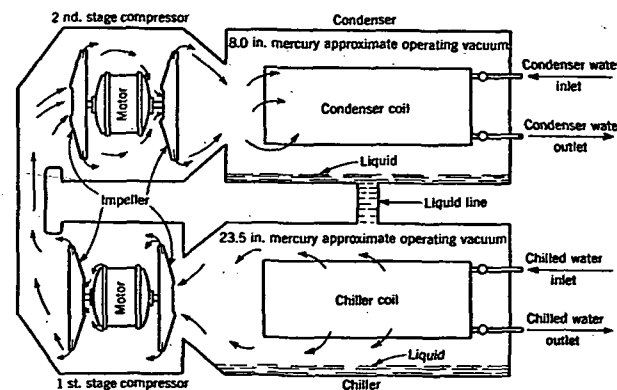


FIG. 11. ENCLOSED TYPE CENTRIFUGAL CONDENSING UNIT

air conditioning system. This is done because it would not be economical to pipe these large volumes of refrigerant any distance.

Centrifugal compressors, like reciprocating compressors, can be divided into two general types, open and enclosed. In general, the open type compressor is geared to the driving mechanism, and operates at higher speed than the driving motor or turbine. A modern, completely enclosed, direct-driven centrifugal compressor is illustrated in Fig. 11.

Centrifugal refrigeration compressors are particularly well suited to direct steam turbine drive because of their high operating speed. Water cooling equipment of one design is operated between 3500 and 4000 rpm for units developing 1000 to 2000 tons capacity, and from 7000 to 8000 rpm for units developing 100 to 200 tons capacity. However, a great many applications, particularly in the smaller sizes, are electric motor-driven and equipped with standard gear-type speed increasers. Centrifugal systems are particularly well adapted to large capacities (up to 3000 tons) although it is also possible to secure units as low as 50 tons in rating. Because centrifugal units operate best with refrigerants possessing a high specific volume, and because of the simplification of lubrication difficulties, they are frequently used for extremely low temperature applications. They are adaptable to a wide range of temperatures from  $-130^\circ\text{F}$  to  $50^\circ\text{F}$ . One important advantage is their flexibility under varying loads, since units may be

designed to operate with reasonable efficiency at capacities as low as 20 percent of normal load.

### Condensers

Condensers used for liquefying the refrigerant are of three general designs: (1) *air cooled*, (2) *water cooled*, and (3) *evaporative* (combination air and water).

1. *Air cooled condensers* are seldom used for capacities above 3 tons of refrigeration, unless an adequate water supply is extremely difficult to obtain, as, for instance, in railway air conditioning. Even on fractional tonnage installations, air is used as the condensing medium only where water is expensive, or where simplicity of installation warrants the higher condensing pressure and consequent power costs higher than would be obtained using water as the condensing medium.

The conventional air cooled condenser consists of an extended surface coil across which air is blown by a fan. The hot discharge gas enters the coil at the top and, as it is condensed, flows to a receiver located below the condenser. Air cooled condensers should always be located in a well ventilated space so that the heated air may escape and be replaced by cooled air.

The principal disadvantages of air cooled condensers are the power required to move the air, and the reduction of capacity on hot days. This loss of capacity, due to high condensing pressures on hot days, requires that equipment of increased capacity be selected to meet the peak load. Thus at normal loads the equipment is oversized. The principal advantages are low installation costs and simplicity, and for these reasons they are frequently used in small self-contained units.

2. *Water cooled condensers* are commonly used with compressors of one horsepower or larger in size, and they are found almost exclusively on large installations. They usually prove to be the most economical choice if an adequate water supply and means for its disposal are available. Although water cooled condensers may be of many designs, the shell and coil and the shell and tube are most commonly found in present day practice.

The amount and temperature of the condensing water determine the condensing temperature and pressure, and indirectly the power required for compression. It is therefore necessary to determine a balance so that the quantity of water insures economical compressor operation.

Because there is a decided tendency to conserve the water in city mains, and because most large cities are restricting the use of water for air conditioning and refrigeration equipment, it is often necessary to install cooling towers or evaporative condensers. Cooling towers, unfortunately, produce the warmest condensing water at the time when the load on the system is greatest, so that the refrigeration equipment must be designed to meet the maximum load at abnormal condensing water temperatures. If properly designed, this makes little difference in the efficiency of operation throughout the year, except at those times when the condensing water temperature is highest. As this occurs only for 5 percent of the entire cooling period, it can be disregarded as a factor in establishing yearly operating costs. For further information on cooling towers, reference may be made to Chapter 35.

3. *Evaporative condensers* were developed to alleviate the over-burdened water supply and drainage facilities of communities where many small air conditioning systems using water cooled condensers were applied. The adaptation of cooling towers to small installations is not practicable. The evaporative condenser combines the functions of the two by using a minimum amount of water on a finned surface, cooling it to approximately the wet-bulb temperature of the surrounding atmosphere.

The end view of a typical evaporative condenser is shown in Fig. 12. The fan draws the air over a finned tube condenser which is kept wet by a water spray. The discharge refrigerant gas from the compressor enters the top of the condenser coil, and the liquid refrigerant is drained from the bottom of the coil into a liquid receiver, and then circulates through the remaining portion of the system in the usual way.

The water is circulated through the spray nozzles, and the level is maintained in the sump by means of a float valve. The eliminator plates are placed in the path of

the water-air mixture so as to remove the entrained water. The air leaving the unit is almost completely saturated, so that care must be taken in locating discharge ducts to prevent condensation.

Evaporative condensers are available in sizes up to 100 tons or more. These units use only a small portion of the water required for a water cooled condenser. The water is vaporized by the heat of the refrigerant so that each pound of water used extracts approximately 1000 Btu from the refrigerant, whereas under standard rating conditions where the water temperature rise is 20 F, each pound of water extracts only 20 Btu from the refrigerant. Including the water lost by entrainment

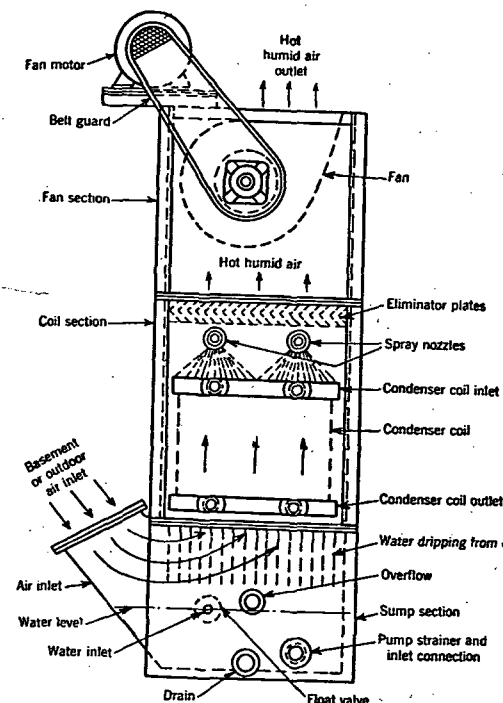


FIG. 12. SCHEMATIC VIEW OF AN EVAPORATIVE CONDENSER

in the discharge air, by overflow and stand-by evaporation, the water used is about 3 to 5 percent of the amount that would be required for a water cooled condenser.

The evaporative condenser requires more maintenance, occupies greater space (must be located where air is available), and has a higher first cost than the water cooled condenser, but where the use of water is restricted or expensive, the evaporative condenser has become widely accepted. Compared with a water cooled condenser and cooling tower, which combination uses about the same quantity of water, the evaporative condenser has the advantage of lower cost and smaller space requirements.

### Evaporators and Coolers

Refrigeration evaporators must be designed for efficient removal of heat from the medium being cooled, as well as effective boiling of the refrigerant and a minimum drop of pressure through the coil. There are two general types of evaporators, dry and flooded. In the dry evaporator the refrigerant enters in the liquid state, and the design provides for complete

evaporation with the vapors leaving slightly superheated. In flooded evaporators not all of the refrigerant is evaporated, the liquid-vapor mixture leaving the evaporator flows into a surge drum from which the vapors are drawn into the compressor suction line, and the liquid is recirculated through the evaporator.

The types of coolers used in connection with air conditioning work fall into three general groups: (1) direct water coolers, (2) direct air coolers, and (3) brine coolers for circulation of the brine in a closed system, and thus cooling indirectly either water or air.

1. *Water coolers.* One method of the direct cooling of water is to install direct expansion coils in the spray chamber so that the water sprayed into the air comes in direct contact with the cooling coils. Another common and efficient method of cooling spray water is to use a Baudelot type of heat absorber where the water flows over direct expansion coils at a rate sufficiently high to give efficient heat transfer from water to refrigerant.

Another type of spray water cooler is the shell and tube heat exchanger in which the refrigerant is expanded into a shell enclosing the tubes through which the water flows. The velocity of the water in the tubes affects the rate of heat transfer, and as the refrigerant is in the shell completely surrounding the tubes at all times, good contact and a high rate of heat transfer are insured. The disadvantage of such a system is that with the falling off of load on the compressor, the suction temperature or the temperature in the evaporator drops, and there is a possibility of freezing the water in the tubes, which, of course, might split the tubes and allow the refrigerant to escape into the water passage. This danger can be eliminated by automatic safety devices.

Another system of cooling spray water is to submerge coils in the spray collecting tank, or in a separate tank used for storage. The heat transmission through the walls of the coils, however, is low and a great deal more surface is required than for any other type of cooler. However, with large storage tanks this type of cooling can be utilized to advantage.

2. *Air coolers.* When direct cooling of air is employed, the refrigerant is inside the coil and the air passes over it. Cooling depends upon convection and conduction for removing the heat from the air. The type of coil used can be either smooth or finned, the finned coil being more economical in space requirement than the smooth coil. The fins, however, must be far enough apart so as not to retain the moisture which condenses out of the air.

When refrigeration evaporators are used for cooling air or other gases by forced convection, they are usually termed blast coils or unit coolers. A blast coil may be placed in a duct or in an assembled unit, and the air forced across the coil and discharged through distributing ducts or directly into the space to be conditioned. Unit coolers, designed much like unit heaters, consist of a finned coil, propeller fan, and controls suspended directly in the space to be cooled.

3. *Indirect brine coolers.* The indirect cooler, where brine is cooled by the refrigerant and the resulting cold brine is used to cool either air or water, introduces several other considerations. It is not the most economical from a power consumption standpoint, as it is necessary to cool the brine to a temperature sufficiently low so that there is an appreciable difference between the average brine temperature and that of the substance being cooled. This requires that the temperature of the refrigerant must be still lower, and consequently the amount of power required to produce a given amount of refrigeration increases due to the higher compression ratio. There are other considerations which make such a system desirable. In the first place, where a toxic refrigerant is undesirable or cannot be used because of fire or other risks, especially in densely populated areas, the brine can be cooled in an isolated room or building and can then be circulated through the air conditioning equipment. This arrangement eliminates any possibility of direct contact between the air and refrigerant.

### REFRIGERATION CONTROL

In addition to the compressor, evaporator, and condenser, several auxiliaries are required for proper operation of a refrigeration system. Some device must be supplied for the controlled expansion of the refrigerant from

the high condenser pressure to the low evaporator pressure; controls are required for the on-off operation of the compressor, the flow of the condensing medium, and for safety devices; proper piping is required for connecting the various portions of the systems. Where refrigerating apparatus is used for the cooling of rooms, additional controls are required.

### Expansion Devices

Some form of expansion device must be provided to control the rate of flow of the liquid refrigerant between the high and low side pressures of the system. This device is usually an expansion valve and may be either manual or automatic; however, with few exceptions, manual valves are obsolete and no longer used.

*Automatic Expansion Valves.* An automatic or pressure controlled expansion valve operates to maintain a constant pressure in the evaporator. The liquid refrigerant passes through an orifice, the opening size of which is controlled by means

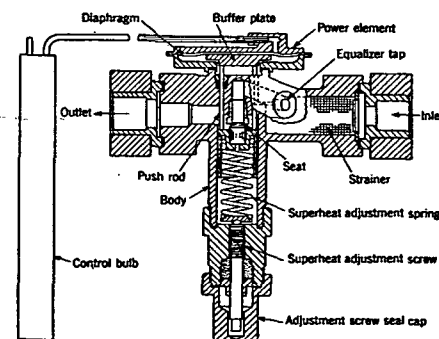


FIG. 13. TYPICAL THERMOSTATIC EXPANSION VALVE

of a needle valve connected to a flexible bellows. This bellows expands or contracts with variations in the evaporator pressure transmitted to the expansion chamber through the refrigerant outlet from the evaporator. The position of this needle valve is controlled by the degree of compression in an adjustable spring, balanced against the bellows, and these two forces operate to maintain a constant pressure in the evaporator by increasing or decreasing the flow of liquid refrigerant. Such an expansion valve is usually applied to evaporators of the direct expansion type, but is not satisfactory for fluctuating loads such as are encountered in air conditioning installations.

*Thermostatic Expansion Valves.* A thermostatic expansion valve controls the flow of liquid refrigerant to the evaporator so as to maintain the entire coil filled with evaporating refrigerant, and to keep a constant superheat in the refrigerant gas leaving the coil. The construction of such a valve is shown in Fig. 13 and is similar to that for an automatic expansion valve but incorporates, in addition, a power element responsive to changes in the degree of superheat of the refrigerant gas leaving the coil. This power element consists of a bellows connected by means of a capillary tube to a feeler bulb fastened to the suction line from the evaporator. The bulb, bellows, and tube are usually charged with the same liquid refrigerant used in the evaporator itself. A starved condition in the evaporator results in a greater superheat in the gas leaving the evaporator, and this in turn operates through the power element to increase the flow of liquid refrigerant. A flooded evaporator reduces the discharge superheat, and thus tends to reduce the flow of liquid refrigerant. Such an expansion valve is satisfactory for operation with fluctuating loads since this type of control tends to keep the evaporator filled with refrigerant at all times.

*Low-Side Float Valves.* A liquid refrigerant control of the low-side float valve type consists of a ball float located in either a receiver or the evaporator itself on

the low pressure side of the system. A needle valve, operated through a simple lever mechanism attached to the float, permits the passage of more or less refrigerant, as the level in the receiver or the evaporator fluctuates. Such a control must be used in conjunction with a flooded evaporator, and has been applied extensively to household refrigerators and, to some extent, in commercial and industrial installations.

**High-Side Float Valves.** A high-side float valve differs from a low-side float valve in that the float is located in a receiver or container on the high pressure side of the system. Proper operation again depends upon metering of the refrigerant through a controlled opening, depending upon the level of the liquid refrigerant in the container. Such a control has the disadvantage that the evaporator must be placed directly adjacent to the float container, or some intermediate pressure device must be applied to prevent flashing of the refrigerant upon pressure drop.

**Capillary Tubes.** A capillary tube may be used as a liquid refrigerant expanding device. Such a device consists of an extremely small bore tube (in the order of 0.04 inch in diameter) of five to twenty feet in length. Although such a restricting device operates as a very simple means of expanding the liquid refrigerant, it has the disadvantage that no modifications are possible to adjust the rate of expansion under various operating conditions. The bore and length of the tube, as well as the proportions of the rest of the system, are critical. It is for these reasons that its application has been limited to factory assembled domestic and commercial units.

### Refrigeration Control Devices

In addition to automatic control of expansion of the liquid refrigerant, a completely automatic refrigeration system requires (1) some means for on-off operation of the compressor motor, (2) control of the flow of the condensing medium, and (3) safety devices for prevention of damage to the equipment. In addition, special controls designed for specific applications are frequently required. The various types of devices used to accomplish these purposes are so numerous that it would be impossible to describe all of their modifications. Only the general purposes and operating characteristics of the more typical mechanisms are here discussed.

**Compressor Motor Controls.** Two types of controls are used for intermittently starting and stopping compressors. The first of these is a pressure motor control responsive to the evaporator pressure, and the second a thermostatic motor control responsive to the temperature of the load surrounding the evaporators. In the first case the compressor operation is indirectly dependent upon the temperature of the load, and is controlled by the refrigerant pressure at the point of control location. The second type is dependent upon the temperature of the load being cooled.

With the pressure actuated device, the control is frequently located directly on the condensing unit, and the low pressure in the suction line or the crankcase of the compressor is used to control motor operation. Such a control usually consists of a low pressure bellows, connected through tubing directly to the low pressure control source, and an electrical switch operated through linkage by the movement of the bellows. The electrical circuit is closed on rising pressure, and opened on falling pressure. The thermostatic type of motor control is usually similar in construction to the pressure control, with the exception that a temperature bulb and capillary tube replace the pressure line, and the temperature bulb is located adjacent to the evaporator itself. In this case motor control is directly responsive to changes in the temperature of the load surrounding the evaporator. Frequently, a high pressure safety cutout switch is combined with the motor control, and operates to cut off the power from the motor in case the high side pressure exceeds a predetermined limit.

**Solenoid Valves.** Solenoid or magnetic stop valves are frequently used in refrigeration systems for control of gas and liquid flow. When applied as liquid stop valves, they are placed in the liquid line between the condenser or receiver and the evaporator, and the line is open to passage of the refrigerant only when the compressor is in operation. When the compressor is not in operation, leakage of liquid refrigerant in the evaporator is prevented. In some cases such a magnetic stop valve is operated directly by a thermostat located at the point of the load, and the compressor motor operation is controlled independently by a low pressure switch.

Magnetic liquid stop valves are also widely used for the control of the refrigerant flow to individual evaporators in a multiple evaporator system operated by one compressor. In some installations magnetic liquid line and suction line valves are used to isolate completely an evaporator for defrosting purposes. A magnetic valve may be installed in a by-pass around one or more cylinders of a multiple cylinder compressor, and thereby be used to unload a compressor during starting to reduce load. Additional applications are found in control of the circulation of brine in a secondary refrigeration system.

**Suction Pressure Valves.** Suction pressure control valves, frequently called back pressure regulators or two-temperature valves, are sometimes placed in the suction line to prevent the evaporator pressure and temperature from dropping below a predetermined level. Typical applications of such controls occur in water cooling or milk cooling systems, where freezing and other damage would result if the evaporator pressure dropped too low, or in multiple systems where several evaporators are supplied by one condensing unit. Thus, different evaporators may be kept at different temperatures by maintaining a pressure drop between the evaporator and the suction line.

**Condensing Water Control.** The majority of the refrigeration systems, other than fractional horsepower, use water cooled rather than air cooled condensers, since the lower condensing temperatures result in more economical operation. Automatic control of the water flow to the condenser must be maintained if water wastage is to be eliminated. Such control may be provided through the use of either an electric solenoid water valve or by means of a pressure control valve. With a solenoid valve, the flow is two-position, either *off* or *on*, and its operation is simultaneous with starting and stopping of the compressor motor. With a pressure operated valve, the flow is modulated and is dependent entirely upon condenser pressure rather than condensing unit operation. Similar water valves controlled thermostatically by the temperature of the water discharged from the condenser are also available.

**Safety Controls.** Many controls are designed not to aid in proper operation of the system, but to prevent damage in case of improper operation. One such safety control is the high-pressure cutoff frequently combined with the low-pressure motor control as previously described. Another safety control often used is a low voltage cut-off which shuts down the system automatically in case the line voltage drops below a minimum value. High pressure relief valves are used for safety purposes to prevent damage in case excessive condensing pressures are encountered.

### Refrigeration Control for Air Conditioning Equipment

When refrigerating equipment is used for space cooling, two major control problems exist: one is control of the temperature and the other, control of the humidity. In some applications the amount of latent heat to be removed is small compared with the sensible heat. In such cases, sufficient dehumidification will usually occur without any special provisions. In other cases, such as theaters, where the latent load is relatively high, the air must be cooled below its dew-point temperature, and sometimes rewarmed to return it to the comfort range. Chapter 39, Automatic Control, discusses, among other topics, control systems for unit coolers, well water and ice cooling systems, central fan systems, and all-year air conditioning systems.

### REFRIGERATION PIPING

The pressure drop which occurs during passage of the refrigerant through connecting piping is similar in effect to that which occurs through suction and discharge valves of the compressor. Thus, the effect of the pressure drop in the suction line between evaporator and compressor requires that a lower pressure be maintained inside the compressor during suction than is maintained in the evaporator. The pressure drop through the connecting piping between the compressor and the condenser requires that a higher pressure be maintained inside the compressor during discharge than in the

condenser. These losses result in a greater compression ratio, and therefore greater power requirements, as well as a lower volumetric efficiency and higher displacement requirements. Pressure losses in the liquid line between condenser or receiver and the expansion valve may result in some flashing of the liquid refrigerant, unless the liquid is subcooled. In all cases, frictional losses should be kept to a minimum, and piping should be selected which will give the smallest loss consistent with overall economy in the system.

Refrigerant liquid lines from the receiver to the expansion valve should be preferably designed with a pressure drop of less than 5 psi, and with 10 psi as the maximum. A velocity of 100 to 250 fpm is recommended to prevent a pressure drop great enough to cause vaporization of the refrigerant ahead of the expansion valve. If the evaporator is to be located at a higher elevation than the condenser or receiver, account should be taken

TABLE 5. DICHLORODIFLUOROMETHANE ( $\text{CCl}_2\text{F}_2$ ) LIQUID LINES, TONS CAPACITY PER 100 FT EQUIVALENT LENGTH

| LINE SIZE, INCHES   | PRESSURE DROP PER 100 FT EQUIVALENT LENGTH, PSI |      |       |       |
|---------------------|-------------------------------------------------|------|-------|-------|
|                     | 3                                               | 5    | 10    | 20    |
| $\frac{3}{8}$ OD    | 0.88                                            | 1.14 | 1.80  | 2.58  |
| $\frac{3}{8}$ IPS   | 2.89                                            | 3.64 | 5.56  | 8.50  |
| $\frac{1}{2}$ OD    | 4.86                                            | 6.81 | 10.2  | 15.8  |
| $\frac{1}{2}$ IPS   | 4.86                                            | 6.81 | 10.2  | 15.8  |
| $\frac{5}{8}$ OD    | 9.73                                            | 12.6 | 18.5  | 27.0  |
| $\frac{5}{8}$ IPS   | 10.5                                            | 14.1 | 21.8  | 33.0  |
| 1 OD                | 21.4                                            | 28.2 | 41.3  | 60.8  |
| 1 IPS               | 21.4                                            | 28.2 | 41.3  | 60.8  |
| 1 $\frac{1}{8}$ OD  | 36.9                                            | 48.1 | 70.5  | 101.  |
| 1 $\frac{1}{8}$ IPS | 36.9                                            | 48.1 | 70.5  | 101.  |
| 1 $\frac{1}{2}$ OD  | 62.0                                            | 80.2 | 114.  | 160.  |
| 1 $\frac{1}{2}$ IPS | 62.0                                            | 80.2 | 114.  | 160.  |
| 2 OD                | 124.                                            | 161. | 231.  | 328.  |
| 2 IPS               | 230.                                            | 297. | 426.  | 607.  |
| 2 $\frac{1}{2}$ OD  | 364.                                            | 469. | 676.  | 972.  |
| 2 $\frac{1}{2}$ IPS | 539.                                            | 704. | 1005. | 1430. |
| 3 OD                | 753.                                            | 972. | 1385. | 1945. |

Note: Tonnage values above those underlined give velocities of 300 fpm or less.

of the pressure drop for each foot of static liquid lift. Approximate values are 0.26 psi per foot for ammonia, 0.57 psi per foot for dichlorodifluoromethane, 0.51 psi per foot for monochlorodifluoromethane, and 0.64 psi per foot for monofluorotrichloromethane. Where there is a possibility of vaporization of some of the liquid before reaching the expansion valves, means for subcooling should be provided.

Since a reduction of suction pressure at the compressor results in an appreciable reduction in capacity and more power input per ton of refrigeration, great care should be given to the proper sizing of suction lines between the evaporator and the compressor. Although comparatively high velocities, 500 to 5000 fpm, may be used, the optimum value will depend upon the refrigerant and the operating pressure range. Since return of the oil to the compressor must be considered in the case of the fluorinated hydrocarbons and methyl chloride, for these refrigerants the minimum velocity should be 500 fpm for horizontal runs and 1000 fpm for vertical runs. For the former, the usual design velocities range between 1000 and 2000

TABLE 6. MAXIMUM TONS OF COMPRESSOR CAPACITY FOR  $\text{CCl}_2\text{F}_2$  LINES (Only for temperatures indicated)

| LINE SIZE INCHES    | SUCTION LINES<br>BASED ON 105 F CONDENSING TEMPERATURE               |      |      |       |      |      | DISCHARGE LINES           |       |
|---------------------|----------------------------------------------------------------------|------|------|-------|------|------|---------------------------|-------|
|                     | Psi Pressure Drop per 100 Ft<br>Equivalent Length at 40 F Saturation |      |      |       |      |      | Condensing<br>Temperature |       |
|                     | $\frac{1}{8}$                                                        | 1    | 2    | 3     | 4    | 5    | 115 F                     | 90 F  |
| $\frac{3}{8}$ OD    | 0.14                                                                 | 0.20 | 0.28 | 0.35  | 0.41 | 0.45 |                           |       |
| $\frac{3}{8}$ IPS   | 0.17                                                                 | 0.24 | 0.34 | 0.42  | 0.49 | 0.54 |                           |       |
| $\frac{1}{2}$ OD    | 0.25                                                                 | 0.35 | 0.51 | 0.62  | 0.73 | 0.81 | 1.43                      | 1.15  |
| $\frac{1}{2}$ IPS   | 0.35                                                                 | 0.45 | 0.65 | 0.79  | 0.93 | 1.03 | 1.87                      | 1.50  |
| $\frac{5}{8}$ OD    | 0.55                                                                 | 0.76 | 1.10 | 1.34  | 1.58 | 1.75 | 2.97                      | 2.38  |
| $\frac{5}{8}$ IPS   | 0.68                                                                 | 0.94 | 1.35 | 1.65  | 1.92 | 2.12 | 3.26                      | 2.62  |
| 1 OD                | 1.26                                                                 | 1.80 | 2.57 | 3.17  | 3.76 | 4.15 | 5.05                      | 4.05  |
| 1 IPS               | 1.43                                                                 | 2.01 | 2.89 | 3.54  | 4.17 | 4.60 | 5.29                      | 4.25  |
| 1 $\frac{1}{8}$ OD  | 2.21                                                                 | 3.12 | 4.45 | 5.50  | 6.38 | 7.05 | 7.72                      | 6.19  |
| 1 $\frac{1}{8}$ IPS | 2.70                                                                 | 3.82 | 5.37 | 6.72  | 7.68 | 8.48 | 9.16                      | 7.35  |
| 1 $\frac{1}{2}$ OD  | 3.40                                                                 | 4.78 | 6.79 | 8.42  | 9.77 | 10.8 | 10.92                     | 8.75  |
| 1 $\frac{1}{2}$ IPS | 4.05                                                                 | 5.75 | 8.10 | 10.12 | 11.6 | 12.8 | 12.5                      | 10.0  |
| 2 OD                | 6.12                                                                 | 8.60 | 12.1 | 15.1  | 17.4 | 19.2 | 19.2                      | 15.3  |
| 2 IPS               | 7.66                                                                 | 10.9 | 15.3 | 19.2  | 22.5 | 24.5 | 20.6                      | 16.5  |
| 2 $\frac{1}{2}$ OD  | 12.0                                                                 | 17.1 | 24.0 | 30.1  | 34.6 | 38.2 | 32.2                      | 25.9  |
| 2 $\frac{1}{2}$ IPS | 12.0                                                                 | 17.1 | 24.0 | 30.1  | 34.6 | 38.2 | 32.2                      | 25.9  |
| 3 OD                | 19.1                                                                 | 27.2 | 38.2 | 47.8  | 55.0 | 60.7 | 51.5                      | 39.8  |
| 3 IPS               | 20.9                                                                 | 29.4 | 42.3 | 51.8  | 60.0 | 66.2 | 54.5                      | 43.8  |
| 3 $\frac{1}{2}$ OD  | 27.8                                                                 | 39.7 | 55.7 | 69.8  | 80.3 | 88.7 | 72.0                      | 57.6  |
| 3 $\frac{1}{2}$ IPS | 30.2                                                                 | 43.2 | 61.0 | 76.1  | 87.0 | 96.0 | 78.8                      | 63.3  |
| 4 OD                | 38.6                                                                 | 55.2 | 78.0 | 97.3  | 111  | 123  | 95.8                      | 77.1  |
| 4 IPS               | 40.7                                                                 | 58.6 | 83.0 | 103   | 118  | 130  | 101.6                     | 81.6  |
| 5 OD                | 71.3                                                                 | 100  | 141  | 176   | 203  | 224  | 171.5                     | 137.8 |
| 5 IPS               | 126                                                                  | 183  | 257  | 322   | 366  | 403  | 266                       | 214   |
| 8 IPS               | 211                                                                  | 297  | 422  | 523   | 602  | 664  | 461                       | 370   |
| 10 IPS              | 352                                                                  | 503  | 712  | 887   | 1024 | 1130 | 725                       | 582   |
| 12 IPS              | 550                                                                  | 780  | 1106 | 1373  | 1582 | 1748 | 1041                      | 836   |

fpm. Too high velocities create noise problems and excessive pressure drops. The total pressure drop in the suction line should be between one and two psi, if the velocity can be kept to within the specified limits.

Compressor discharge or hot gas lines may be designed with velocities from 1000 to 5000 fpm, except for dense gases such as carbon dioxide, where noise considerations will reduce the upper limit. A pressure drop of 2 to 4 psi is recommended for the discharge lines. Extensive tables are available in the literature for the determination of pressure drops through refrigerant lines with various refrigerants. The capacities listed in Tables 5, 6 and 7 are published in *ARI Equipment Standards-1946*, of the *Air-Conditioning and Refrigeration Institute*, and are used by permission.

TABLE 7. APPROXIMATE SUCTION-LINE CAPACITY FACTORS FOR EQUAL PRESSURE DROP OF  $\text{CCl}_2\text{F}_2$

| SATURATED SUCTION TEMPERATURE, F. | 50   | 40   | 30   | 20   | 10   | 0    | -10  | -20  |
|-----------------------------------|------|------|------|------|------|------|------|------|
| Factor                            | 1.09 | 1.00 | 0.92 | 0.86 | 0.80 | 0.74 | 0.66 | 0.56 |



Table 5 shows the tonnage capacity normally allowed for  $\text{CCl}_2\text{F}_2$  liquid lines per foot equivalent length of pipe, and Table 6 the maximum tonnage for suction and discharge  $\text{CCl}_2\text{F}_2$  lines. Table 7 presents suction-line capacity factors for equal pressure drop.

### ACCESSORIES

Dehydrators, oil separators, strainers, vibration eliminators, sight glasses, and various types of valves are accessories frequently needed for the proper

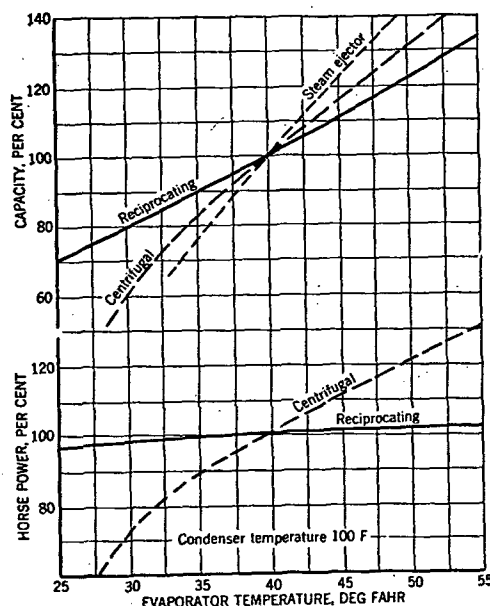


FIG. 14. PERFORMANCE CHARACTERISTICS OF COMPRESSION REFRIGERATION MACHINES AT CONSTANT SPEED

installation and operation of refrigeration systems. Refrigerant-line dehydrators or dryers usually consist of copper containers fitted with tubing connections at either end, and contain a desiccant such as silica gel, activated alumina, or calcium chloride. The liquid refrigerant is circulated through the dryer during operation of the system, and the moisture content of the refrigerant charge is thus kept to a minimum.

Oil separators are installed between the compressor and condenser to prevent excessive oil removal from the compressor crankcase and its passage into the condenser and evaporator. The oil is separated from the gaseous refrigerant by gravity during its passage through a chamber of sufficient size to reduce the velocity. A float-operated valve maintains a maximum oil level in the separator, and additional oil is forced by pressure difference through a line back to the crankcase.

Screen strainers are frequently installed in the liquid line piping before solenoid valves and expansion valves, as well as before regulating valves

in water lines leading to water cooled condensers. Sight glasses which permit visual inspection of the condition of the refrigerant are sometimes installed on factory assembled commercial unit systems. It is particularly advisable to place such a fitting before the expansion valve, if the evaporator is located above the condenser.

Flexible vibration eliminators, usually consisting of a bellows design covered with woven copper wire, are sometimes installed in copper lines where units such as compressors are installed on flexible mountings, or where vibration is otherwise a problem. Packed or packless shut-off valves are necessary where it may be required to isolate portions of a system.

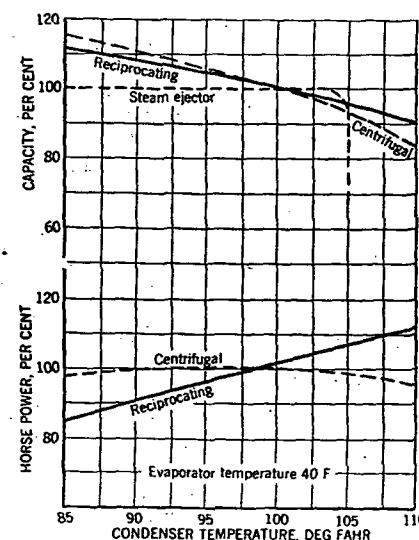


FIG. 15. PERFORMANCE CHARACTERISTICS OF COMPRESSION REFRIGERATION MACHINES AT CONSTANT SPEED

### EQUIPMENT CHARACTERISTICS AND SELECTION

The various types of compression systems have quite different characteristics of capacity and power with varying evaporator and condenser temperatures, as may be noted from curves in Figs. 14 and 15.

From Fig. 14 it may be observed that power requirements for the centrifugal compressor increase much more rapidly than for the reciprocating compressor, with increase in evaporator temperature. Similarly, the capacities of the steam ejector and centrifugal compressors increase more rapidly than those of the reciprocating compressor with increase in evaporator temperature. Thus, both the steam jet and centrifugal machines tend to be more self-regulating than the reciprocating. It is also evident from Fig. 14 that the steam jet equipment is best suited for operation at high evaporator temperatures.

The effect of condenser temperature upon the power and capacity of the different types of compressors is shown in Fig. 15. It may be noted



that the power required by the reciprocating compressor increases rapidly with increase in condenser temperature, while the power curve for the centrifugal compressor is relatively flat. It is also evident that the capacity of the steam jet compressor is independent of condenser temperature until a certain point is reached, where it drops to zero. As previously stated, steam jet equipment requires more condensing water than other types of compression systems. Consequently, steam jet systems are well suited to those applications where condensing water is cheap, or where condensing water is rather high in temperature.

The selection of proper refrigeration equipment for any air conditioning

TABLE 8. BASIS OF EQUIPMENT SELECTION

| CAPACITY TONS | MAJORITY USED                                             | SOME USED                                                             | FEW USED                                                                                        |
|---------------|-----------------------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| 0 to 5        | Unit systems in conditioned space.                        | Unit central systems using duct distribution.                         | Built up central systems.                                                                       |
| 5 to 25       | Built up central systems using reciprocating compressors. | Unit central systems using duct distribution.                         | Unit systems in conditioned space.<br>Built up systems using absorption and adsorption systems. |
| 25 to 50      | Built up central systems using reciprocating compressors. | Built up central systems using centrifugal compressors.               | Central systems using adsorption systems.                                                       |
| 50 to 400     | Built up central systems using reciprocating compressors. | Built up central systems using steam jet and centrifugal compressors. |                                                                                                 |
| 400 and Over  | Built up central systems using centrifugal compressors.   | Built up central systems using steam jet.                             |                                                                                                 |

job is of utmost importance for satisfactory results. The most important factors in the selection of the equipment are:

1. Loads (as determined by the conditions of the space to be cooled).
2. Economics (both initial and operating costs).
3. Codes (local safety codes must be adhered to and influence the type of system to be used).

A broad division of equipment to be used for a particular installation or application may be made on the basis of the magnitude of the load. Current general practice is outlined in Table 8.

Unit or *packaged* systems, consisting of a reciprocating compressor, condenser, evaporator, and fans, are generally used in the smaller sized jobs where electric power is available, as they are manufactured complete, ready to install, and are the most economical (see Chapter 26).

The reciprocating compressor in the built-up central system (see

Chapter 30) covers the widest range of application since it is applicable to either the direct expansion or indirect systems, and can be driven by steam or gas engines, or by electric motors. The quantity of condensing cooling medium required is also less than for any other system, with the exception of the centrifugal compressor, which uses the same amount.

Centrifugal compressors are used for large installations, and usually where the indirect system is required. The driving mechanism can be a steam turbine or electric motor. The steam jet system is used where steam is available and cooling water can be had in large quantities.

It will be noted by referring to Fig. 14 that all systems using compressors have a common characteristic, namely, that the capacity varies with the evaporating temperature. Not only can the equipment be selected to

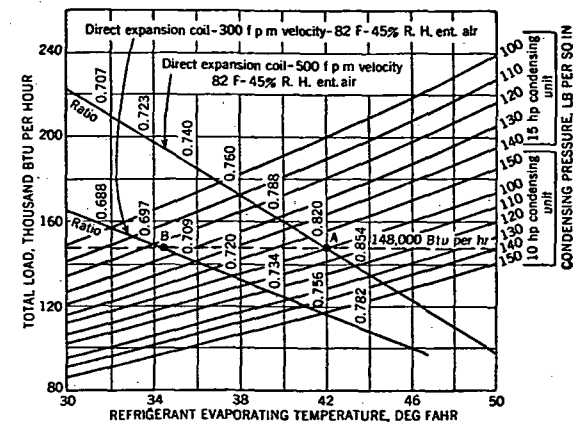


FIG. 16. COMPRESSOR AND COIL PERFORMANCE

produce a given result, but the performance can be predicted under varying load conditions by the simple expedient of using the variable of evaporating temperature as the abscissa, and the load or capacity as the ordinate in a series of curves.

Manufacturers of compressors and cooling coils furnish performance data for apparatus that can be plotted in the form of curves similar to those shown in Fig. 16. The performance of a compressor is plotted as a series of curves, each curve being drawn for a given condensing pressure. The performance of a direct expansion coil at two different air velocities is plotted on the same graph. The operating point will be, of course, where the two curves cross.

Data given in Table 9 illustrate two types of conditioned enclosures having the same total load of 148,000 Btu per hour, but with two different ratios of sensible to total heat. In the case of the office with a ratio of 82 percent sensible to total heat, the operating point A in Fig. 16 is found to be 42.2 F evaporating temperature, with a face velocity of 500 fpm. In the case of the restaurant, with a ratio of 69.5 percent sensible to total heat, the air velocity is lowered to 300 fpm, and the evaporating tempera-

TABLE 9. TYPICAL OPERATING CONDITIONS FOR TWO TYPES OF LOAD

| TYPE OF ENCLOSURE    | LOAD, BTU PER HOUR |        |         | RATIO SENSIBLE TO TOTAL | AIR ENTERING COIL |               | OPERATING BALANCE POINT |                                  |                        |
|----------------------|--------------------|--------|---------|-------------------------|-------------------|---------------|-------------------------|----------------------------------|------------------------|
|                      | Sensible           | Latent | Total   |                         | F Deg             | Per Cent R.H. | Evaporator Temp F Deg   | Condenser Pressure Lb per Sq In. | Per Cent Sensible Heat |
| Restaurant . . . . . | 103,000            | 45,000 | 148,000 | 0.695                   | 82                | 45            | 34.4                    | 123                              | 69.9                   |
| Office . . . . .     | 121,000            | 27,000 | 148,000 | 0.820                   | 82                | 45            | 42.2                    | 100                              | 82.1                   |

ture is lowered to 34.4 F as shown in point B of Fig. 16. In order to obtain the same capacity, a larger condensing unit is used. This illustration assumes zero pressure drop through the suction line. The pressure drop can be taken into account by shifting the compressor performance curves by the amount of pressure drop expressed in Fahrenheit degrees.

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## CHAPTER 38

## DEHUMIDIFICATION BY SORBENT MATERIALS

Definitions and Principles, Adsorbents, Dehumidification by Solid Adsorbents, Dehumidification Equipment Using Solid Adsorbents, Absorbents, Dehumidification by Liquid Absorbents, Dehumidification Equipment Using Liquid Absorbents, Calculation of Moisture Load, Vapor Transfer to Dehumidified Space

**D**E HUMIDIFICATION as used herein is the reduction of the water vapor content of a given volume of air or other gas. The term thus describes a special case of dehydration which covers the removal of moisture in any form from matter. The degree of dehumidification required varies greatly with different applications, and is one of the prime considerations influencing the choice of a method. Dehumidification may be accomplished by latent heat removal, together with sensible heat removal, as described in Chapters 30, 35, and 36, or by the use of sorbents.

Sorbents are substances which have the property of extracting and holding other substances (usually gases or vapors, e.g., water vapor), brought into contact with them. All materials are sorbents to a greater or lesser degree. The weight of water held by a substance will increase or decrease, depending upon whether the vapor pressure of the water held by the substance is less or greater, respectively, than the partial pressure of water vapor in the surrounding atmosphere. As generally used, however, the term sorbents refers to those materials having a capacity for moisture which is large compared to their volume and weight. Such materials are divided into two general classifications:

1. *Adsorbent*—A sorbent which does not change physically or chemically during the sorption process. Certain solid materials, such as activated alumina, silica gel, activated bauxites, and activated charcoal have this property. The action of adsorbents, most of which adsorb some gases and condensable vapors besides water vapor, is selective. Thus, in the case of a mixture containing both water and organic vapors, silica gel would remove the water vapor in preference to the organic vapors, while the reverse would be true in the case of activated carbon. The selective property of adsorbents is made use of in some instances for the removal of objectionable and contaminating vapors from an air or gas mixture. (See Chapter 8.)
2. *Absorbent*—A sorbent which changes either physically, chemically, or both, during the sorption process. Calcium chloride is an example of a solid absorbent, while liquid absorbents include solutions of lithium chloride, calcium chloride, lithium bromide, and the ethylene glycols.

## ADSORBENTS

The ability of an adsorbent to remove water vapor from a gas is explained by the fact that the vapor pressure of the water in the adsorbent (when in the reactivated condition) is less than the partial pressure of the water vapor in the surrounding atmosphere. For instance, when an active adsorbent is brought into contact with a gas of high humidity, there is a tendency for the vapor pressure of the water in the adsorbent to reach equilibrium with the partial pressure of the water in the surrounding gas, with

the result that water is extracted by the adsorbent and its weight increased, while the moisture content of the gas is correspondingly reduced. (The adsorbent is said to be saturated for a given condition when equilibrium is attained.) The weight of water a given adsorbent will extract is dependent upon the relative humidity (ratio of the partial pressure in the gas to the saturation pressure at a given temperature) and the temperature of the adsorbent. The process is reversible; if the temperature of the adsorbent is raised until the vapor pressure of the adsorbed water becomes greater than the partial pressure of the vapor in the surrounding atmosphere, water will be released by the adsorbent. After the adsorbent cools to room temperature, for instance, the vapor pressure of the water in the adsorbent falls below the partial pressure of the vapor in the atmosphere, and the adsorbent will again start extracting water. The elimination of water by the addition of heat is known as reactivation, and is a means of regenerating the adsorbent so that it may be used repeatedly.

Adsorption is proportional to the amount of surface (internal and external) of the sorbent. The materials that are used commercially as solid adsorbents have a porous structure of sub-microscopic dimensions, which gives them extensive surface area. An adsorbent should meet the following requirements in order to be satisfactory for dehumidification purposes:

1. Have a high adsorptive capacity under normal atmospheric conditions.
2. Be chemically stable, resisting contamination from impurities.
3. Be physically rugged to resist breakdown from handling and use.
4. Be capable of reactivation at temperatures generally obtainable.
5. Be heat-stable at reactivation temperatures.
6. Have a weight per unit volume such as to avoid excessive bulk.
7. Be available at reasonable cost.

#### Activated Alumina

Activated alumina is a granular porous material which removes by adsorption substantially 100 percent of the moisture from gases, vapors, and certain liquids. Regeneration or reactivation may be accomplished by employing a heating medium at temperatures ranging from 350 to 600 F. After many cycles of adsorption and reactivation it is substantially as effective as originally, and retains its original size and shape.

Activated alumina is produced by chemically controlled precipitation from a sodium aluminate solution resulting from the extraction of alumina from bauxite by the Bayer process. By subsequent processes this precipitate is converted into a highly porous adsorptive material. It is low in iron and silica, each normally less than 1/10 of 1 percent. Commercially produced material is uniform in analysis and physical form.

Activated alumina is a partially dehydrated aluminum trihydrate containing about 7 percent water and small amounts of soda, oxides of iron, silicon, and titanium, as well as very minor amounts of other elements indicated spectrographically. Substantially all of the soda is combined with silica and alumina as an insoluble constituent.

Activated alumina is inert chemically to most gases and vapors, is non-toxic, and will not soften, swell or disintegrate when immersed in water. High resistance to shock and abrasion is one of its more important physical characteristics. Commercial sizes range from a powder passing through 300 mesh screen to particles 1 in. in diameter. The sizes commonly used are 8-14 mesh and  $\frac{1}{4}$  in. to 8 mesh. The average weight for most forms is 50 lb per cubic foot. Its high degree of purity warrants classification among commercially pure chemicals.

#### Silica Gel

Silica gel is a prepared form of silicon dioxide (silica) having an extremely porous structure which makes it an efficient adsorbent. It is made by mixing predetermined concentrations of an acid, such as sulfuric acid, and a soluble silicate, usually sodium silicate, and allowing the mixture to set to a jelly-like mass called hydrogel. The product takes its name from its condition as a colloid at this stage of its manufacture. After setting, the hydrogel is broken into small lumps, washed, dried, crushed, and screened to the desired particle sizes and then given a final heat treatment or activation. The surface area of silica gel has been found to be in excess of 50,000 sq ft per cubic inch of product. Silica gel has high adsorptive capacity per unit weight, and may be reactivated repeatedly at temperatures up to 600 F. Reactivation is generally accomplished by blowing gases through the silica gel at approximately 300 F, or by heating in a well vented oven maintained at this temperature until no more moisture is given off. Silica gel is a high purity, rugged, non-toxic, heat-stable material, having a specific heat of 0.2, and is most inert. There is no change in the size or shape of the particles as it becomes saturated, and no corrosive or injurious compounds are given off. It is available commercially in a number of grades, ranging in particle size from a 3 to 8 mesh product to an impalpable powder passing through a 325 mesh screen. The product generally used for dehumidification applications has a particle size of 6 to 12 mesh, and a bulk density of between 40 and 45 lb per cubic foot.

#### Activated Bauxite

Activated bauxites are certain natural products which, after controlled heat treatment, have properties which make them suitable for use as solid adsorbents. They are marketed under different trade names by several processors. The activated bauxites consist primarily of  $Al_2O_3$ ,  $Fe_2O_3$ ,  $SiO_2$ ,  $TiO_2$ , and  $H_2O$  in varying percentages. The surface area, adsorptive capacity, and other properties of the several products differ to some extent, depending upon the source of the original material and its subsequent treatment. The available activated bauxites are durable products having a specific heat of about 0.24, and can be regenerated at temperatures between 300 F and 500 F. They are usually supplied in a number of particle sizes, and have a bulk density of between 55 and 65 lb per cubic foot.

There are other solid substances having marked adsorbent properties, but details concerning them are not available.

#### DEHUMIDIFICATION BY SOLID ADSORBENTS

Since adsorption is primarily a condensation process, heat, equivalent to the latent heat of evaporation of the vapor, plus the heat of wetting (which is an additional amount of heat, depending upon the vapor being adsorbed and the adsorbent used) is liberated. The sum of the latent heat of evaporation and the heat of wetting is known as the heat of adsorption. During adsorption it might be said that latent heat is transformed into sensible heat, which is dissipated into the adsorbent, into the metal of the adsorbent container, and into the gas mixture, resulting in a rise in temperature. Fig. 1 shows the relationship between temperature, vapor pressure, and moisture content of a solid adsorbent. These curves indicate the general performance of solid adsorbents, although the exact values vary for the different adsorbents, and may vary even for different types of the same compound. The effects of vapor pressure and temperature upon the moisture content of an adsorbent may be observed by referring to Fig. 1. When the given type of solid adsorbent is in equilibrium with air having a dry-

bulb temperature of 70 F and 70 percent relative humidity, that is, having a dew-point of 60 F or a water vapor pressure of 13.2 mm Hg, the water content of the adsorbent is 33 percent. With air having the same dry-bulb temperature and a dew-point of 37 F, or a vapor pressure of 5.6 mm Hg, the water content is 20 percent. The increase in weight for an activated solid adsorbent, after it reaches equilibrium with a gas of any given water vapor content, may be found by subtracting the residual water content (for example 6 percent) from the equilibrium value. In the case of the two examples cited, the actual water gain would be 27 percent and 14 percent,

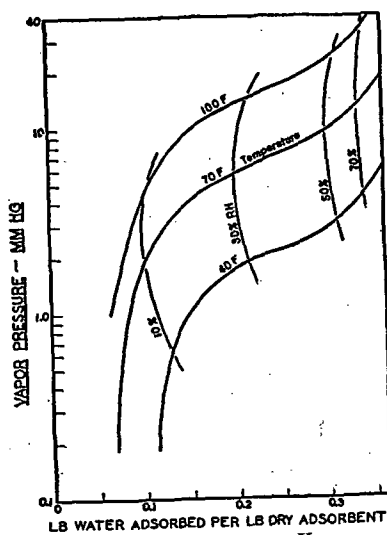


FIG. 1. TEMPERATURE—VAPOR PRESSURE—CONCENTRATION CHARACTERISTICS FOR A TYPICAL SOLID ADSORBENT

respectively. The effect of temperature upon the adsorptive capacity may be observed by following the 5.6 mm Hg vapor pressure line. At a temperature of 70 F, the moisture content of the adsorbent is 20 percent, while at 100 F, the equilibrium water content is 11 percent.

In practice, the temperature rise in the dehumidified air caused by the adsorption heat, is approximately 10 deg F for each grain of moisture removed per cubic foot of air at atmospheric pressure. This temperature rise occurs progressively through the adsorbent bed, and is an important consideration in predetermining the performance of a given design of apparatus. Data such as these, together with information covering other characteristics such as specific heat, resistance to air flow, etc., are of value in the basic design of adsorption apparatus. In the solution of air conditioning problems, however, reference must be made to performance data on established apparatus designs.

#### DEHUMIDIFICATION EQUIPMENT USING SOLID ADSORBENTS

A typical solid adsorbent dehumidification unit air flow diagram is shown in Fig. 2. The apparatus consists of two adsorbent containers (adsorbers)

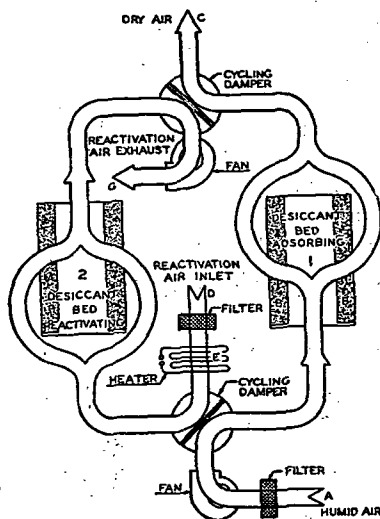


FIG. 2. A TYPICAL SOLID ADSORBENT DEHUMIDIFICATION UNIT AIR FLOW DIAGRAM

with necessary interconnecting piping, valves, and auxiliaries consisting of filters, fans, activation air heater, controls, and, in some instances, a cooler for the dehumidified air. Before entering the adsorber, the air to be dehumidified is drawn into a filter to remove dust and other impurities. In passing through the adsorbent bed, the moisture content of the air is reduced and the dehumidified air is then introduced into the space or process requiring it. While the first adsorber is dehumidifying the air, the second adsorber is being reactivated by means of outside air drawn through a filter and heater in which its temperature is raised to 300 F. The heat may be supplied by electric heating elements, steam coils, the direct products of combustion of gas, oil, waste heat, or any other convenient source. In passing through the adsorbent bed, the hot gases supply the necessary heat for releasing adsorbed water from the adsorbent, and then carry it out of the adsorber to the activation gas outlet, where it is exhausted to the outside atmosphere. In some instances a thermostat placed in the activation outlet connection shuts off the activation fan and heater when the adsorbent is completely reactivated, as indicated by a rapid rise in the temperature of the outlet activation gas. The length of the adsorption period may be controlled by a timing device which changes the valves or dampers from the adsorbing to the activating position, or by a humidistat located in the dehumidified air connection or in the dehumidified space. The majority of commercial units are time controlled.

In applications where a continuous stream of dehumidified air is not required, a single adsorber type unit may be used, while in other cases where a continuous stream of dehumidified air is required, a multiple number of adsorbers, or even a continuously rotating system, may be used.

If the air to be dehumidified is very warm, and especially where exceedingly low dew-point dehumidified air is required, it is advantageous to install a pre-cooler to reduce the temperature of the inlet air. In this way the working temperature in the adsorber is lowered, and the overall performance appreciably increased. Some equipment manufacturers install cooling coils in the adsorbent beds for the same purpose, while others divide the adsorbent bed and install coolers between the sections.

Dehumidification equipment is employed to the best advantage where the air conditioning problem is primarily one of obtaining low relative humidity control rather than temperature control. This requirement is found in the case of the preservation of inactive naval vessels where the interior of the ship must be kept at a relative humidity below 30 percent to avoid corrosion, mold, mildew, and other moisture damage that occurs at humidities substantially in excess of this figure. Other advantageous applications for dehumidification systems are found in industrial processes where low relative humidity atmospheres are required during the manufacture, as well as for preservation of the finished products. Dehumidification with cooling may be used to advantage in work-rooms or other spaces occupied by humans, where the moisture load is high in comparison to the sensible heat load. In many instances, where independent control of temperature and humidity is important, dehumidification is used to advantage in conjunction with cooling.

#### ABSORBENTS

Any absorbent substance may be used as a dehumidifying agent if it has a vapor pressure with respect to water lower than the partial pressure of the water vapor in the mixture from which the moisture is to be removed.

*Solid Absorbents.* The substances used are generally the solid forms of the liquid absorbents. At present they are used principally in small desiccating chambers

and in small dryers of the cartridge type, through which air is forced under pressure. Calcium chloride is frequently used because of low cost.

**Liquid Absorbents.** These are primarily water solutions of materials in which the vapor pressure is reduced to a suitable level by controlling the concentration and temperature of the dehumidifying solution. Water solutions of the chlorides or bromides of various inorganic elements and certain organic compounds, are the liquid absorbents used in air conditioning.

In addition to having suitable water vapor pressure characteristics, an absorbent, to be satisfactory, should also meet the following requirements:

1. Be widely available at low cost.
2. Be non-corrosive, odorless, non-toxic, and non-inflammable.
3. Be chemically inert against any impurities in the air stream.
4. Be stable over the range of use.
5. Must not precipitate at the lowest temperature to which the apparatus is exposed.
6. Have low viscosity, and be capable of being economically regenerated or concentrated after having been diluted by the moisture absorbed.

### DEHUMIDIFICATION BY LIQUID ABSORBENTS

In liquid absorption systems the air-vapor stream is brought into intimate contact with the absorbent solution by passing the air stream through a tower into which the brine is introduced as a finely divided spray, or by passing the air through a tower or contactor which is continuously sprayed with the brine, thereby presenting a large surface of absorbent to the air to be dehumidified. The difference in the partial pressure of the water in the concentrated brine and the partial pressure of the water vapor in the air, causes the water vapor to be given up by the air to the brine until equilibrium is approached. The water vapor is condensed during this operation, and its addition to the absorbent solution results in a decrease in the concentration of the solution. As the water vapor condenses, the latent heat of condensation is released in the absorbent solution. An additional, frequently appreciable, quantity of heat known as the heat of solution or heat of mixing, is also released. The heat released as the result of condensation and mixing, is directly transferred to the liquid absorbent, equipment, and air being dehumidified, thereby causing a rise in temperature.

A modified system includes means for removing heat from the absorbent solution, either within the contactor or externally. Thus the temperature of the solution may be higher than, equal to, or lower than that of the air, depending on the chemical employed and the ultimate use of the dehumidified air.

Fig. 3 shows the relationship between temperature, vapor pressure and moisture content of a typical absorbent of the *inorganic* type. These curves indicate the general performance of such absorbents, although the exact values vary for the different compounds.

When the given absorbent is in equilibrium with air having a dry-bulb temperature of 70 F and a relative humidity of 70 percent, i.e., having a dew-point of 60 F, or a water vapor pressure of 13.2 mm Hg, the water content of the solution is 4.8 lb water per pound of anhydrous absorbent. With air having the same dry-bulb temperature and a dew-point of 37 F, or a vapor pressure of 5.6 mm Hg, the water content is 2.1 lb per pound of absorbent. Therefore, when a solution of 2.1 lb water per pound of absorbent is exposed to an atmosphere of 70 F and 70 percent relative humidity, it will absorb an additional 2.7 lb of water in reaching equilibrium.

The effect of temperature on the absorptive capacity may be observed by following a constant vapor pressure line in Fig. 3. At a temperature of 70 F and a vapor pressure of 13.2 mm Hg, the moisture content is 4.8 lb

water per pound of absorbent. At 100 F, the moisture content is 1.8 lb water per pound of absorbent.

Fig. 4 shows the relationship between temperature, vapor pressure, and moisture content of a typical liquid absorbent of the *organic* type.

### DEHUMIDIFICATION EQUIPMENT USING LIQUID ABSORBENTS

One type of system utilizing liquid absorbents includes an external inter-changer having essential parts consisting of a liquid contactor, a solution

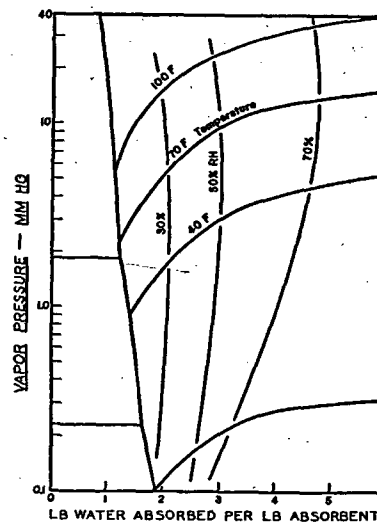


FIG. 3. TEMPERATURE—VAPOR PRESSURE—CONCENTRATION CHARACTERISTICS FOR A TYPICAL INORGANIC ABSORBENT (HALOGEN SALT GROUP)

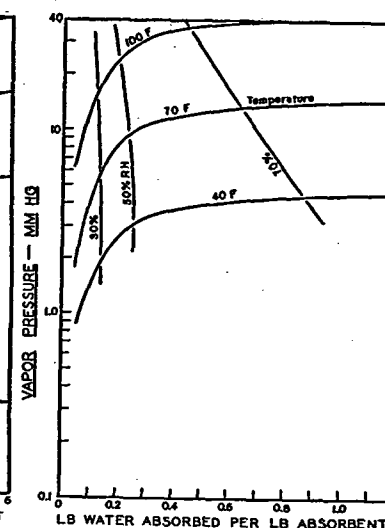


FIG. 4. TEMPERATURE—VAPOR PRESSURE—CONCENTRATION CHARACTERISTICS FOR A TYPICAL ORGANIC LIQUID ABSORBENT

concentrator, a solution heater and a cooling coil, all as shown in Fig. 5. The contactor and cooling coil are located in the wet air stream. The air to be conditioned is brought into contact with a liquid absorbent having a vapor pressure below that of the entering air, resulting in a transfer of moisture from the air to the brine solution. This results in a conversion of latent heat to sensible heat, which raises the solution temperature and consequently, the air temperature. The temperature change of the air being processed is determined by the cooling water temperature and the amount of moisture removed in the equipment. Control of leaving air temperature may be obtained by precooling the absorbent solution in a suitable surface cooler, by tap, well, or chilled water.

The excess water of condensation, which dilutes the liquid absorbent, is removed in the solution concentrator. This is a low pressure steam heat exchanger which over-concentrates a portion of the weak liquor, and returns it to the main reservoir for re-cycling. The concentrator operates in the manner of an evaporative condenser, whereby moisture is evaporated from the liquid absorbent by the heating coils into a stream of regeneration air taken from, and rejected to, the outside atmosphere. Low pressure

steam is normally used for heating the liquid absorbent. When it is desirable or necessary to use gas or electricity, an auxiliary low pressure steam boiler is usually added to the equipment. Concentrators operating on a simple boiler principle have not as yet been commercially practical.

It should be noted that the solution concentration phase is the reverse of the absorption process. During concentration, the aqueous vapor pressure of the solution is greater than that of the surrounding air, while during dehumidification, the reverse is the case. Utilization of this principle permits winter humidification by heating (instead of cooling) the solution pumped to the contactor. Water is thereby evaporated into, rather than condensed out of, the conditioned air stream. This requires dilution of the liquid absorber externally to the contactor.

### CALCULATION OF MOISTURE LOAD

Calculation of the dehumidification required to maintain lower than normal moisture content in a given room begins with determination of the

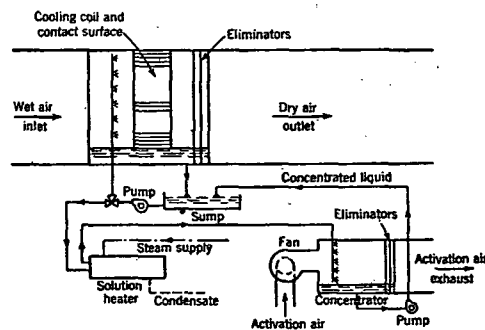


FIG. 5. LIQUID ABSORBENT EQUIPMENT IN WHICH SOLUTION COOLER AND CONCENTRATOR ARE COMBINED

rate of moisture gain in the room from all sources. It is common practice, when maintaining a low humidity ratio, to recirculate a large percentage of the air in the room through the dehumidifier, and to add only enough outside air to meet the needs of the problem. The humidity ratio of the mixture of outside and recirculated air and the dehumidifier performance data can be used to calculate the humidity ratio of the air leaving the dehumidifier. The difference between the humidity ratio of the air in the room and that of the dehumidified air entering the room represents the effective dehumidification per pound of air. The rate of internal moisture gain in grains per minute, divided by the effective dehumidification in grains per pound of air, equals the air quantity required in pounds per minute. The following typical example using arbitrary values shows a general method of determining the dehumidifying requirements. Sensible heat determination considerations are discussed in other chapters, and are purposely omitted here.

**Example 1:** A solid absorbent dehumidifier having performance characteristics as shown in Fig. 6 is to be used to maintain inside conditions of 73 F and 20 percent relative humidity, i.e., 24.1 grains per pound of dry air, 30 F dew-point, in a room 20 ft x 30 ft x 10 ft high, having a total wall, ceiling, and floor surface area of 2200 sq ft. Outside design conditions are 72 F dew-point (118.4 grains per pound).

### Dehumidification by Sorbent Materials

Internal sources of moisture are: 4 occupants; an open natural gas burner using 15 cu ft of natural gas per hour; an open top water tank, having an area of 2 sq ft exposed surface, in which water is maintained at 87 F, with air movement over the water surface being 100 fpm. Determine the quantity and condition of the dehumidified air to be supplied to the room.

**Solution:** The internal moisture gain consists of items 1 to 5.

- |                                               |                                                                                                                                  | Grains per Minute |
|-----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|-------------------|
| 1. From occupants:                            | $4 \times 1800/60 =$                                                                                                             | 120               |
|                                               | 1800 grains per person per hour is obtained from Fig. 7, Chapter 6, by interpolation between curves C and D.                     |                   |
| 2. From burned gas:                           | $15 \times 650/60 =$                                                                                                             | 162               |
|                                               | 1 cu ft natural gas produces approximately 650 grains of moisture.                                                               |                   |
| 3. From exposed water surface:                | $2 \times 20 =$                                                                                                                  | 40                |
|                                               | Evaporation from water surface is assumed to be 20 grains per (minute) (square foot) at 87 F water with air movement of 100 fpm. |                   |
| 4. From infiltration:                         | $\frac{6000}{60 \times 13.56} \times (118.4 - 24.1) =$                                                                           | 696               |
|                                               | One air change, 6000 cu ft, assumed per hour (see Chapter 11).                                                                   |                   |
| 5. Moisture transmitted through room surface: | $\frac{2200}{60} \times 3 \times (0.783 - 0.176) =$                                                                              | 67                |
|                                               | Permeability assumed to be 3 grains per (square foot) (hour) (inch Hg vapor pressure difference on two sides of wall).           |                   |

Total moisture gain from internal sources

1085

Let  $q$  be the air delivered to the room, pounds per minute. Let it be assumed for this problem that 85 percent of the air is recirculated and 15 percent is outside air. Enough air must be supplied to replace leakage from the system or to satisfy normal ventilating requirements for the occupants of the room as given in Chapter 6, whichever is greater. The amount is estimated from experience or obtained by test.

The humidity ratio of the mixture of recirculated and outside air entering the dehumidifier is then:

$$\frac{0.85q(24.1) + 0.15q(118.4)}{0.85q + 0.15q} = 38.3 \text{ grains per pound entering dehumidifier.}$$

For the dehumidifier whose performance is shown in Fig. 6, for 38.3 grains per pound in entering air, the leaving humidity ratio will be 6.5 grains per pound.

Effective dehumidification in the room is  $24.1 - 6.5$  or 17.6 grains per pound of supply air.

Then  $q = \frac{1085 \text{ grains per minute}}{17.6 \text{ grains per pound}} = 61.6 \text{ lb air per minute minimum}$  that must be supplied to the room to maintain 30 F dew point.

Note that this figure represents the minimum requirement for the arbitrary conditions set forth and that in practice, safety margins should be added to the outside air percentage figure and to the calculated internal moisture gain.

### VAPOR TRANSFER TO DEHUMIDIFIED SPACE

The walls enclosing a dehumidified space are subjected to a vapor pressure differential. The pressure of the vapor outside the walls tends to force moisture through the walls into the dehumidified zone of relatively low vapor pressure. As this process can be an unnecessary load on the



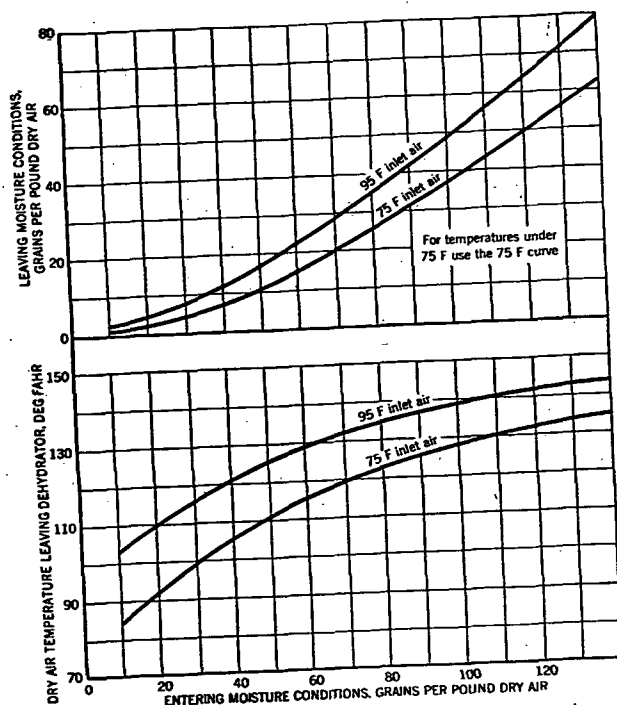


FIG. 6. PERFORMANCE DATA FOR TYPICAL COMMERCIAL SOLID ADSORBENT DEHUMIDIFIER

dehumidifying equipment, provisions should be made for keeping the vapor transfer to a minimum. Also, if the space is cooled below the ambient dew point, there is a possibility that condensation may occur within the walls, unless vapor transfer is controlled. For these reasons a vapor barrier should be located within the wall construction as near to the high vapor pressure side as feasible. To be effective, a barrier must be continuous and should be so located within the structure that it will be protected from rupture. (See Chapter 10, Moisture In Building Construction).

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## AUTOMATIC CONTROL

**Fundamentals:** Type of Control Systems and Action, System Components, Controlled Devices, Auxiliary Control Equipment; **Control Applications:** Automatic Fuel Burning, Residential Heating and Air Conditioning, Zoning, Individual Room Control, Central-Fan Systems, Outdoor Air, Reheater Coil, Humidity, Cooling and Dehumidification, Static Pressure, Space Condition, Typical System, Unit Heaters, Unit Ventilators; **Design Coordination:** Size of Controlled Area, Equipment Selection and Layout, Location of Space Controllers, Control of Steam or Water Flow.

PRESENT-day standards of comfort combined with the capacity and rapid response of modern heating and cooling equipment make automatic controls an essential part of heating, ventilating, and air conditioning systems. These automatic controls respond to variables such as temperature, relative humidity, and pressure. They operate individually or in sequence to maintain the desired conditions throughout the system and in the occupied space. A factor which has made the subject of automatic control somewhat confusing has been the matter of terminology. Many different expressions or words have sometimes been used to convey a single idea or concept. This chapter, therefore, attempts to use and define the terms which are most common and suitable so that they will be more precise and readily understood. The terms and definitions used are also selected so as to conform, as nearly as possible, to automatic control terminology used by engineers in other realms of engineering endeavor.

### PART I—FUNDAMENTALS OF AUTOMATIC CONTROL

A control system, Fig. 1, consists essentially of (1) a controller, (2) a controlled device, and (3) a source of energy.

A controller is a device which measures a variable condition such as temperature, humidity, pressure, and liquid level, and produces a suitable action or impulse for transmission to the controlled devices. Thermostats, humidistats, and pressure controllers are examples.

A controlled device reacts to the impulse received from a controller and varies the flow of the control agent. It may be a valve, damper, electric relay, or a motor driving a pump, fan, etc.

The control agent is the medium manipulated by the controlled device. It may be air or gas flowing through a damper, gas, steam, water, etc., flowing through a valve, or an electric current.

The controlled variable is the condition such as temperature, humidity, or pressure, being controlled.

Most control systems, of which Fig. 1 is typical, form a closed loop. That is, the controller measures and responds to changes in the controlled variable and actuates the controlled device to bring about an opposite change which is again measured by the controller. This system of transmitting information about the results of an action or operation back to its origin is known as feedback, and makes true automatic control possible.

An open-loop system is sometimes employed in control circuits, but it does not provide complete control. An outdoor thermostat arranged to control the flow of heat to a building in proportion to the load caused by



changes in outdoor temperature is an example. This system depends for its operation on a prearranged relationship between outdoor temperature and heat input to the building, and room temperature has no effect on the controller.

As there is no feedback, the control corrects only for those disturbances of room temperature caused by changes in outdoor temperature.

### TYPES OF CONTROL SYSTEMS

Control systems are divided into five main groups according to the primary source of energy:

1. A *self-contained system* combines the controller and controlled device in one unit and employs the power of the measuring system to effect the necessary corrective action. The measuring system derives its energy from the process under control without amplification by any auxiliary source of energy, and may be of the sealed-bellows or remote-bulb type as described under Types of Measuring Elements

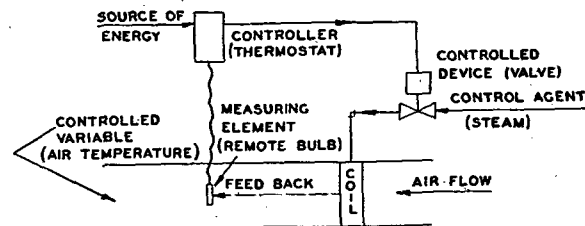


FIG. 1. ESSENTIALS OF A CONTROL SYSTEM

Temperature changes at the bellows or the remote bulb result in pressure or volume changes of the enclosed media which are transmitted directly to the operating device of the valve or damper.

2. A *pneumatic system* utilizes compressed air, usually at a pressure of 15 to 25 psig, as a source of energy. This is supplied to the controller which in turn regulates the pressure supplied to the controlled device.

3. A *hydraulic system* utilizes a suitable liquid under pressure as the source of energy. The pressure often is considerably higher than in a pneumatic system, but in other respects the systems are similar. Hydraulic systems find their chief use in applications where large forces are required for operation of the controlled devices.

4. An *electric system* utilizes electric energy, either low or line voltage as the energy source. The electric energy supplied to the controlled device is regulated by the controller either directly or through relays.

5. An *electronic system* also utilizes electric energy, but employs an electronic amplifier to increase the minute voltage variations of the measuring element to values required for operation of standard electrically-controlled devices. Measuring elements usually are of the resistance type, but thermocouples also are employed. Combination electronic-pneumatic systems utilize compressed air for operation of the controlled device by converting the output of the electronic amplifier into suitable air pressure changes by means of an electronic-pneumatic transducer.

### TYPES OF CONTROL ACTION

Control action may be divided into five types:

1. *Two-position action*, Fig. 2, is the type in which the controlled device can be positioned only to a maximum or minimum position, or can be either *on* or *off*. A thermostat which opens and closes a valve, or starts and stops a burner, is an example.

2. *Timed two-position action* is a common variation of two-position control action in which the time of *on* periods are prematurely shortened. This type of action usually is employed only in room thermostats, and is accomplished by a heater element

in the thermostat which is energized during the *on* periods. The percentage of time *on* is varied in proportion to the system load.

*Controller differential* applying to two-position control action, is the difference between the setting at which the controller operates to one position and the setting at which it operates to the other position. As an example, if a pressure controller starts a pump at 12 psi and stops it at 15 psi, the differential is 3 psi. It is sometimes

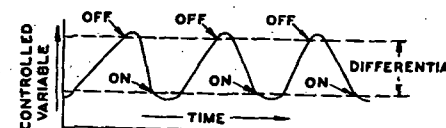


FIG. 2. TWO-POSITION CONTROL

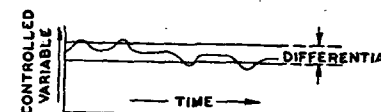


FIG. 3. FLOATING CONTROL SHOWING VARIATIONS IN CONTROLLED VARIABLE AS LOAD CHANGES

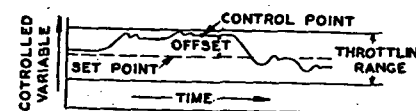


FIG. 4. PROPORTIONAL CONTROL SHOWING VARIATIONS IN CONTROLLED VARIABLE AS LOAD CHANGES

desirable to have a controller in which the differential can be changed by manual adjustment. This is designated as an adjustable differential.

3. *Floating action*, Fig. 3, is the type, as with two-position action, where the controller can perform only two operations: moving the controlled device usually at a constant rate either towards its open or its closed position. Generally there is a neutral zone between the two positions which allows the controlled device to stop at any position whenever the controlled variable is within the differential of the controller. When the controlled variable gets outside the differential of the controller, the controller moves the controlled device in the proper direction. An example of floating control is a fire box draft controller positioning a damper in the breeching of a boiler.

4. *Proportional action*, Fig. 4, is the type where the controlled device is positioned proportionately in response to slight changes in the controlled variable. It does not run through its complete stroke, as is the case with two-position control, nor does it continue to move until the change in the controlled variable resulting from that movement is felt by the controller, as is the case with floating control, but it immediately assumes a position in proportion to the system requirement.

An example of proportional control is a thermostat in a fan discharge duct actuating an automatic valve in the steam supply to a coil to regulate the air temperature leaving the coil. This control would be similar to that shown in Fig. 1.

*Throttling range* is the total amount of change in the controlled variable required

to move the controlled device through its complete stroke, from one extreme to the other. It is often adjustable to meet job requirements.

*Set Point* is the value at which the controller is set and represents the desired value of the controlled variable.

*Control Point* is the actual value of the controlled variable at which the instrument is controlling. It will vary within the throttling range of the controller according to the demand on the system and other variables.

*Offset* is the difference between the set point and the actual control point under stable conditions. This is sometimes also called *drift*, *deviation*, or *droop*.

5. *Proportional plus Automatic Reset Action*, Fig. 5 combines floating action with proportional action to achieve both the stability of proportional control, with a relatively wide throttling range, and the invariable control point of floating control. The system functions the same as proportional action, the automatic reset serving to shift the control point back to the set point whenever any offset occurs.

*Reset rate* is the number of times per minute the proportional action is duplicated by the reset action, and usually is expressed as *repeats per minute*. The reset rate in most controllers is adjustable and must be carefully matched to the system characteristics to avoid unstable operation. Because automatic reset is necessarily slow-acting, it should be used only when load changes are of reasonably long duration and when the maximum offset resulting from proportional control alone is outside of acceptable limits.

Figs. 4 and 5 show the results of rather abrupt demand changes, which usually result in two or three cycles before stability is restored. More gradual demand changes will result in a smoother curve.

### AUTOMATIC CONTROL SYSTEM COMPONENTS

In addition to controllers and controlled devices, many control systems include auxiliary apparatus such as switches and relays of various kinds, clocks or timers, thermometers, gauges, pilot lights, and other indicators for observing the operation of the system. Only those more commonly used will be described here.

#### Controllers

Automatic controllers have both a measuring element and a controlling element.

The *measuring element* measures changes in the controlled variable and produces a proportional effect on the controlling element. This effect usually is a change in position, force or electrical resistance.

The *controlling element* converts the effect produced by the measuring element into an effect suitable for operation of the controlled device. (In self-contained controllers the measuring element produces a force which is directly applied to the controlled device. In pneumatic or electric controllers the controlling element regulates the application of energy such as compressed air or electricity.)

#### Types of Measuring Elements

*Temperature measuring elements* usually consist of (1) a bimetal strip, (2) a rod and tube of dissimilar metals, (3) a sealed bellows, with or without a remote bulb or (4) an electrical resistance.

1. A *bimetal element* is composed of two thin strips of dissimilar metals fused together. Because the two metals have different coefficients of thermal expansion, the element bends as the temperature varies and produces a change in position. Depending on the space available and the movement required, it may be in the form of a straight strip, U-shaped, or wound into a spiral. This element finds its most common application in room thermostats, but is also used in insertion and immersion thermostats.

2. A *rod-and-tube element* consists of a high-expansion metal tube inside of which is a low-expansion rod with one end attached to the rear of the tube. The tube changes length with changes in temperature, causing the free end of the rod to move. The

rod-and-tube element is commonly employed on certain types of insertion and immersion thermostats.

3. A *sealed bellows-element* is either vapor filled, gas filled, or liquid filled, after being evacuated of air. Changes of temperature cause changes in pressure or volume of the gas or liquid, resulting in a change in force or a movement. This element is often employed in room thermostats.

A *remote-bulb element* is a sealed bellows or diaphragm to which a bulb or capsule is attached by means of a capillary tube, the entire system being filled with vapor, gas or liquid. Changes of temperature at the bulb result in changes of pressure or volume which are communicated to the bellows or diaphragm through the capillary tube. The remote-bulb element is useful where the temperature measuring point is remote from the desired thermostat location. It usually is provided with fittings suitable for insertion into a duct or into a pipe or tank.

4. A *resistance element* is made of wire whose electrical resistance changes with temperature changes. It is used with electronic controllers. It is available in forms suitable for measuring room temperature or for insertion into a duct or into a pipe or tank.

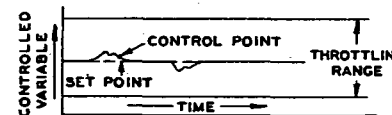


FIG. 5. PROPORTIONAL PLUS AUTOMATIC RESET CONTROL SHOWING HOW CONTROL POINT IS RETURNED TO SET POINT AFTER A LOAD CHANGE

*Humidity measuring elements* are made of (1) hygroscopic organic materials or (2) an electrical resistance.

1. An *organic element* usually is made of human hair, wood, paper, or animal membrane. Changes in relative humidity cause the element to expand and contract.

2. A *resistance element*, for use with electronic controllers, frequently consists of a thin coating of hygroscopic salt on an insulating form. The resistance of the salt varies with the relative humidity.

*Pressure measuring elements* can be divided into one of two general classes depending upon pressure range.

1. For pressures or vacuums measured in pounds per square inch or inches of mercury, the element usually is a bellows, diaphragm, or Bourdon tube. One side of the element may be open to atmosphere in which case the element responds to pressures above or below atmospheric. A differential pressure element has connections to both sides so that it will respond to the difference between two pressures.

2. For low ranges of pressure or vacuum which are usually measured in inches of water, such as the static pressure in an air duct, the measuring element may be an inverted bell immersed in oil, a large slack diaphragm, or a large flexible metal bellows. The element usually is of the differential type, and when employed in conjunction with orifices, pitot tubes, and similar accessories, may be used to measure flow, velocity or liquid level as well as static pressure.

Measuring elements for other purposes, such as flame detection or for measuring smoke density, specific gravity, CO<sub>2</sub>, CO, etc., often are necessary for the complete control of a heating, ventilating or air conditioning system.

#### Types of Controlling Elements

Controlling elements differ because some regulate the application of pneumatic energy while others regulate the application of electrical energy. They also differ according to the type of control action produced.

An *electric controlling element* is used in several of the common types of control action.

For *two-position control* it may simply make and break an electrical contact, to start a burner, motor, etc., or to actuate a spring-return valve or damper operator. Another type makes one contact while breaking another and is used to control unidirectional valve or damper operators. Either type may be used for timed two-position action by the addition of a small resistance heater.

For *floating control* two contacts are employed, but there is a neutral zone between the two contacts where neither is made. This type is commonly used with reversible valve or damper operators.

For *proportional control* a contact is moved across a potentiometer to vary the voltage applied to a relay. The relay controls the operation of a reversible valve or damper operator and is re-balanced as the controlled device is positioned. In another arrangement the controlling element has two contacts and a neutral zone as described for floating control and is re-balanced by a small solenoid which is energized by a variable voltage feedback from the reversible valve or damper operator which it positions.

An *electronic controlling element* consists of an electronic amplifier and an electric relay or relays. The amplifier receives the minute electrical signals from the measuring element and amplifies them sufficiently to actuate the relays. The electronic controlling element may be two-position, floating, or proportional, depending upon the amplifier and relay arrangement.

A *pneumatic controlling element* is most often of the proportional-action type but may also be used for the other types of control action. It may be classified as non-relay type and relay type.

A *non-relay type* of pneumatic controlling element is the simplest form and employs a restricted air supply and a nozzle or control port. The measuring element varies the opening of the nozzle and the resulting variable pressure is applied to the controlled device. This type is limited to applications requiring small volumes of air.

In a *relay-type* pneumatic controlling element the relay contains both a supply and an exhaust valve usually arranged so that the exhaust valve must close before the supply valve opens. Both valves are closed except when the control pressure is required to change. The variable force for operating the valves may be supplied directly by the measuring element or it may be supplied by a diaphragm actuated by air pressure from a very small nozzle and restrictor arrangement, this air pressure being varied by the measuring element. In either case the control pressure, operating on a diaphragm within the relay, produces a force which balances the force produced by the measuring element.

Pneumatic controllers may be either direct or reverse acting.

A *direct-acting controller* increases the control air pressure as the controlled variable increases. For example a direct-acting thermostat increases the air pressure as the temperature increases.

A *reverse-acting controller* decreases the control air pressure as the controlled variable increases. A reverse-acting thermostat decreases the air pressure as the temperature increases.

### Indicating and Recording Features

Controllers may be of the indicating or recording type.

The *non-indicating controller* is most common in heating, ventilating, and air conditioning work, and includes all those in which the measuring element does not provide a visual indication of the value of the controlled variable. If an indication is desired, a separate thermometer, relative humidity indicator, pressure gauge, etc., is required. With room thermostats, for example, a separate thermometer often is attached to the cover.

An *indicating controller* has a pointer added to the measuring element or attached to it by a linkage so that the value of the controlled variable is indicated on a suitable scale.

A *recording controller* is similar to an indicating controller except that the indicating pointer is replaced by a recording pen which provides a permanent record on a chart driven by a clockmotor.

*Proportional band* is a term used in connection with indicating and recording con-

trollers and has the same meaning as throttling range. It is usually expressed in per cent of the scale or chart range of the controller.

### Types of Controllers

Controllers are mainly (1) thermostats, (2) humidistats, and (3) pressure types.

1. Many thermostats are of the simple, single-purpose type, but there are many others for various special purposes. Various types are indicated in paragraphs (a) to (k) which follow.

a. The *room type* is designed for mounting on a wall and responds to room temperature.

b. The *insertion type* is designed for mounting on a duct with its measuring element extending into the duct.

c. The *immersion type* is designed for mounting on a pipe or tank. It has a fluid-tight connection to allow the measuring element to extend into the fluid. A separable socket or well is often used with immersion thermostats to avoid the need for draining the system when removal of the thermostat is required. Since the separable socket will reduce the response rate of the thermostat, the socket should be no heavier than necessary and should fit snugly around the element.

d. The *remote bulb type* is designed for applications where the point of temperature measurement is at some distance from the desired thermostat location. It is often used for centralized panel mounting of the controller. The remote bulb element may be of either the insertion or immersion type.

e. The *surface type* is designed for mounting on and measuring the temperature of a pipe or similar surface.

f. The *day-night, or dual room thermostat* controls at a reduced temperature at night. It may be indexed (changed from day to night operation) individually or in groups from a remote point by a manual or time switch. Some electric types have an individual clock and switch built into the thermostat.

g. The *pneumatic day-night thermostat* uses a two-pressure air supply system, the two pressures often being 13 and 17 psi or 15 and 20 psi. Changing the pressure at a central point from one value to the other actuates switching devices in the thermostat and indexes them from day to night or vice versa. Supply-air mains often are divided into two or more circuits so that switching can be accomplished in various areas of the building at different times, in accordance with use. For example a school building may have the separate circuits: for classrooms, offices and administrative areas, auditorium, and gymnasium and locker rooms.

h. The *heating-cooling or summer-winter thermostat* can have its action reversed and, if desired, have its set point changed by the indexing means. It is used to actuate controlled devices, such as valves or dampers, that regulate a heating source at one time and a cooling source at another time. It is often indexed in groups manually by a switch or automatically by a thermostat measuring the temperature of the control agent, the outdoor temperature, or other suitable variable.

i. The *pneumatic heating-cooling thermostat* uses a two-pressure air supply system as described for day-night thermostats.

j. A *two-stage thermostat* is arranged to operate in two successive steps.

k. A *submaster thermostat* has its set point raised or lowered over a predetermined range in accordance with variations in output from a master controller. The master controller can be a thermostat, manual switch, pressure controller or similar device. For example, a master thermostat measuring outdoor air temperature can be used to readjust a submaster thermostat controlling the water temperature in a heating system. Master-submaster combinations are sometimes designated as *single cascade action*. When such action is accomplished by a single thermostat having more than one measuring element, it is known as *compensated control*.

2. *Humidistats* are of either the room or insertion type. Submaster humidistats of either type are sometimes used in conjunction with an outdoor master thermostat to reduce the humidity in cold weather and prevent condensation on windows.

A *wet-bulb thermostat* is often used for humidity control in conjunction with proper control of the dry-bulb temperature. A wick or other means for keeping the bulb wet is required, and rapid air motion to assure a true wet-bulb measurement is essential.

3. A *pressure or static-pressure controller* is made for mounting directly on a pipe

or remotely on a panel or wall. A small pipe or tube may be used for transmitting the pressure signals to the instrument.

### Controlled Devices

Controlled devices consist of (1) automatic valves (2) valve operators, (3) automatic dampers, and (4) damper operators. Other controlled devices include electric heaters, and motors on such equipment as fans, pumps, burners, refrigeration compressors and similar apparatus.

1. An *automatic valve* is designed to control the flow of steam, water, gas, and other fluids and may be considered as a variable orifice which is positioned by an electric or pneumatic operator in response to impulses from the controller. It may be equipped with a throttling plug or v-port of special design to provide the desired flow characteristics.

Renewable composition discs are common. They are made of materials best suited to the media handled by the valve, and its temperature and pressure. For high pressures or for superheated steam, metal discs are often employed. Internal parts of valves such as the seat ring, throttling plug or v-port skirt, disc holder, and stem sometimes are made of stainless steel or other hard and corrosion resistant metals for use in severe service. Automatic valves should be properly selected and sized for the specific applications. See the section on Design Coordination in this chapter for further details.

The functions of various types of automatic valves are as follows:

a. A *single-seated valve* is designed for tight shut-off. Appropriate disc materials for various pressure ranges and media are used.

b. A *pilot piston valve* utilizes the pressure of the control agent as an aid in operating the valve. It usually is single-seated and is used where large forces are required for valve operation.

c. A *double-seated or balanced valve* is designed so that the media pressure acting against the valve disc is essentially balanced thereby reducing the force required of the operator. It is widely used where the fluid pressure is too high to permit a single-seated valve to close. It cannot be used where tight shut-off is required.

d. A *three-way mixing valve* has two inlet connections and one outlet connection and a double-faced disc operating between two seats. It is used to mix, as required, two fluids entering the inlet connections and leaving through the common outlet.

e. A *three-way diverting valve* has one inlet connection and two outlet connections and two separate discs and seats. It is used to divert the flow to either of the outlets or to proportion the flow to both outlets.

f. A *butterfly valve* consists of a heavy ring enclosing a disc which rotates on an axis at or near its center, and in principle is similar to a round single-blade damper. The disc usually seats against a ring machined within the body.

2. Valve operators are of three general types:

a. A *solenoid* consists of a magnetic coil operating a movable plunger. It is used for two-position operation. The most common use of a solenoid-operated valve is to control the flow of gas, water, air and refrigerants and generally it is limited to relatively small sizes.

b. An *electric motor* operates the valve stem through a gear train and linkage. Electric motor operators are classified in three distinct types. *Unidirectional*, for two-position operation. The valve opens during one-half revolution of the output shaft and closes during the other one-half revolution. Once started, it continues until the half revolution is completed, regardless of subsequent action by the controller. Limit switches built into the operator stop the motor at the end of each stroke. If the controller has been satisfied during this interval the operator will continue to the other position. *Spring-return*, for two-position operation. Electric energy drives the valve to one position and holds it. When the circuit is broken, the spring returns the valve to its normal position. *Reversible*, for floating and proportional operation. The motor can run in either direction and can stop in any position. It is sometimes equipped with a return spring. For proportional control applications, a potentiometer for rebalancing the control circuit is also driven by the motor.

c. A *pneumatic operator* consists of a spring-opposed flexible diaphragm or bellows attached to the valve stem in such a way that an increase in air pressure moves the valve stem and at the same time compresses the spring. Springs of various ranges in terms of air pressure can be employed to provide sequence operation of two or more

devices by proper selection or adjustment of the springs. Springless pneumatic operators, using two opposed diaphragms or two sides of a single diaphragm, also are used but generally are limited to special applications involving large valves or high pressures. Pneumatic operators are designed primarily for proportional control. Two-position control is accomplished by use of a two-position controller, or a two-position pneumatic relay to apply either full air pressure or no pressure to the valve operator.

Pneumatic valves and valves with spring-return electric operators can be classified as normally open or normally closed.

A *normally-open* valve will assume an open position when all operating force is removed.

A *normally-closed* valve will assume a closed position when all operating force is removed.

3. *Automatic dampers* are designed to control the flow of air or gases and function like valves in this respect. Steel blades and frames are most common, but other materials are used for special applications such as those involving corrosive fumes. Large dampers often are made in two or more sections for strength and convenience in handling, the sections being inter-connected so as to operate as a unit. The damper types commonly used are:

a. *Single-blade*, which is generally restricted to small sizes because of the difficulty of securing proper operation with high velocity air.

b. *Multi-blade or lower damper* which has two or more blades linked together. It may be arranged for (a) *parallel operation*, in which all blades rotate in the same direction or (b) *opposed operation*, in which adjacent blades rotate in opposite directions and provide more linear air flow characteristics than obtained with parallel operation.

c. *Mixing dampers*, composed of two sections interlinked so that one section opens as the other closes.

4. *Damper operators* of the electric type may be unidirectional, spring-return, or reversible similarly to electric-motor valve operators. Pneumatic damper operators are similar to pneumatic valve operators except that they usually have a longer stroke or the stroke is increased by means of a multiplying lever. Damper operators are mounted on the damper frame and are connected with linkage directly to a damper blade or are mounted outside the duct and connected to a crank arm attached to a shaft extension of one of the blades. On large dampers two or more operators may be required, and usually are applied at separate points on the damper. Normally-open or normally-closed operation is obtained according to the method of mounting the operator and connecting the linkage.

### Auxiliary Control Equipment

In addition to the conventional controllers and controlled devices described, many control systems require auxiliary devices to perform various functions. Auxiliary controls for electric systems include:

1. *Transformers* to provide current at the required voltage.

2. *Electric relays* for control of electric heaters or to start and stop oil burners, refrigeration compressors, fans, pumps, or other apparatus for which the electrical load is too large to be handled directly by the controller. Other uses include time delay, circuit interlocking safety applications, and similar functions.

3. *Potentiometers* for manual positioning of proportional controlled devices or for remote set point adjustment of electronic controllers.

4. *Manual switches* for manually performing a variety of operations. These may be of two-position or multiple-position type or may be of single or multiple-pole type.

5. *Auxiliary switches* on valve and damper operators for providing a selected sequence of operations.

Auxiliary control equipment for pneumatic systems include:

1. *Air compressors and accessories*, to provide a source of air at the required pressure.

2. *Electro-pneumatic relays*, which are electrically-actuated air valves for operating pneumatic equipment when an electrical circuit is energized or de-energized.

3. *Pneumatic-electric relays*, which are actuated by air pressure and make or break an electrical circuit.

4. *Pneumatic relays*, which are actuated by the pressure from a controller and perform numerous functions. They may be divided into two groups:

a. *Two-position relays*, which permit a controller actuating a proportional device to also actuate one or more two-position devices. They also are used in various automatic switching operations.

b. *Proportional relays*, which are used to reverse the action of a proportional controller, select the higher or lower of two pressures, average two or more pressures, respond to the difference between two pressures, add or subtract pressures, amplify or retard pressure changes, and perform other similar functions.

5. *Positioning relays*, which are devices for assuring accurate positioning of a valve or damper operator in response to changes in pressure from a controller. They are affected by the position of the operator and the pressure from the controller, and whenever the two are out of balance will change the pressure applied to the operator until balance is restored.

6. *Switching relays*, which are pneumatically operated air valves for diverting air from one circuit to another or for opening and closing air circuits.

7. *Pneumatic switches*, which are manually operated devices for diverting air from one circuit to another or for opening and closing air circuits. They may be of two-position or multiple-position type.

8. *Gradual switches*, which are proportional devices for manually varying the air pressure in a circuit.

Auxiliary control devices common to both electric and pneumatic systems include:

1. *Sequence controllers* for operating a number of electric switches in sequence by means of a proportional electric or pneumatic operator. They are commonly used for controlling a number of steps of refrigeration capacity and may be arranged to prevent simultaneous starting of compressors and to alternate the sequence to equalize wear. They may also be used for sequence operation of electric heaters and other equipment in response to the demands of a proportional controller.

2. *Clocks or timers* for turning apparatus on and off at predetermined times, for switching control systems from day to night operation, and for other time sequence functions.

## PART II—CONTROL APPLICATIONS

Applications of controls to systems or apparatus of a general nature will be found in this chapter. Applications pertaining to specific systems or apparatus will be found in the chapters covering those subjects.

### CONTROLS FOR AUTOMATIC FUEL BURNING EQUIPMENT

Controls for the automatic fuel burning equipment described in Chapter 15 are outlined here. The basic requirements for oil burners, gas burners and coal burners (stokers) are included and the term *burner* refers to all three types of fuel burning equipment. Controls for these burners can be classified as *operating controls*, *limit controls* and *primary controls*. The schematic diagrams shown in Fig. 6 indicate the relationships of the basic components. The *power supply* may be line voltage for each type of burner. In control systems for domestic burners the line voltage may be stepped down by means of a transformer for those portions of the circuits indicated by dotted lines. Such transformers are usually built into the stoker and oil burner *primary controls*. Control systems for domestic gas burners frequently use a separate transformer as shown. There are domestic gas burner control systems which obtain their electrical power supply from the conversion of heat to low voltage electrical energy, in which case no transformer would be required. As the burner sizes increase, the tendency to use all line voltage controls increases in each of these general categories.

### Operating Controls

*Operating controls* initiate the starting and stopping of the burner and on larger burners they usually vary the fuel and air input to the combustion chamber in response to varying load demands. For residential and small commercial heating plants with fuel inputs up to approximately 500,000 Btu per hour, the *operating controller* is usually some form of room thermostat which automatically starts and stops the burner through the *primary control* as the *limit controls* permit. As the size of the heating system increases, the use of a room thermostat as the *operating controller* for the burner becomes less common. An insertion thermostat (for furnaces), immersion thermostat (for hot water boilers) or pressure controller (for steam boilers) may be applied as an *operating controller*. Also, such

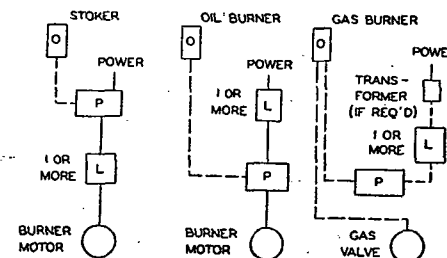


FIG. 6. SCHEMATIC DIAGRAMS OF SOME TYPICAL BURNER CONTROL SYSTEMS (O = Operating Control; P = Primary Control; L = Limit Control)

devices as submaster and compensated controllers (which are reset from outdoor temperature for governing the bonnet temperature in large furnaces or the water temperature in a boiler) come into more frequent use on the larger installations. The still larger burners are usually equipped to vary the rate of fuel and air input in response to varying load demands.

### Limit Controls

Limit controls guard against unsafe temperature, pressure or water level to assure that safe conditions prevail for the operation of the burner. Draft controls protect the firebox against excessive drafts, regardless of the type of fuel being burned, to increase combustion efficiencies and reduce stack losses. For fuel input requirements above approximately 1,000,000 Btu per hour some additional factors become common to all types of burners. For example, the draft in the firebox is controlled at a suitable constant for all firing rates, including the *off* period, by measuring the draft conditions in the firebox and actuating a *damper operator* to position the damper at the boiler outlet. Where necessary, provision may be made to open the boiler outlet damper wide before permitting the burner to start and then return this damper to automatic control after the burner has been started. Also, the firing rate of these larger burners is frequently automatically adjustable and provisions are made for always starting the burner on its low firing rate, with facilities for increasing the firing rate slowly after the burner has been started. It is not recommended and codes seldom permit the use of one and the same instrument as both an *operating controller* and a *high limit control*. In such cases an *operating controller* will be adjusted to control at the desired set point while the *high limit*

control will be adjusted to stop the burner at some higher point in the event that the *operating controller* fails to stop the burner before the higher shut-off point is reached. For example, to maintain a constant water temperature in a hot water boiler, the operating controller may be set to stop the burner when the boiler water temperature reaches 180 F. The *high limit control* should then be set to stop the burner at a higher temperature, say 200 F.

Various interlocks or limit controls are usually included to assure safe operation of these larger burners. A latch switch interlock prevents burner operation if the burner is not in its proper firing position. Another interlock must prove that the burner is in its low-fire position before the burner can be started. Safe draft conditions should be proved before the burner can be started or allowed to run, especially where induced draft fans are involved. A smoke detecting device may sound an alarm and stop the burner if excessive smoke is produced. Also, protection against electrical overloads must be provided.

### Primary Controls

*Primary controls* provide for the safe start and operating procedure of the burner. They are somewhat different for each of the three types of fuel burners.

1. *Stokers.* Stokers are equipped with refueling, or *hold-fire*, controls. These *primary controls* cause the stoker to intermittently feed a predetermined amount of coal during the long off periods of the *operating controller* to maintain ignition and to reduce the possibility of having idle fuel beds damage stoker castings. In some cases the *primary control* system includes an *out-fire* feature which stops the feeding of coal into the firebox if the fire goes out.

2. *Oil Burners.* *Primary controls* required for oil burners depend on the size and type of burner. Some of the more common *primary controls* are discussed in following paragraphs a to d.

a. Domestic oil burners of the vaporizing type usually require a *primary control* which will (1) meter the correct amount of oil into the burner to maintain the pilot flame; (2) regulate the required amount of oil into the burner for its high flame operation; and (3) completely shut off the flow of oil in the event of a flame failure.

b. Domestic oil burners of the pressure atomizing type require a *primary control* which will (1) energize the burner motor and electric ignition; (2) test for the establishment of main burner flame and stop the burner and ignition if flame has not been established; (3) cut off the ignition after a safe burner flame has been established (does not apply to constant ignition type burners); (4) monitor the flame continuously during burner operation and stop the burner in the event of flame failure (manual reset is necessary following a flame failure lock-out); and (5) stop the burner when either the *operating controller* or *limit control* requires it.

c. Commercial and industrial oil burners of the pressure atomizing type have *primary controls* that are essentially the same as those outlined for domestic oil burners of the pressure atomizing type. In addition, some models are equipped with a solenoid oil-shut-off valve to provide a pre-purge period, if desired, and a quick shut-off of the oil flow when the burner is stopped.

d. Commercial and industrial oil burners of the horizontal rotary cup type are usually equipped with a more elaborate *primary control* system. The *primary control* is often described as a programming combustion safety control. Its most important operations include (1) starting the burner upon a call for heat; (2) providing a pre-purge period before activating the gas-electric ignition; (3) proving the presence of proper ignition before permitting the flow of oil to the main burner; (4) proving the presence of a stable main burner flame within a predetermined period of time; (5) shutting off the gas-electric ignition after a predetermined length of time has elapsed; (6) monitoring the main burner flame during its entire on period and stopping the burner quickly in the event of a flame failure (it is usually required that the flow of oil through the burner be stopped within four seconds following a flame failure); (7) stopping the flow of oil through the burner when either the *operating controller* or a *limit control* requires it; (8) operating the burner for a predetermined length of time

after the main fuel valve has been closed; and (9) locking out on a flame failure shut-down (the programming control then must be manually reset prior to a restart).

When steam, air or mechanical atomizing burners are automatically controlled, their sequence of control is similar to that described for horizontal rotary cup burners.

3. *Gas Burners.* Some of the more common *primary controls* for gas burners are as follows.

a. Domestic gas burners of the atmospheric type require a *primary control*, to insure safe starting and operating conditions, which will (1) prevent opening of the gas valve unless the pilot is operating properly, and (2) stop the flow of gas through the burner if safe ignition conditions do not prevail at all times.

b. Commercial and industrial gas burners of the atmospheric type require a *primary control* whose function is similar to that for domestic sizes of these burners except in the rate of response to a pilot flame failure. The pilot flame burns constantly and, in general, the *primary control* system will (1) assure operation only when ignition of the main burner will be safe; (2) start and stop the main burner when required to do so by either the *operating controller* or a *limit control*; and (3) close the safety shut-off valve in the gas supply line to the burner upon a flame failure or an electrical power failure.

c. Commercial and industrial gas burners of the power type equipped with electric ignition require a *primary control* whose most important operations include: (1) starting the burner motor upon a call for heat by the *operating controller*; (2) providing a pre-purge period before activating the gas-electric ignition; (3) proving the presence of proper ignition before allowing gas to flow to the main burner or shutting off the electric ignitor; (4) closing the safety shut-off valve in the event of a flame failure (it is usually required that the flow of gas be stopped within four seconds following a flame failure); (5) stopping the burner when either an *operating controller* or a *limit control* requires it; and (6) locking out on a flame failure shut-down (the programming control then must be manually reset prior to a re-start).

### RESIDENTIAL HEATING AND AIR CONDITIONING

The control equipment function in the residence may vary from the regulation of a coal fired heating plant to the completely automatic control of a year-around heating and cooling system. Regardless of the type of heating or air conditioning system used, the control system should be selected carefully to insure safety and comfort of the occupants as well as economy of operation.

The simplest type of domestic control is one in which the room thermostat starts and stops the burner, as described in the preceding section. It may be used on gravity or forced warm air, hot water or steam systems. In forced warm air or forced hot water systems the fan or circulator usually is controlled by a thermostat in the furnace or boiler and runs whenever the air or water temperature is above a minimum value, as discussed in Chapter 20. If straight two-position control is used for this application, the *on* and *off* periods are relatively long and there is a tendency towards cold drafts on the floor during off periods. If timed two-position control is used, the burner may be cycled (started and stopped) often enough to provide results very comparable to proportioning control. The heat input to the home is proportioned continuously to the heat loss from the home. The fan of a forced warm air system or the circulator of a forced hot water system may be run almost continuously, thus minimizing the possibility of cold drafts.

Proportional control is used on residential applications when provisions are made for it in the design of the system. Face and bypass dampers on warm air systems, throttling valves on steam systems and three-way mixing valves on hot water systems are typical examples of controlled devices which permit proportional control. With these arrangements the burner usually is controlled by a thermostat in the furnace or boiler. Proportional control will permit nearly continuous circulation of warm air or hot water, thus reducing cold drafts.

Automatic night set-back through the use of a day-night type room



thermostat is a refinement frequently added to residential control systems. Though opinions vary regarding the amount of fuel that can be saved by automatic night set-back, tests made both in the warm air heating research residence and the I=B=R research home at the University of Illinois indicate that, on thermostatically controlled systems, a possible fuel saving of from 7 to 10 percent may be obtained by reducing the house temperature 6 to 10 F from about 10:00 p.m. to 5:30 a.m.

It is often desirable to divide the house into two or more zones for greater accuracy of control and comfort. Each zone may then be maintained individually at the desired temperature level. The division into zones should be based upon exposure or occupancy; the most common division is usually found to be (1) the living section such as living room, dining room, den; (2) the sleeping section; (3) the service section such as kitchen, pantry, servants' quarters; and (4) the recreational areas.

Further discussion of zone control will be found in the following section on Zone Control and Zone Control Systems.

Year-round residential air conditioning systems which provide for heating in winter and cooling in summer should be given the same consideration in selecting the control system as required for commercial air conditioning systems. See Chapter 30. The basic principles are the same and the final results must provide for the comfort of the occupants. A reduction in investment for automatic controls may result in wasteful operation of the system and discomfort for the occupants.

Special thermostats have been designed to take care of the year-round residential air conditioning systems. These thermostats offer manual, semi-automatic, and automatic changeover from heating to cooling as selected by the unit manufacturer. Generally speaking, the heating unit is controlled by timed two-position action and the cooling unit by straight two-position action. Some form of humidity control may be added.

When an *add-on* unit is installed to obtain a year-round air conditioning system by change of straight heating system, it may be controlled separately or integrated with the heating control system. However it is accomplished, the control system should be simple enough for the user to understand how to operate it effectively.

### ZONE CONTROL

Zone control for any heating, ventilating or air conditioning system is employed where it is desired to control the heating or cooling effect in a number of rooms or areas, having similar orientation or occupancy, through one set of controls. For zone control to be successful the requirements must be approximately consistent throughout the extent of the zone. Whether zoning a building for heating or cooling the following factors should be considered in determining the number and arrangement of the zones:

1. *Exposure.* Solar effect, prevailing winds, and the shelter afforded by surrounding structures affect the heat gain or loss.
2. *Occupancy.* Indoor temperature requirements for the various activities carried on in different portions of the building and the hours of occupancy of the various spaces impose definite control problems.
3. *Building Structure.* The physical characteristics of the building will influence the subdivisions of the system into zones since satisfactory temperature conditions throughout a single zone of given extent may not be enjoyed equally in buildings of dissimilar types of construction. Other factors are the height of the building and its horizontal extent and form.
4. *Floors.* Even though several floors have the same wall exposure, it is advisable

to have separate zones on the lowest and highest floors due to variations of basement or ground floor requirements and those with roof exposure. It is also desirable to have a separate zone or zones for the intermediate floors.

The initial investment will often influence the decision as to the final number of zones to be employed. In larger buildings accepted practice is to have at least one zone for each exposure. Each exposure may require subdivision vertically into two or more zones for the higher structures. Also, the presence of two or more wings having the same general exposure may suggest the desirability of more restrictive zoning. When the street floor or any other portion of the building is used for public occupancy or activities which differ from those carried on in the remainder of the building, it is desirable to provide separate thermostats and controls for each individual area.

Zone controls alone may not provide satisfactory temperature conditions in all rooms or areas within the zone because occupancy, lighting load, space arrangements and similar factors cannot always be predicted with accuracy. A combination of zone controls with individual room control in critical areas may be necessary to achieve complete satisfaction.

### ZONE CONTROL SYSTEMS

This section is concerned with zone controls for steam or hot water heating systems.

Most zone control systems are designed to supply heat to a zone at a rate equal to the heat loss. This rate of heat input may be established by room thermostats, by controllers responsive to outdoor conditions, or by a combination of both. The outdoor controller responds to temperature and may respond to solar radiation and wind velocity and direction. Features which may be added to the basic zone control system include:

1. Means for automatically or manually varying the heat input to the zone to compensate for variations in internal heat gain. The automatic arrangement requires a thermostat at a representative location within the zone. The manual arrangement usually consists of a switch located where convenient.
2. Means for maintaining a lowered economy temperature or shutting off the heat completely at night or at other times when the zone is unoccupied. This may be accomplished manually or by means of a clock.
3. An arrangement providing rapid warm-up following a period at the non-occupancy temperature. During this warm-up period full heat may be admitted to the system or the heat input may be controlled at a higher-than-normal rate. The warm-up may be accomplished by a manual switch or may be part of the clock program. A warm-up thermostat located within the zone may be arranged to terminate the warm-up period independently of the switch or clock when the zone approaches the desired occupancy temperature.
4. A manual switch to provide full heat or no heat independently of other controls and to permit manual selection of the various clock functions.
5. Means for shutting off the heat completely when the outdoor temperature reaches a point where heat no longer is needed.
6. A high limit thermostat in the zone to shut off the heat completely when the zone becomes overheated.

### Steam Heating Systems

In *continuous-flow steam systems* the quantity of steam supplied to the zone is varied in accordance with the demands of the control system. To obtain equalized distribution of the steam, metering orifices are generally required on the inlets to all radiators or convectors. Supplementary controls for low heat output are often desirable. The following two arrangements are common:

1. Varying the difference in pressure between the supply and return which results



in partially filling the heating units in accordance with demand. This method can be used on atmospheric or vacuum return systems.

2. Varying the pressure in the system while maintaining a constant differential pressure between the supply and return. This results in the heating units being filled with steam at a temperature which is proportional to demand. A vacuum pump maintaining a vacuum slightly below the supply pressure is required, and vacuums as high as 20 in. Hg during mild heating weather are common.

In *intermittent systems* steam at full pressure is supplied intermittently to the zone, the length of the *on* and *off* periods being varied in accordance with the demands of the control system. Two common arrangements are:

1. A timing device controlled by an outdoor thermostatic element which can be used to vary the on-off periods of boiler operation or the opening and closing of a steam valve as a function of outdoor temperature.
2. A control responding to an outdoor element and an element attached to a radiator or convector, so that it varies the length and frequency of the on-off intervals in such a way that the radiator or convector temperature is varied in accordance with outdoor temperature.

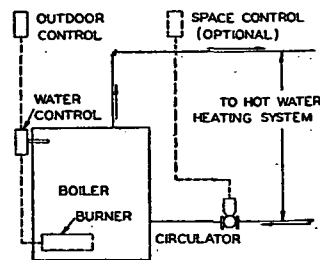


FIG. 7. CONTROL OF HOT WATER HEATING WITHOUT DOMESTIC HOT WATER SERVICE  
(Limit and primary controls not shown)

For proper operation of zone control equipment the heating system must be carefully designed and installed, and maintained in good operating condition. Vents, traps, vacuum pumps and valves must be given a careful inspection and repaired or replaced when required. Piping must be of adequate size graded and dripped. Return piping must be vented and any pockets or lifts removed.

### Hot Water Heating Systems

A common method of obtaining zone control of hot water systems consists of varying the temperature of water supplied to the zone inversely as the outdoor temperature varies. This may be accomplished by a submaster thermostat in the zone supply line readjusted by an outdoor master thermostat, or by a single controller having one measuring element in the supply line and another compensating element outdoors. On single zone installations the controller may actuate the burner directly as shown in Fig. 7. If the boiler is also used for domestic hot water the controls may be arranged as in Fig. 8. In this case the boiler is controlled at a fixed temperature and the zone controller is arranged to operate a valve to proportion hot water from the boiler with cooler return water to obtain the desired zone water temperature. On multiple zone installations the boiler usually is controlled at a fixed temperature, and each zone is controlled by a separate valve and outdoor compensated controller. Each zone should be equipped with a

separate pump because in many cases the return water from some zones is warmer than the required supply water for other zones. By using individual zone pumps the returns can be separated and thus prevent overheating that would otherwise occur.

To compensate for variations in internal load, the action of the zone control may be modified by a room thermostat in each zone which either starts and stops the zone pump, modifies the relationship between outdoor temperature and water temperature, or operates an automatic valve in the zone supply or return line. Each zone may be further subdivided by providing a separate thermostat and valve for each subdivision.

Another zone control method for hot water systems consists of maintaining a constant water temperature and varying the volume of water supplied to the zone by means of a room thermostat which either starts and stops the zone pump or operates a two-position valve in the zone supply or return line.

Whenever flow control valves are employed in water circuits it is necessary to employ a relief valve or pressure-regulating valve in a bypass connection around the pump.

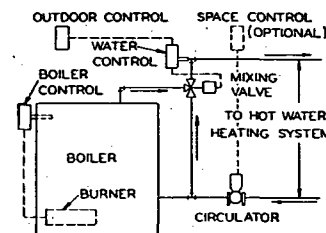


FIG. 8. CONTROL OF HOT WATER HEATING WITH PROVISIONS FOR DOMESTIC WATER HEATING  
(Limit and primary controls not shown)

### PANEL HEATING SYSTEMS

Automatic controls for panel heating differ somewhat from those described for convective heating because of the thermal inertia characteristics of the panel heating surface and the increase in the mean radiant temperature within the space under increasing loads for panel heating. However, many of the same control principles for hot water heating systems will also apply to panel heating.

Panels such as concrete slabs have large heat storage capacity and continue to emit heat long after the room thermostat has shut off the supply of heating medium. In addition, there is a considerable time lag between thermostat demand and heat delivery to the space due to the large part of the heat which must first be stored in the thermally heavy radiant surface. This inertia will cause uncomfortable cycling of space conditions unless controls for detecting load changes as early as possible are provided.

In general, the temperature of the heating medium supplied to the panel surface should be varied in accordance with outdoor temperature, as described in the first paragraph under Hot Water Heating Systems in the section on Zone Control Systems. Controls indicated in Figs. 7 and 8 apply and, in addition, consideration should be given to preventing the introduction of excessively hot water in the event of control failure which might

damage the panels, and to a manual boiler bypass or other means of reducing the water temperature to prevent too rapid drying out of new panels (see Chapter 24, Panel Heating). Due to the increase in MRT (mean radiant temperature) within a panel heated space which necessarily takes place as the heating load increases, the air temperature under such conditions, theoretically, should be lowered in the order of 1 or 2 degrees to maintain comfort. In ordinary structures with normal infiltration loads the required reduction in air temperature is small and, consequently, a conventional room thermostat may be used.

In panel heating systems, lowered night temperatures will produce unsatisfactory results with heavy panels such as concrete floors. These panels cannot respond to either quick increase or decrease in heating demand within the relatively short time required, with the result that there will be a very slow reduction of space temperature at night and a correspondingly slow pick-up in the morning. Panels of light weight construction, such as plaster or metal ceilings and walls, may respond to changes in demand with sufficient rapidity that moderately satisfactory results can be expected from lowered night temperatures. However, very little fuel saving can be expected even with the light panels unless the lowered temperature is maintained for long periods. If reduced non-occupancy temperatures are employed, some means of providing a higher-than-normal rate of heat input for rapid warm-up is necessary, or a long warm-up period should be provided for, as explained under Zone Control Systems.

### INDIVIDUAL ROOM CONTROL

The ideal temperature control system for any building is one that promotes maintenance of the desired temperature in every room at all times regardless of location and occupancy. Individual room temperature control is desirable for securing proper thermal environment in schools, hospitals and offices.

Control of the temperature in each room, or possibly of adjacent rooms having the same orientation (as in an apartment), overcomes many of the problems encountered when attempting to regulate the temperature of a building as a whole or of large areas or zones. Each individual thermostat controls the heat input to its particular space regardless of occupancy or exposure to sun and wind. The advantage of individual room control is in fuel economy and comfort for the occupants. Each room should have a thermostat that controls valves or dampers on all the controllable sources of heating and cooling. One such uncontrolled source may prevent proper operation of the control system.

### CONTROL OF CENTRAL FAN SYSTEMS

Local practice, local climatic conditions and economic factors influence control system design.

The following sections describe some of the more common methods of controlling the different pieces of equipment used in central fan systems. The complete control system is made up by combining the selected method for each item into an integrated arrangement with proper consideration being given to the interrelation of the several parts, necessary sequence of operations, etc.

#### Outdoor Air Damper Control

Outdoor air for ventilation is usually controlled by a damper arrangement to provide a homogeneous mixture of outdoor air and recirculated air. Outdoor air to meet minimum ventilation requirements should be available

whenever the fan is running and is usually provided in one of the following ways:

- By a minimum outdoor-air damper which opens when the fan is started. A maximum outdoor-air damper may also be provided if additional outdoor air for natural cooling is desired.
- By an outdoor-air damper opening to a minimum position when the fan is started. Additional outdoor air is provided by further opening of the damper under automatic control.

Recirculated-air and exhaust-air dampers are synchronized to operate with the outdoor air dampers. Mechanical interconnections are preferable but separate operators on each of the dampers can be used when mechanical interconnections are impractical. Control of outdoor air quantities beyond the minimum amount can be accomplished by:

- A thermostat set for about 55 F and having its bulb located where there is a true mixture of outdoor air and return air.
- A thermostat in the outdoor air which will gradually open the outdoor-air damper as the outdoor-air temperature increases during mild heating weather.
- A combination of outdoor-air and return-air thermostats operating to select the cooler source of air when cooling is required.
- The preheater thermostat, arranged so that after the preheat valve is closed the outdoor-air damper gradually opens.
- The apparatus dew-point thermostat, arranged so that the outdoor-air damper opens before mechanical cooling is used.

In most arrangements provisions are made to prevent admission of more than minimum outdoor air required for ventilation both during heating operation and when the outdoor-air temperature is too high to provide some natural cooling. Provisions should also be made to close the outdoor-air damper and open the return-air damper whenever the fan is stopped.

#### Preheater Coil Control

The function of a preheater is to temper the outdoor air to prevent the possibility of freezing beyond the coil. Care must be taken to avoid freezing in the coil itself. The proper selection, installation and sizing of steam traps are very important to assure rapid elimination of condensate to prevent freezing.

Steam-distributing-type coils usually are controlled by a thermostat located downstream from the coil and operating a valve in the steam supply line. Where a large temperature rise is required, two or more coils in series should be used, each having a separate valve. The valves should be arranged to operate in sequence, with the valve on the upstream coil opening first.

Non-distributing-type coils should be controlled by a thermostat located ahead of the preheat coil and adjusted to completely open the valve before the incoming air temperature drops to 35 F, to avoid freezing in the coil.

It is important that the preheat coil and its valve be selected so as to prevent overheating the conditioned space when the valve is fully open at 35 F incoming temperature. The use of preheat coil-face and bypass dampers will permit proportional control from a thermostat located beyond the preheat coil, and will prevent such overheating. The coil valve should be wide open whenever the incoming air temperature is below 35 F.

Hot water preheat coils should be controlled by face and bypass dampers operated by a thermostat downstream from the coil, with continuous water circulation when the outdoor air is below freezing. A pressure switch to stop the fan in case of pump failure is often employed. Further freeze protection can be accomplished by a thermostat in the coil outlet arranged

to stop the fan if the water temperature approaches 35 F. In all applications where face and bypass dampers are used, precautionary measures must be taken to prevent stratification of the mixture beyond the coil.

#### Reheater Coil Control

Reheat coils when used for tempering air for ventilation can be controlled by a proportional insertion thermostat, preferably located in the fan discharge to minimize the effect of stratification. This thermostat operates the reheat coil valve or valves, or face and bypass dampers, to maintain a constant discharge air temperature. When face and bypass dampers are used it is good practice to have a valve on the coil which closes after the face damper is closed to prevent overheating due to radiation from the coil or to damper leakage. When used for space heating, reheat coils are controlled by valves or face and bypass dampers actuated by a thermostat in the space or the return air. Usually a low-limit discharge thermostat is used in conjunction with the space or return-air thermostat to maintain the delivered air temperature above the design minimum. To avoid the lag associated with room or return-air control of the reheat coil, it often is preferable to use a controller in the fan discharge which is compensated by space temperature.

#### Humidity Controls

Steam-pan or grid type humidifiers usually are controlled by a valve actuated by a proportional room or return air humidistat or wet-bulb thermostat. The valve should close when the fan stops.

Single-bank sprays, when used primarily for humidification, are usually controlled by a two-position room or return-air humidistat or a wet-bulb thermostat operating a valve in the water line or starting and stopping the pump. Air washers should be run continuously and are usually controlled by varying the temperature of the washer water or the air entering the spray chamber. An apparatus dew-point thermostat with its measuring element located in the air washer water, or in the outlet of the washer beyond the eliminator plates, may be used to (1) operate a mixing valve, or a steam valve on the water heater, to control the washer water temperature; (2) control a valve on the tempering coil ahead of the washer; (3) operate outdoor-air and return-air dampers to control the mixed air temperature entering the washer; or (4) operate a combination of these arrangements.

#### Cooling and Dehumidification Controls

Dehumidification by condensation is so closely related to sensible cooling that it is convenient to discuss them together. Three typical applications of controls are discussed.

**Direct Expansion Systems.** A thermostat measuring the space temperature may be used to open and close a solenoid refrigerant valve on the coil inlet; control the starting and stopping of one or more refrigerating compressors, or otherwise control the compressor capacity; position face and bypass dampers, or a return-air bypass damper, in combination with the opening and closing of the refrigerant coil valve or the starting and stopping of the compressor; control a back pressure regulating valve with proportional action; or control a liquid-refrigerant valve on the inlet to the coil with proportional action. The positive opening and closing of the refrigerant valve or the starting and stopping of the refrigeration compressor will result in wide variations in discharge temperature and dehumidification. When such variations are objectionable, it is desirable to employ proportional damper controls or proportional control of refrigerant flow in conjunction with refrigeration equipment capacity controls as discussed in Chapter 37.

**Chilled Water and Brine Coils.** A thermostat measuring the space temperature may be used to control a valve on the inlet or outlet of the cooling coil; control a

#### Automatic Control

three-way mixing valve; position face and bypass dampers at the coil; or position a return-air bypass damper. An apparatus dew-point thermostat may also be used to control the cooling coil valve.

**Air Washers.** Since the air leaving an efficient washer is practically saturated, the temperature of the spray water will determine the dew-point temperature of the air leaving the washer. With this condition it is possible to maintain very accurate dew-point temperatures and consequently accurate relative humidities under a given ratio of sensible-to-latent heat gain in the conditioned space, provided the space dry-bulb temperature is accurately controlled. In general, the water pump operates continuously and a thermostat measuring the dew-point temperature is used to position a three-way valve to mix refrigerated water with bypassed washer water. To compensate for variations in latent load, a humidistat measuring the space relative humidity may be employed as a master controller to readjust the set point of a dew-point submaster controller.

#### Static Pressure Control

Since fans are selected to produce the desired results for a certain system characteristic, any change in the system characteristic will change the output of the fan. Such changes occur, for example, on single-duct systems in which the volume of air delivered is varied and in double-duct systems where quantities of air are shifted from one duct to the other to obtain final space control. System characteristics may also change when the relative quantities of outdoor air and recirculated air are varied, when exhaust fans are run intermittently, and for other reasons. Such changes result in a changing static pressure in the system, a changing noise level, and changing velocities at air outlets which upset the air flow patterns.

Static pressure control of some form is usually required on such systems, and it is accomplished by a static pressure controller measuring the pressure at a selected point in the system with respect to an atmospheric reference point or some other point inside the building. It can be used to actuate a damper operator on fan inlet vanes, on a multi-blade damper on the suction or discharge side of the fan, or on a damper in a bypass connection between the fan discharge and the fan suction.

#### Control of Final Space Conditions

It is sometimes satisfactory to control the entire area or zone served by a central fan system from a single point as described in previous sections relating to reheat coils, humidifiers and to cooling and dehumidification. The factors to be considered in properly zoning the building are discussed in the section on zone control. Where the entire area does not meet the requirements of a single zone, it may be subdivided so that the air distribution system can be arranged for individual control of each smaller area. This may be accomplished by a thermostat in each space operating warm- and cold-air mixing dampers in the duct serving the space, or operating valves on individual reheat or cooling coils for each space. By providing a sufficient number of subdivisions of the area served by a central fan system, individual room control can be achieved.

#### Control of a Typical System

Fig. 9 shows a complete control arrangement for a typical central-fan air conditioning system in which individual room control is not provided. The controls can be pneumatic, electric, or electronic.

When the fan is started relay E-1, actuated by the fan-motor starter, opens outdoor-air damper D-1, places humidistat H in service, and allows insertion thermostat T-1 to operate preheat coil valve V-1, maximum-outdoor-air damper D-2, return-air damper D-3 and exhaust damper D-4. When the fan stops, E-1 is de-energized and closes the outdoor-air dampers and humidifier valve V-4.

The sequence of operation described will in general also apply to high-pressure

fan systems except that it is considered desirable to open the outdoor-air damper before starting the fan. With this arrangement, a manual switch operates damper D-1. A mercury contactor mounted on the damper starts the fan when the damper is fully open. It also stops the fan when the damper starts to close.

Insertion thermostat T-1 maintains a temperature of 65 F at the preheat coil discharge by operating preheat coil valve V-1. This serves as a low limit for the fan discharge temperature during heating operation. When V-1 is closed, thermostat T-1 then gradually opens maximum-outdoor-air damper D-2 and closes return-air damper D-3 proportionately. At 65 F outdoor temperature D-2 is wide open and D-3 is closed. Exhaust air damper D-4 opens and closes in synchronization with D-2. At 75 F outdoors, when the outdoor air is no longer useful for natural cooling, T-2 closes D-2 and D-4 and opens D-3.

Reheater coil valve V-3 is controlled by submaster thermostat T-3 in the fan discharge. This thermostat is automatically readjusted over an appropriate range of temperature by room thermostat T-4 so that the discharge temperature matches

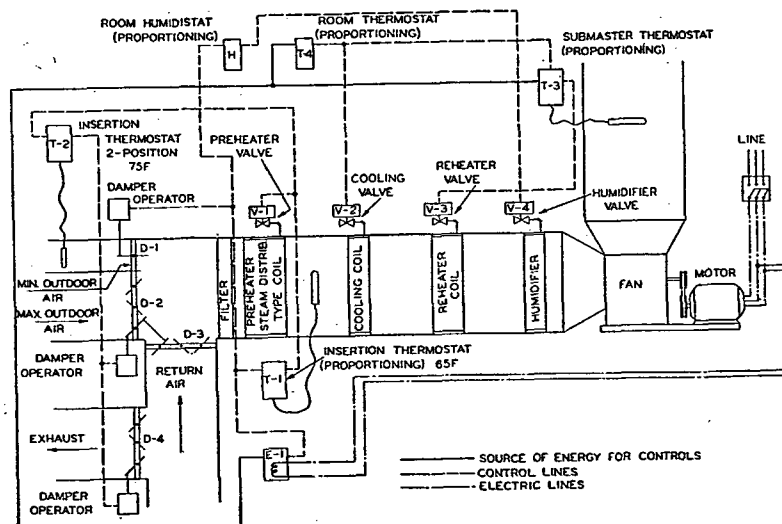


FIG. 9. CONTROL DIAGRAM FOR TYPICAL CENTRAL FAN AIR CONDITIONING SYSTEM

the space requirements. When the room temperature tends to rise above a predetermined value, T-3 has been readjusted downward far enough to keep reheat valve V-3 closed. T-4 then controls cooling coil valve V-2 directly to maintain the desired space temperature.

Humidistat H operates humidifier valve V-4 to maintain the desired humidity in the conditioned space. It is usually adjusted to maintain 30 to 40 percent relative humidity, and therefore keeps the humidifier off during cooling operation when the humidity is higher.

### AUTOMATIC CONTROL OF UNIT HEATERS

The controls for a unit heater can either provide (1) on-off operation of the unit fan or (2) continuous fan operation with modulation of the heat output.

For on-off operation a room thermostat is used to start and stop the fan motor. A limit thermostat, often strapped to the supply pipe, prevents fan operation in the event heat is not being supplied to the unit coil.

Continuous fan operation practically eliminates the intermittent blasts of hot air resulting from on-off operation, and the stratification of tempera-

ture from floor to ceiling which often occurs during the off periods. In this arrangement a proportional room thermostat controls a modulating valve in the steam or hot water supply line to the coil. A limit thermostat or auxiliary switch stops the fan when the valve is closed.

Unit heaters may be used in summer as a means of circulating air to give some measure of comfort due to air motion. In such cases the source of heat should be shut off and the thermostat should be provided with a bypass switch which will permit fan operation independently of the controls.

### AUTOMATIC CONTROL OF UNIT VENTILATORS

Many different control cycles are available. The principle difference in the various cycles pertains to the amount of outdoor air delivered to the room during normal periods of heating. The choice may be governed by compulsory ventilation codes.

Usually a room thermostat controls both a valve to regulate the heat supply and a damper to regulate the supply of cool outdoor air. An insertion thermostat at the unit ventilator prevents the discharge of air below the desired minimum temperature. Any auxiliary heating devices in the same room should be controlled, by the room thermostat, in the proper sequence to fit into the unit ventilator cycle during the following stages:

**Warm-up Stage.** All control cycles function to provide rapid warm-up by having all heating valves wide open and the outdoor damper closed. Thus 100 percent room air is recirculated and heated until the room temperature approaches the desired temperature level.

**Heating and Ventilating Stage.** As the room temperature rises into the operating range of the thermostat, ventilation is accomplished by the partial or complete opening of the outdoor damper according to the cycle used. Valves on auxiliary heating devices are often closed at about the same time. As the room temperature continues to rise the unit ventilator valve is throttled as required to control the heat supply.

**Cooling and Ventilating Stage.** When the room temperature rises above the normal level, cool air is discharged into the room. The room thermostat accomplishes this by throttling the valve further, and then closing it and opening the outdoor damper, if necessary, to prevent the room from overheating. The insertion thermostat frequently takes control during this stage to prevent the discharge of objectionably cold air.

The three basic control cycles commonly used are as follows:

**Cycle X.** A fixed percentage (often 100 percent) of outdoor air is admitted at all times except during the warm-up stage.

**Cycle Y.** A minimum amount of outdoor air (normally 25 to 50 percent) is admitted during the heating and ventilating stage. This percentage is gradually increased to 100 percent, if needed, during the cooling and ventilating stage.

**Cycle Z.** Except during the warm-up stage a variable amount of outdoor air is admitted as needed to maintain a fixed temperature of air entering the heating coil. This is controlled by the insertion thermostat which must be set low enough (often 60 F) to provide cooling when needed.

Day-night thermostats are often used with unit ventilators. Separate switching circuits are used to permit daytime temperatures in some areas and lowered temperatures in others for maximum economy. Several day-night arrangements are in common use. One uses the unit as a convector. Another turns the fan on and off like a unit heater. More elaborate arrangements are available.

### PART III—DESIGN COORDINATION

A heating or cooling system is designed to meet maximum conditions but functions at partial capacity much of the time. The ability to properly

control the system at all times is one of the most important factors having to do with the design of the system and for this reason the proper use and application of controls should be considered at the time the heating or cooling system is being designed. Wherever possible the system should be designed to facilitate control operation. This section includes factors which should be considered in the design of a new heating or cooling system, or the modernization of an existing one, to enable the control system to produce the best possible results.

The design of the system and its controls should take into consideration the nature and type of the building in which it is to be used and the results it is desired to accomplish. Quality of the control equipment should be consistent with the accuracy of control required. Where results more precise than those for normal comfort applications are required, such as in certain manufacturing areas, constant temperature rooms, etc., both the air conditioning system and the control system should be given special consideration so that the required results can be produced. Controls can be made to produce almost any degree of accuracy required, but it is useless to provide such controls unless the air conditioning system is capable of properly responding to the demands of the controllers. For example, it is virtually impossible to maintain close control of temperature and humidity by starting and stopping a refrigeration compressor or opening and closing a refrigerant valve. It is necessary instead to employ refrigeration equipment which will permit proportional control by one of the methods discussed in Chapter 37, or to use a chilled-water system with a cooling coil or air washer that will permit proportional control. Neither is it good practice or economical to select equipment capable of producing far more precise control than the application requires, or to unnecessarily complicate the system to obtain special sequences or cycles of operation. It is well to remember that the system must be adjusted and maintained in operation for many years, and the simplest system that will produce the necessary results is usually the best.

### SIZE OF CONTROLLED AREA

No individually controlled area should be excessively large because the difficulties of obtaining good distribution and of finding a representative location for the space controls become greater as the area increases. Each individually controlled area must have similar load characteristics throughout and otherwise should conform to the recommendations given in the section on Zone Control. For uniform conditions throughout the area equitable distribution must be provided by competent engineering design, careful sizing of equipment and proper balancing of the system. The control can measure conditions only at the point where it is located, and it cannot compensate for variable conditions throughout the area caused by improper distribution or inadequate design. Areas or rooms having dissimilar load characteristics, or having different conditions to be maintained, should be individually controlled. The smaller the controlled area the better will be the control obtained and the more nearly will the system approach the optimum in performance and flexibility.

Even when individual room control is employed it often is well to consider some form of overall zone control of the whole system in accordance with the major factor influencing system load. Thus the water temperature in a hot water heating system, the steam temperature or pressure in a steam heating system, or the delivered air temperature in a central fan system may be varied inversely as the outdoor temperature varies. This obtains a fair share of the necessary control on the system as a whole, relieves the indi-

vidual space controls of a part of their burden and makes more accurate space control possible. Furthermore, modifying the basic rate of heating or cooling input to the system in accordance with system load reduces losses in the distribution system. The cost of the additional controls is often justified by the reduction in operating costs.

Where such overall system controls are employed, accurate zoning, while desirable, is not necessary. The system must always be able to satisfy the area or room having the greatest demand. The individual controls take care of the variations in demand within the area served by the system. The more accurately the system is zoned the larger will be the share of the control accomplished by the overall system controls, the smaller will be the system distribution losses, and the more accurately will the individual space controls be able to maintain the space conditions.

### EQUIPMENT SELECTION AND LAYOUT

Heating and cooling coils should be carefully selected to avoid oversizing. A coil that is too large is not only more difficult to control but may increase air temperature stratification. When temperature measuring elements are to be placed between coils, ample space between the coils must be provided. The measuring element should be located as near as possible to the coil it is controlling. For example, an idle water coil interposed between a thermostat and the coil it is controlling introduces enough thermal inertia to make it difficult to produce stable control.

The elimination of stratification in an air handling system is essential not only in producing good control but in obtaining equitable distribution of heating or cooling. Outdoor-air and return-air dampers should be arranged in such a way as to help blend the outdoor air and return air. Face dampers should be placed far enough from coils to allow for equalization of air flow over the coil surface. The controller for face and bypass dampers must be located far enough downstream so that the air has become thoroughly mixed before reaching the controller. Other sources of stratification are coils which heat or cool unevenly and coils arranged in parallel and controlled in sequence. Whenever stratification cannot be eliminated by proper design or arrangement of equipment, special baffles, mixing chambers or other mechanical devices should be used for this purpose. If stratification still exists at a point where the measuring element of a thermostat is to be located, the use of a long averaging element, or one made up of a number of small elements, may make a suitable temperature measurement possible. This does not solve the other problems relating to stratification which can cause discomfort or, in extreme cases, freezing of equipment.

Good air distribution and properly spaced diffusers and grilles will greatly assist in maintaining even temperatures throughout an area. A space temperature controller cannot prevent drafts. This can be accomplished only by proper attention to such factors as balancing the system, by introducing air in the correct manner, and by providing a suitable low-limit control on the delivered-air temperature. A system that employs constant air volume with variable air temperature results in more uniform distribution than one which requires variations in air volume to achieve temperature control. Varying the volume of air affects both ventilation and distribution, two factors which usually have little relation to thermal requirements. Return air grilles usually can and should be located so as to aid both the distribution and control of the system.

A further aid to both distribution and control is the provision of adequate facilities for exhausting air from the building. The larger the percentage of outdoor air introduced the more important becomes the provi-

sion for adequate exhaust. To prevent drafts due to infiltration, it is quite common to provide for positive exhaust of less air than is brought in. On systems where the quantity of outdoor air is large but constant, this may be accomplished by use of a properly sized exhaust fan. Systems having large internal heat gains, or large solar gains, may use a variable amount of outdoor air up to 100 percent when cooling is required during cool weather. In such cases the outdoor-air quantity may be controlled from space conditions and the quantity of exhaust air may be controlled by a static-pressure controller set to maintain the space under a slight positive pressure.

### LOCATION OF SPACE CONTROLLERS

Space controllers such as room thermostats must be placed where they will measure the variables they are to control and where the condition is representative of the whole area served by the controller. If the return-air duct is used to represent space conditions, the controller should be located as near the space as possible to eliminate the effect of any heat gain or loss in the duct.

Room thermostats should usually be placed in occupied areas on inside walls or columns. They should never be placed in spaces such as corridors, lobbies, and foyers unless they are used for the control of these areas only.

In a typical home which is not zoned a satisfactory location for a room thermostat can usually be found on an inside wall of the living room or dining room. It should always be located toward the center of a relatively open room on the coolest rather than the warmest side of the building. It should not be mounted on an outside wall or other cold surface where it is exposed to cold drafts from an outside door. Neither should it be mounted where it will be affected by direct rays of the sun, by heat from a nearby warm surface such as a chimney, pipes or ducts in the wall, or radiators, or by direct air currents from a register. The location should provide ample air circulation unimpeded by furniture or other obstructions, and should afford protection from mechanical injury.

### THE CONTROL OF STEAM FLOW

The size of an automatic steam valve is based on the required capacity at maximum load, under the conditions which will exist at that time. Equation 52, Chapter 4, for mass flow through an orifice or nozzle can be rewritten as

$$w = C_A \sqrt{P_1 - P_2} \quad (1)$$

where

$w$  = the flow of steam in pounds per hour.

$A$  = the area of the port opening in square inches.

$P_1$  = the steam supply pressure, pounds per square inch, absolute.

$P_2$  = the downstream pressure, pounds per square inch, absolute.

$C$  = a constant for a given steam supply pressure and a given valve body.

Valves for two-position operation usually are selected of a size adequate to supply the required maximum capacity with a reasonably low pressure drop ( $P_1 - P_2$ ). It is necessary only to be sure that the valve will close against the system pressure and will have ample capacity when fully open.

Proportional valves for steam service must be carefully sized if stable control is to be achieved. In general the tendency is to oversize such valves and no controller can produce its best results if handicapped by a valve which is too large. The function of the valve is to vary the value of

area  $A$  in Equation 1 and it is desirable that the flow vary in proportion to the value of  $A$ . The correct maximum required capacity must first be determined. There should be no factor of safety in this determination, and it should be based on actual heating requirements rather than on the condensing capacity of the coil, since the coil may be larger than necessary. It is also necessary to base the valve size on the actual supply pressure ( $P_1$ ) which will exist at the valve, since this supply pressure affects both the density of the steam and the pressure drop which will be selected.

Selecting the proper pressure drop ( $P_1 - P_2$ ) across the valve when it is wide open and is supplying the maximum steam requirement is the most important consideration in determining the valve size. For purposes of discussion it will be assumed that  $P_1$  is constant and that the valve is supplying steam to a heating coil which has air entering at a constant temperature and velocity. Any pressure drop between the valve and the coil will be neglected so that  $P_2$  represents the pressure in the coil. The condensing capacity of the coil varies with changing values of  $P_2$ . When the valve is fully open,  $P_2$  assumes a value such that the capacity of the valve and the condensing rate of the coil are in balance. If this value of  $P_2$  is relatively large, then as the valve is partially closed  $P_2$  will decrease until the capacity of the valve and the condensing rate of the coil are again in balance. Reducing the value of  $A$  in Equation 1 results in an increase in the value of  $\sqrt{P_1 - P_2}$  and partially offsets the effect of closing the valve. This effect is greatest when  $P_2$  is nearly equal to  $P_1$  and diminishes as  $P_2$  decreases.

The minimum value which  $P_2$  can assume is established by the return line pressure (or vacuum) of the system. However,  $P_2$  may reach a value which results in the critical velocity through the valve before it has been reduced to its minimum value. If so, any reduction of  $P_2$  beyond this value has no further effect on the valve capacity. The critical velocity exists when  $P_2$  is approximately 58 percent of  $P_1$ . The undesirable effect caused by variations in  $P_2$  can be eliminated by selecting a valve size such that  $P_2$  is at or near its minimum value, or the value corresponding to the critical velocity, whichever is higher, when the valve is wide open.

On low pressure steam applications it is good practice to base the valve size on a pressure differential equal to 75 or 100 percent of the gauge supply pressure. When the supply pressure is high enough so  $P_2$  at the critical velocity (58 percent of  $P_1$ ) is above atmospheric pressure, the valve size can be based on a pressure differential of 42 percent of  $P_1$  absolute. All valves of the same size do not have the same capacity for a given pressure differential. Having established the supply pressure and the pressure differential, the valve manufacturer's tables or charts should be consulted in selecting the proper size of valve for the required capacity.

It is important that the supply pressure to an automatic steam valve be constant because it is difficult for a thermostat to produce stable results if the pressure is constantly changing. This situation arises, for example, when a steam boiler is operated by a two-position pressure controller. A pressure reducing valve, which will supply a constant pressure to the steam mains while permitting the boiler pressure to fluctuate between the limits of the pressure controller, is recommended. Lacking this, the differential of the pressure controller should be set as narrow as is consistent with efficient boiler and burner operation. On vacuum return systems the vacuum pump also should operate on a narrow differential.

The use of two automatic control valves in parallel will often provide more stable control than a single larger valve, especially on large coils or steam-to-water heat exchangers. The valves should be sized so that one



valve handles about one-third of the total capacity and the other about two-thirds. They are controlled in sequence so that the small valve operates during periods of light load and the large valve begins to open only after the load exceeds the capacity of the small valve.

The steam piping from the valve to the coil inlet, and from the outlet to the trap should be the full size of the coil tapping or size specified by the manufacturer of the coil and should conform to good standard practice as illustrated in Chapter 21. It is very important that condensate be promptly drained from the coil. When the coil is at reduced pressure, as it will be much of the time, there will not be sufficient difference in pressure between the coil and the return line to obtain any lifting of the condensate.

### THE CONTROL OF WATER FLOW

The capacity of a proportional valve for water service is not influenced by the supply water pressure but only by the pressure differential. If a certain water circuit has a total resistance of 30 psi at maximum flow, of which 1 psi is through the valve, the resistance of the rest of the circuit is 29 psi. When the valve is closed and there is no flow, the entire 30 psi resistance is across the valve. Thus the pressure drop across the valve increased by a ratio of 30:1 as the valve closed. This increase in pressure drop as the valve opening is decreased offsets partially the effect of closing the valve. It is obviously impracticable to design a water system such that there will be no increase in pressure drop across the valve as it closes. However, it is important to design the system, including the valve, in such a manner that the ratio of this increase in pressure drop as the valve closes is kept as low as possible. Thus, if the design pressure drop across the valve is 5 psi instead of 1 psi, the ratio of increase is only 6:1 instead of 30:1 and the performance of the valve will be improved accordingly. This discussion assumes a circuit in which the entire flow is controlled by a single valve. The same reasoning will apply to the more complicated systems involving a multiplicity of parallel circuits, each having a valve. In general it can be said that the pressure drop across a water valve at full flow should be a reasonable percentage of the resistance of the circuit in which the valve controls the flow. Due consideration should be given to any resultant increase in pumping head and operating costs.

Water circuits involving variable flow are subject to variable pressures in accordance with the pressure vs flow characteristic of the pump. On such circuits it is desirable to provide pressure control by means of a bypass connection around the pump. This bypass connection either has a spring-loaded relief valve, subject to the system pressure difference, or an automatic control valve operated by a differential pressure controller. The total resistance through the bypass connection at full flow should be equal to the total system resistance.

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## CHAPTER 40

### MOTORS AND MOTOR CONTROLS

Fundamentals of Motor Selection; Alternating Current Motors, Types and Control Equipment; Motor Rating; Functions of Motor Control Equipment; Glossary of Motor Terms, Enclosures, Speed Classification and Mounting

THE electric motor, available in many different types suitable for various services, is now the most widely used form of motive power. The equipment for starting, controlling and protecting these motors varies with the type and with the functions it is desired to attain. Motors are divided into two general classifications, *alternating-current* or *direct-current*, depending on the power source to be used.

### FUNDAMENTALS OF MOTOR SELECTION

The following characteristics of the *power supply* should be determined:

- (1) whether current is alternating or direct, (2) voltage, (3) alternating current phase, (4) alternating current frequency, (5) voltage regulation, (6) continuity of power.

1. *A-C vs. D-C Systems.* For most applications, a-c supply is satisfactory since suitable performance can usually be obtained with a-c motors and control. Where special characteristics, such as an extra wide speed range and severe accelerating or reversing duty are involved, conversion by means of motor generator sets, by rectifiers, or in special cases by converters, may be justified.

2. *Voltage.* Standard conditions of voltage and frequency are the values listed on the name plate of the motor. Reasonable horsepower design limits are given in Table 1. Power lines are often given voltage ratings known as *nominal system voltages* which are numerically slightly different from the standardized motor voltages.

3. *Phases.* Three-phase power supply is most desirable, but only single phase is offered for most residential and rural districts.

4. *Frequency.* Sixty-cycle systems predominate in the United States. In foreign countries, 50-cycle systems are common and nominal system voltages are frequently different.

5. *Voltage Regulation.* The voltage regulation of the power supply should be known in order to select motors which will deliver sufficient torque even with the probable drop in voltage, to start and carry the load. All induction motor torques and synchronous-motor starting and pull-in torques vary as the square of the voltage.

6. *Continuity of Power.* Dips in voltage from switching or other line disturbances may necessitate time-delay undervoltage protection, and, in case of synchronous-motors, high torque designs and resynchronizing control. Sustained low voltage may necessitate higher torque motors.

The following characteristics of the *driven machine* should be determined:

- (1) mechanical arrangement including position of motor and shaft, portability desired, drive connection, and space limitations; (2) speed range desired; (3) horsepower requirement; (4) torque; (5) inertia; and (6) frequency of starting.

1. *Mechanical Arrangement.* Arrangement of the driven machine usually determines whether a *horizontal* or *vertical* motor is needed. Horizontal motors are more generally available and less expensive; most grease-lubricated ball-bearing motors will operate in either position. Fractional-horsepower waste-packed sleeve-bearing



TABLE 1. REASONABLE HORSEPOWER DESIGN LIMITS FOR STANDARD MOTOR VOLTAGES

| POWER SUPPLY        | STANDARD MOTOR VOLTAGE | SUGGESTED MINIMUM HORSEPOWER | SUGGESTED MAXIMUM HORSEPOWER |
|---------------------|------------------------|------------------------------|------------------------------|
| Alternating 1-phase | 115                    | None                         | 1                            |
|                     | 230                    | None                         | 15                           |
| Alternating 3-phase | 110                    | None                         | 15                           |
|                     | 220                    | None                         | 200                          |
|                     | 440-550                | None                         | 1000                         |
|                     | 2300                   | 1                            | 6000                         |
|                     | 4000                   | 50                           | 7500                         |
|                     | 4600                   | 100                          | 8000                         |
|                     | 6600                   | 250                          | None                         |
|                     |                        | 400                          |                              |

motors are satisfactory for short periods of vertical operation where no thrust is involved.

If shaft is tilted for momentary operation, special construction of bearing housings will be required for oil-ring-lubricated sleeve-bearing motors, to avoid loss of lubricant. In case of long periods of tilted operation, bearings suitable for end thrust may be necessary. Ball-bearing motors with grease lubrication are suitable for tilted operation.

Most motors are suitable for mounting with base above a horizontal shaft or to one side of the shaft, provided the end shields are rearranged. If, during operation, the angle of the motor (with regard to the horizontal shaft) changes more than 10 or 12 deg, a ball-bearing motor will usually be required. Sleeve-bearing motors are also applicable within the angle given if modified oil gages are provided.

On portable machines, motors of greater compactness and less weight than standard may be required, and special bearing construction may be needed, except for ball-bearing motors. Direct connection should always be considered where machine speed coincides with available motor speed.

Maintenance, efficiency, power factor, space and initial cost, will determine the choice between direct connection and other methods, such as belt, chain or gear drive. When direct connection is possible (where parts of the driven machine, such as shaft or bearings, are common with the motor structure) a built-in construction may be advantageous.

**Belt Drive.** Diameters and widths of pulleys or sheaves and center distances are factors in determining motor-bearing pressures and shaft deflection. Flat belts should not run at greater speeds than about 5000 fpm. Application of flat belting to vertical-shaft motors is difficult.

**Chain Drive.** The chain manufacture should be consulted so that the best drive on a basis of quietness and economy of operation may be selected.

**Gear Drive.** Compactness and arrangement of drive often indicate gear motors, which are obtainable in a variety of mechanical constructions with speed ratios of 3 to 1 upwards, and are generally limited to about 75 hp maximum. Where the pinion of ordinary spur gearing is mounted on the motor shaft, two-bearing motors

TABLE 2. SPEED RANGES FOR VARIOUS TYPES OF MOTORS

| POWER SUPPLY     | TYPE                                                         | SPEED RANGE            |
|------------------|--------------------------------------------------------------|------------------------|
| Single Phase a-c | • Brush-shifting repulsion motor                             | 3:1                    |
|                  | • Capacitor-motor with tapped winding                        | 2:1                    |
|                  | Multi-speed capacitor-motor                                  | 2 or 3 fixed speeds    |
| Poly-phase a-c   | Multi-speed squirrel-cage                                    | 2, 3 or 4 fixed speeds |
|                  | • Wound-rotor motor                                          | 2:1                    |
|                  | • 2-speed wound-rotor motor                                  | 4:1                    |
|                  | • Brush-shifting shunt motor                                 | 20:1                   |
|                  | • Brush-shifting series motor                                | 3:1                    |
|                  | Squirrel-cage motors with variable frequency supply          | Very wide range        |
| d-c              | Motor-Generator Set—D-c Drive Motor                          | Very wide range        |
|                  | Rectifiers—D-c Drive Motor                                   | Very wide range        |
|                  | Shunt-wound standard constant-speed motor with field control | 2:1 in some cases      |
|                  | • D-c motor with armature control                            | Wide                   |
|                  | Adjustable-speed motor                                       | From 3:1 to 6:1        |
|                  | Shunt motor with adjustable voltage supply                   | Very wide              |

\*Speed regulation relatively wide. Unsuitable for some loads.

are limited in horsepower ratings. Maximum pitch-line speed with steel pinions is about 1400 fpm.

The selection of the motor part of a gear-motor is the same as for a conventional motor.

Space limitations may affect the choice of motor and require (a) built-in construction; (b) a gear-motor; (c) forced ventilation using an external blower; or (d) a small frame with Class B or H insulation permitting higher temperature rise.

**2. Speed Range.** Where more than one speed or a range of speeds is required, one of the motor types listed in Table 2 may be applicable, depending upon the power supply and the speed range required.

**3. Horsepower Requirement.** The horsepower required by the driven machine determines the motor rating. Where the load varies with time, a horsepower vs. time curve will permit determination of the peak horsepower required. The calculation of the root-mean-square (rms) horsepower indicates the proper motor rating from a heating standpoint. In case of extremely large variations in load, or where shut-down, accelerating, or decelerating periods constitute a large portion of the cycle, the rms horsepower may not give a true indication of the equivalent continuous load, and the motor manufacturer should therefore be consulted.

Where the load is maintained at a constant value for an extended period (varying from 15 min to 2 hr, depending on the size), the horsepower rating required will usually not be less than this constant value, regardless of other parts of the cycle.

If the driven machine is to operate at more than one speed, the horsepower required at each speed must be determined.

**4. Torque.** The torque required to operate the driven machine at every moment between initial breakaway and final shutdown is important in determining the type of motor. A torque-speed curve is desirable and sometimes essential.

The starting torque or breakaway torque required by the driven machine may be as low as 10 percent, as in the case of medium-sized centrifugal pumps, or as high as 225 to 250 percent of full-load torque, as in the case of a loaded reciprocating two-cylinder compressor. The breakaway torque may vary greatly at different times because of frequency of start, temperature changes, type and amount of lubricant, etc. The motor torque available at the shaft must be well above the torque required by the driven machine, taking into consideration these variables as well as the possibility of low voltage and the type of starter used.

The torque required after breakaway for acceleration to full speed varies with different driven machines, remaining at a rather high value throughout acceleration for such machines as loaded compressors and plunger pumps. The torque delivered by the motor must at all points, up to full speed, be in excess of the torque required by the driven machine. The greater this excess torque, the faster will be the acceleration. The approximate time required for acceleration from rest to full speed is:

$$\text{Time in seconds} = (\text{rpm}) \times WR^2 \div (T \times 308) \quad (1)$$

where

(rpm) = full-load speed in revolutions per minute.

$T$  = average torque available for acceleration, foot-pound.

$WR^2$  = inertia of rotating parts, pound-foot square.

If the time to accelerate on full voltage is greater than about 20 sec, special motors or starters may be required to avoid overheating.

**5. Inertia of Driven Machine.** The inertia or flywheel effect  $WR^2$  of the rotating parts of the driven machine affects the accelerating time and, therefore, the heating of motors and control, particularly where reversing duty or frequent starting is involved.

Where synchronous motors are applied, the  $WR^2$  must be known, since the pull-in torque required of this motor varies approximately as the square root of the total  $WR^2$  of motor and load.

The  $WR^2$  of a rotating member of the driven machine which operates at a speed different from that of the motor may be converted to an equivalent value at the motor shaft by multiplying by

$$[(\text{rpm of rotating member}) \div (\text{rpm of motor})]^2 \quad (2)$$

**6. Frequency of Starting.** The frequency of starting the driven machine affects the motor and control by increasing their heating, particularly where accelerating

TABLE 3. CLASSIFICATION OF MOTORS

TABLE 3. CLASSIFICATION OF MOTORS

| TYPE                         | SPEED CHARACTERISTICS                  | FULL VOLTAGE            |                                           | HP RANGE         | APPLICATION<br>SEE FOOTNOTES<br>(a) to (e) |                                                                                       |
|------------------------------|----------------------------------------|-------------------------|-------------------------------------------|------------------|--------------------------------------------|---------------------------------------------------------------------------------------|
|                              |                                        | Starting Torque         | Starting Current                          |                  |                                            |                                                                                       |
| <b>Constant Speed Drives</b> |                                        |                         |                                           |                  |                                            |                                                                                       |
| Polyphase a-c                | Squirrel-cage general purpose Design A | Constant                | Normal 1-2.5 times                        | High 6-8 times   | All                                        | (a) Fans and (c) centrifugal pumps and centrifugal compressors                        |
|                              | Squirrel-cage Design B                 | Constant                | Normal 1-2.5 times                        | Normal 5-6 times | Medium Small                               | (a) Fans and centrifugal pumps and centrifugal compressors                            |
|                              | Squirrel-cage Design C                 | Constant                | High 2-2.5 times                          | Normal 5-6 times | Medium Small                               | (b) Reciprocating pumps (e) and compressors started loaded                            |
|                              | Squirrel-cage Design F                 | Constant                | Low 1.25                                  | Low 4 times      | Medium Large                               | Fans, pumps and compressors                                                           |
|                              | Wound rotor                            | Constant or variable    | High 1-2.5 times (with secondary control) | Low 1-3 times    | All                                        | (a) Hoists (b) reciprocating pumps and compressors (c) and frequent (e) or hard start |
|                              | Synchronous high speed                 | Exactly constant        | Normal 0.75-1.75 times                    | Normal 5-7 times | Medium Large                               | (a) Fans and centrifugal pumps and centrifugal compressors                            |
|                              | Synchronous low speed                  | Exactly constant        | Low 0.3-0.4 times                         | Low 3-4 times    | Medium Large                               | (a) Reciprocating compressors starting unloaded                                       |
| Single phase a-c             | Two value capacitor                    | Constant                | High                                      | Normal           | Small                                      | (b) Pumps and compressors                                                             |
|                              | Permanent split capacitor              | Constant                | Low                                       | Normal           | Fractional                                 | (a) Fans, Blowers                                                                     |
|                              | Capacitor start                        | Constant                | Moderate                                  | Normal           | Small Fractional                           | (a) Fans and pumps                                                                    |
|                              | Repulsion Induction                    | Constant                | High                                      | Normal           | Medium Small                               | (a) Fans (b) pumps and compressors                                                    |
|                              | Split phase                            | Constant and adjustable | Normal                                    | Normal           | Fractional                                 | (a) Fans (b) pumps and compressors (d) fans—direct                                    |

**Adjustable Speed Drives**

|                  |                                                   |                      |                               |               |                    |                                                              |
|------------------|---------------------------------------------------|----------------------|-------------------------------|---------------|--------------------|--------------------------------------------------------------|
| Polyphase a-c    | Squirrel-cage high slip. Transformer adjustment   | Variable             | Normal                        | Normal        | Medium Small       | (a) Fans                                                     |
|                  | Squirrel-cage separate winding or regrouped poles | Constant multi-speed | Normal or high                | Normal or low | All                | (a) Fans (b) pumps and (c) compressors                       |
|                  | Wound rotor                                       | Variable             | High (with secondary control) | Low           | All                | (a) Fans (b) centrifugal pumps and compressors               |
| Single phase a-c | Repulsion                                         | Variable             | High                          | Normal        | Low and Fractional | (a) Fans, centrifugal pumps (b) compressors (d) Fans, direct |
|                  | Capacitor low torque tapped winding               | Variable two speed   | Low                           | Normal        | Fractional         | (d) Fans                                                     |
|                  | Capacitor low torque transformer adjustment       | Variable             | Low                           | Low           | Fractional         | (d) Fans                                                     |
|                  | Split phase regrouped poles                       | Constant             | Normal                        | Normal        | Fractional         | (d) Fans                                                     |

a. Drives having medium or low starting torque and inertia ( $WR^2$ ) such as fans and centrifugal pumps or reciprocating pumps and compressors started unloaded.  
 b. Drives having high starting torques, such as reciprocating pumps and compressors started loaded.  
 c. Similar to (a) except where frequent or hard starting (large  $WR^2$ ) requires a higher starting and accelerating torque.  
 d. Fans direct connected.  
 e. Starter drives.  
 f. Torque depends on hp rating and speed. See NEMA Standard MG1-4.10 on Motors and Generators.

time is prolonged by high  $WR^2$  and high load torques. In general, driven machines starting more than 4 to 6 times per hour may require special motors and control.

## ALTERNATING CURRENT MOTORS

Alternating current motors are divided into two main classifications: *polyphase* and *single phase* (see Table 3), according to the type of power supply. They are further subdivided by type of motor winding.

When polyphase power is available it is usually found more economical to apply polyphase motors in preference to single phase motors. A typical 5 hp, 1200 rpm capacitor start-induction run single phase motor, for instance, will cost approximately twice as much as the corresponding three phase *Design B* squirrel-cage motor. In addition, the polyphase motor has the advantage of higher efficiency.

TABLE 4. LOCKED-ROTOR CURRENT OF THREE-PHASE, 60-CYCLE MOTORS: AT 220 VOLTS<sup>a, b</sup>

| HP        | DESIGN B, C, AND D Amperes | DESIGN F Amperes | HP  | DESIGN B, C AND D Amperes | DESIGN F Amperes |
|-----------|----------------------------|------------------|-----|---------------------------|------------------|
| 1 or less | 24 <sup>c</sup>            | ..               | 30  | 435                       | 270              |
| 1½        | 35                         | ..               | 40  | 580                       | 360              |
| 2         | 45                         | ..               | 50  | 725                       | 450              |
| 3         | 60                         | ..               | 60  | 870                       | 540              |
| 5         | 90                         | ..               | 75  | 1085                      | 675              |
| 7½        | 120                        | ..               | 100 | 1450                      | 900              |
| 10        | 150                        | ..               | 125 | 1815                      | 1125             |
| 15        | 225                        | ..               | 150 | 2170                      | 1350             |
| 20        | 290                        | ..               | 200 | 2900                      | 1800             |
| 25        | 365                        | ..               |     |                           |                  |

<sup>a</sup> The locked-rotor current of three-phase, 60-cycle, constant-speed, induction motors, measured with rated voltage and frequency impressed and with rotor locked, shall not exceed the tabulated values.

<sup>b</sup> Locked-rotor current at other voltages shall be inversely proportional to the voltage.

<sup>c</sup> For 1 hp or less the value is given per hp.

## Polyphase Motors

The three types of polyphase motors are: *squirrel-cage induction* motors, *wound rotor induction* motors, and *synchronous* motors.

*Squirrel-cage* motors are specific by NEMA standards providing a variety of speed and torque characteristics. *Design A* motors provide normal starting torque at starting current in excess of *Design B* motors, and are suitable for constant speed application to equipment such as fans and blowers. *Design B* motors provide normal starting torque with NEMA starting current values shown in Table 4, which are acceptable by many power companies for full voltage starting. They are used for the same type of application as *Design A*. *Design C* motors provide high starting torque with starting current same as *Design B*, and are used on compressors started without unloaders, and on reciprocating pumps. *Design D* motors have high slip\* and are used with flywheels for widely pulsating loads on equipment such as reciprocating compressors and pumps where other motors would draw high peak currents. *Design F* Motors have low starting current and low torques. They are used on power systems of limited capacity. Careful application must be made since the low breakdown torque provides only limited safety margin for overload or low voltage conditions. A drop in voltage, for instance, could cause the motor to stall.

Figs. 1 and 2 illustrate the characteristics of squirrel-cage motors. The motor operates under load from near synchronous speed at light load to

\* Refer to Glossary at end of chapter.

about 95 percent synchronous speed at full load. Overloads decrease the speed further until the maximum torque point is reached. If the load torque exceeds this point the motor will stall. The motor torque varies as the square of the voltage. If the voltage drops 10 percent, the motor torque will be only 81 percent of rated value. Both power factor and efficiency are improved if the motor is operating as near rated load as possible. In addition, as shown in Fig. 2, power factor and efficiency are better for higher speed motors.

*Wound Rotor* motors are used for applications requiring high starting torque at low starting current, because a wound rotor motor with its controller and resistance can develop full load torque when starting with about full load current. For comparison, a squirrel-cage motor would require from 3 to 5 times as much current to develop full load torque at starting. The wound rotor motor is also used for varying speed service to drive fans, blowers, and other continuous duty apparatus.

The addition of resistance to the secondary winding of the wound rotor motor changes the speed torque characteristics. The motor speed, with

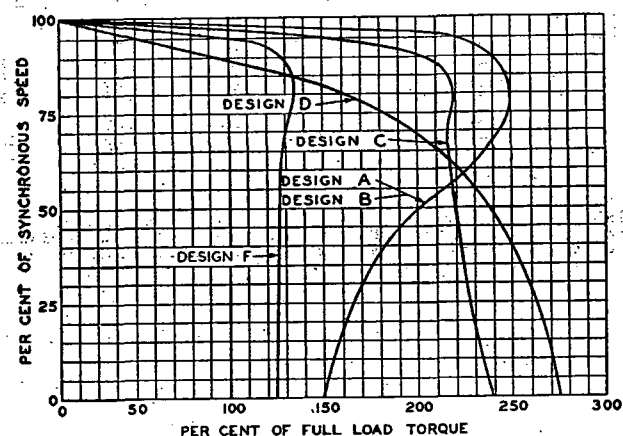


FIG. 1. SPEED TORQUE CHARACTERISTICS OF SQUIRREL-CAGE MOTORS

the resistance added, is dependent on load, and consequently, the motor has very poor speed regulation when secondary resistance is added to reduce the speed to values below 50 percent. Fig. 3 illustrates the characteristics of wound rotor motors.

*Synchronous* motors are used for continuous duty applications at constant speed where efficiency and power factor are important. Another advantage of these motors is that of lower initial cost in large sizes and for low speeds when compared with squirrel-cage type motors.

The outstanding advantage of the synchronous motor is that its power factor can be changed to compensate for the low power factor of other drives in the same location. Lagging power factor is an inherent characteristic of all induction apparatus, such as induction motors and neon signs. Unless synchronous motors or capacitors are installed, the plant power factor may be comparatively low. This does not necessarily mean that corrective equipment must always be installed, but in most cases it

\* Refer to Glossary at end of chapter.

is desirable to determine what advantages may be gained by improving the power factor. With purchased power, if the rates include a clause embodying a penalty for low power factor, or a bonus for high power factor, the saving in power costs may often make a very good return on the investment required for the corrective equipment.

Synchronous motors are used to drive fans, blowers, pumps, compressors and other applications. Compressor applications having a high peak torque require the use of flywheels to smooth out power peaks, and should always be referred to the electrical manufacturer for recommendations.

Synchronous motors are provided with built-in damper windings on the rotor and operate during the starting period similarly to squirrel-cage

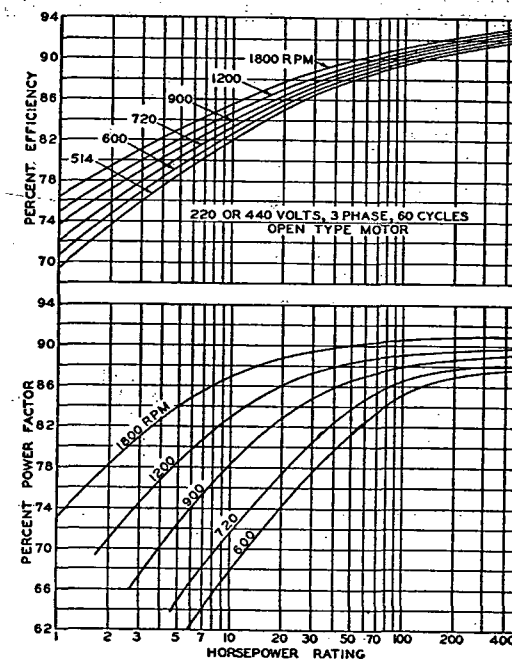


FIG. 2. EFFICIENCIES AND POWER FACTORS FOR SQUIRREL-CAGE INDUCTION MOTORS

motors. After the motor is nearly up to speed, field excitation is applied and the motor draws into step at synchronous speed. After excitation is applied, the motor runs at exactly constant speed and will remain at this speed until a load approaching the pull-out load is reached, whereupon the motor pulls out of synchronism and stops.

In applying synchronous motors consideration must be given to the torque the motor can develop on pull-in, that is, at the instant when field excitation is applied. Table 5 shows typical application requirements of synchronous motor drives, listing starting, pull-in, and pull-out torques.

*Multi-Speed* motors provide flexibility in many types of drives. Synchronous motors can be furnished only with a 2 to 1 ratio in speed, single

winding. Squirrel-cage induction motors may be 2, 3 or 4 speed. Two-speed induction motors are usually of single winding type, having a 2 to 1 speed ratio such as 600 rpm and 1200 rpm, or may be double winding. Three-speed induction motors are always two winding, and four-speed motors are usually two winding with a 2 to 1 speed ratio in each winding. Motors can be provided in constant torque, varying torque, or constant horsepower ratings. The constant horsepower type of motor is considerably larger than the constant torque motor, due to the fact that the same horsepower must be developed at either reduced speed or high speed.

In selecting two-speed motors for fan, pump, blower, or compressor applications, it is usually found that two winding motors are more expensive than the single winding type. The control cost for two-speed, two winding motors, however, is more economical, and therefore the combined

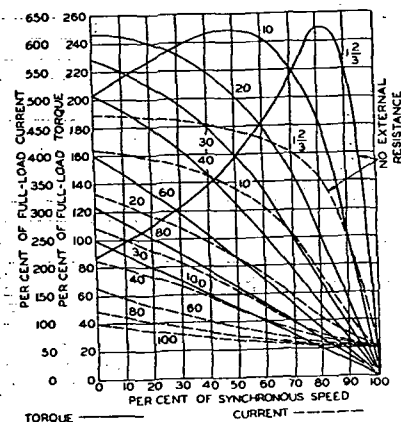


FIG. 3. SPEED-TORQUE SPEED-CURRENT CHARACTERISTICS OF WOUND ROTOR MOTORS

price of both motor and control for the two winding motor is only slightly higher. Because of the improved performance of the two winding motors, and because of the factor of safety provided by two independent windings, the increased cost is frequently worth the difference.

### Single Phase Motors

Single phase induction motors have auxiliary windings or devices for starting, and are classified by the method used.

**Capacitor start** motors develop high starting torque in fractional horsepower ratings, and moderate starting torque in larger ratings. They are used for constant speed drive such as fans, blowers and centrifugal pumps. During the starting period, a winding with a capacitor in series is connected to the motor circuit and when the motor comes up to speed, a centrifugal switch cuts the capacitor and second winding out of the circuit.

**Two-value capacitor** motors develop high starting torque employing a starting capacitor and a running capacitor. The starting capacitor gives high starting ability, but is suited for short time operation only, and is cut out for the running condition by a centrifugal switch. The running ca-

### Motors and Motor Controls

pacitor gives high efficiency at full speed. These motors are used on compressors, reciprocating pumps and similar equipment which may start under heavy load.

**Permanent split capacitor** motors have low starting torque and are ideally suited for small fan drives. Operation is similar to the capacitor start motor, except that the capacitor is not cut out when running.

**Repulsion-Start Induction-Run** motors develop high starting torque. The motors have a wound rotor connected to a commutator for starting. A centrifugal switch shorts the commutator bars when the motor comes up to speed to obtain a winding approximately like the squirrel cage in its function.

**Repulsion-Start Induction-Run** motors are suitable for applications, such

TABLE 5. TYPICAL APPLICATION REQUIREMENTS OF SYNCHRONOUS MOTOR DRIVES SHOWING STARTING, PULL-IN AND PULL-OUT TORQUES

| APPLICATION |                                    | METHOD OF<br>CONNECTING MOTOR<br>TO LOAD                              | STARTING<br>CONDITIONS        | TORQUES       |             |              | REMARKS                                         |
|-------------|------------------------------------|-----------------------------------------------------------------------|-------------------------------|---------------|-------------|--------------|-------------------------------------------------|
|             |                                    |                                                                       |                               | Start-<br>ing | Pull-<br>in | Pull-<br>Out |                                                 |
| Fans        | Exhaust and venti-<br>lating       | Coupled or belted                                                     | Usually loaded                | 50            | 60-125      | 150          | WR <sup>2</sup> of fan must be<br>considered    |
|             | Cycloidal positive                 | Coupled or engine<br>type                                             | Unloaded                      | 40-60         | 40-60       | 150          | Two-speed motors<br>sometimes used              |
| Blowers     | Blowing engines re-<br>ciprocating | Engine type                                                           | Unloaded                      | 40            | 40-60       | 150          |                                                 |
|             | Turbo high speed                   | Direct connected or<br>step up gear                                   | Unloaded (in-<br>take closed) | 30            | 50          | 150          | WR <sup>2</sup> of blower must<br>be considered |
| Compressors | Air                                | Engine type                                                           | Unloaded                      | 40            | 30          | 150          | Flywheel effect im-<br>portant                  |
|             | Ammonia and am-<br>monia booster   | High speed—belted<br>Low speed—engine<br>type occasionally<br>coupled | Unloaded (by<br>by-pass)      | 40            | 30          | 150          | Flywheel effect im-<br>portant                  |
|             | Freon                              | High speed—belted<br>Low speed—engine                                 | Unloaded (by<br>by-pass)      | 45            | 50          | 150          | Flywheel effect im-<br>portant                  |
|             | Gas reciprocating                  | High speed—belted<br>Low speed—engine                                 | Unloaded (by<br>by-pass)      | 40            | 30          | 150          | Flywheel effect im-<br>portant                  |

as industrial compressors, requiring high breakaway torque, and where commutator and brush noise are not factors.

**Split Phase** motors have a high resistance auxiliary winding which is in the circuit during starting, but is disconnected through the action of a centrifugal switch as the motor comes up to speed. Under running conditions it operates as a single phase induction motor with one winding in the circuit. These units are available for the small horsepower ratings, and when equipped with a high slip rotor, may be used for adjustable varying speeds through line voltage control. The motors are ideally suited for fan duty.

Speed-torque characteristics of single phase motors are shown in Fig. 4.

**Full voltage starting** of single phase motors is general practice, but since most of these motors are connected to secondary distribution systems located in light load density areas, power companies check carefully the starting currents in order to prevent objectionable voltage dips. This is particularly important for motors started frequently, such as those controlled by pressure or temperature sensitive devices and applied to refrigerators, stokers, oil burners, and water pumps.

The report of a joint committee of *AIEC-EEI-NEMA*\* recommended three application rules taking into account the greater annoyances resulting from frequent motor starting during lighting hours against infrequent starting at any time. Table 6 shows typical applications of these rules which are becoming widely accepted for full voltage starting. Rules 1 and 2 apply to general use.

Rule 1 limits the locked-rotor current to 20 amp at 115 volts, and 25 amp at 230 volts when automatically controlled (usually frequently started) motors are used. Rule 2 permits twice these values when manually controlled (usually infrequent starting) motors are used. Rule 3 applies to

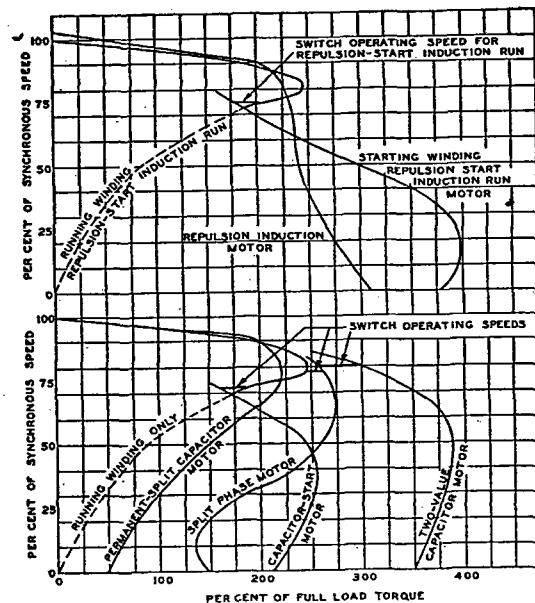


FIG. 4. SPEED-TORQUE CHARACTERISTICS OF SINGLE PHASE MOTORS

special conditions where larger currents may be allowed above Rules 1 and 2 upon approval of the electric company.

*Hermetically enclosed* single-phase a-c motors are widely used in appliances such as domestic and commercial refrigerators, room air conditioners, beverage coolers, freezer chests, and water coolers. In such appliances, the motors are sealed inside the compressor, and the gas and oil circulate freely within and around the motor. Centrifugal starting switches are not used on such motors because any arcing in the gas and oil atmosphere would be detrimental, and also because the units are permanently sealed and cannot be serviced or repaired in the field. In place of a centrifugal switch, an external relay is used to start hermetically enclosed motors.

Hermetically enclosed motors for refrigeration compressors will, in the future, have the horsepower rating eliminated. The full load current is to be the operating current in amperes, when the compressor is deliver-

\* Refer to Glossary at end of chapter.

ing rated output. The motors for hermetically enclosed service are usually of the split-phase type or of the capacitor-start (or two-value capacitor) type.

For starting the split-phase type of motor, two methods are generally acceptable. In one method a thermally-operated time delay is used. When the motor is started, a contact which is normally closed applies power to the starting winding. A thermal element which controls these contacts is in series with the motor and carries line current. Due to the current flow through this element, it is heated until, after a definite period of time, it is warmed sufficiently to open the contacts and remove power from the starting winding. The running current then heats the element enough to keep the contacts open. The setting of the time for the starting contacts to open is determined by tests on the system components, i.e.,

TABLE 6. RECOMMENDED SINGLE PHASE MOTOR RATINGS FOR FULL VOLTAGE STARTING

| HP RATING | LOCKED-ROTOR CURRENT*<br>AT 25 C<br>Amperes |       | GENERAL USE<br>(Rules 1 & 2) |       | SPECIAL CONDITIONS<br>(WITH UTILITY PERMISSION)<br>(Rule 3) |       |
|-----------|---------------------------------------------|-------|------------------------------|-------|-------------------------------------------------------------|-------|
|           | 115 V                                       | 230 V | 115 V                        | 230 V | 115 V                                                       | 230 V |
| 1/50      | 20                                          | 10    | A-M                          | A-M   | A-M                                                         | A-M   |
| 1/4       | 20                                          | 10    | A-M                          | A-M   | A-M                                                         | A-M   |
| 1/3       | 20                                          | 10    | A-M                          | A-M   | A-M                                                         | A-M   |
| 1/2       | 23                                          | 11.5  | A-M                          | A-M   | A-M                                                         | A-M   |
| 3/4       | 31                                          | 15.5  | M                            | A-M   | A-M                                                         | A-M   |
| 1         | 45                                          | 22.5  | M                            | A-M   | A-M                                                         | A-M   |
| 1 1/4     | 61                                          | 30.5  |                              | M     | A-M                                                         | A-M   |
| 1 1/2     | 70                                          | 35    |                              | M     | A-M                                                         | A-M   |
| 2         |                                             | 40    |                              | M     |                                                             | A-M   |
| 3         |                                             | 50    |                              | M     |                                                             | A-M   |
| 5         |                                             | 70    |                              |       |                                                             | A-M   |
|           |                                             | 100   |                              |       |                                                             | A-M   |

A refers to automatically controlled devices.

M refers to manually controlled devices.

\* These values of Locked-rotor current are the same as the NEMA standard for single-phase Design M motors.

the relay, the motor, and the compressor, and is based on a prediction of the amount of time delay required to bring the motor up to speed.

The second method of starting split-phase motors utilizes a series-coil or current-operated relay. This device is affected indirectly by motor speed.

In this type of connection, a relay coil carries the line current going to the motor. When the motor is started, the inrush current to the running winding, passing through the relay coil, causes the contacts to close, and applies power to the starting winding. As the motor comes up to speed, the current decreases until at a definite calibrated value of current corresponding to a pre-selected speed, the magnetic force of the coil diminishes to a point which allows the contacts to open, removing power from the starting winding.

*Capacitor-start* and *two-value capacitor hermetically sealed* motors are usually started with a voltage-type relay. In this method of starting the relay coil is connected in parallel with the starting winding. When power is applied to the line, the relay does not operate because it is calibrated to operate on a higher voltage. As the motor comes up to speed, the voltage across the starting winding and relay coil increases in proportion to the motor speed. At a definite voltage corresponding to a pre-selected speed, the relay operates and opens its contacts, thereby opening the starting

winding circuit. The relay then keeps these contacts open because there is sufficient voltage induced in the starting winding, when the motor is running, to hold the relay in the open contact position.

### CONTROL FOR ALTERNATING CURRENT MOTORS

*Squirrel-Cage* motors are usually linestarted where power company limitations permit. In sizes up to 5 hp at 220 volts, or  $7\frac{1}{2}$  hp at 440 volts, polyphase motors may be started by means of manual switches having overload current elements for motor protection. In larger ratings a linestarter is usually provided with either an additional safety switch or circuit breaker for disconnecting and short circuit protection. Reduced voltage starting may be used when the current inrush on full voltage exceeds the limitations set by the power company. The magnitude of this inrush current is entirely independent of the load on the motor, and is the same whether the motor is lightly loaded or heavily loaded.

TABLE 7. COMPARISON OF SQUIRREL CAGE AND SYNCHRONOUS MOTOR STARTING METHODS

| TYPE OF STARTER       | PERCENT OF MOTOR RATED VALUES |                 |              |
|-----------------------|-------------------------------|-----------------|--------------|
|                       | Line Voltage                  | Starting Torque | Line Current |
| Full Voltage Starter  | 100                           | 100             | 100          |
| Autotransformer       |                               |                 |              |
| 80 percent tap        | 80                            | 64              | 68           |
| 65 percent tap        | 65                            | 42              | 46           |
| 50 percent tap        | 50                            | 25              | 30           |
| Resistor, single step | 80                            | 64              | 80           |
| Reactor               |                               |                 |              |
| 50 percent tap        | 50                            | 25              | 50           |
| 45 percent tap        | 45                            | 20              | 45           |
| 37.5 percent tap      | 37.5                          | 14              | 37.5         |
| Part Winding          | 60                            | 50              | 60           |

Restrictions on starting current may limit the maximum current inrush or may limit the increments of current inrush which may be drawn on each step. Table 7 shows a comparison of the various methods of reduced voltage starting. The choice may depend upon the limitation to be met. Fig. 5 shows examples for maximum current limitations. Fig. 6 shows examples for increment limitations. The increment starters would not be satisfactory for meeting maximum current limitations as they exceed the maximum value before the motor reaches full speed. Both Curves B and C of Fig. 6 would be satisfactory if the increment limitation were 400 percent but only the starter illustrated by Curve C would meet a limitation of 200 percent increments.

When increment starters are used the motor may not develop enough torque to start until the last step. Fig. 6 shows that with the resistor step starter the motor does not start until step 3 or after 2 seconds on Curve C. Part-winding motors may start and then stall at about half speed until the second step which applies full torque.

The load inertia ( $WK^2$ ) may also affect the selection of reduced current starting method since the reduced torques may not be sufficient to accelerate the load without overheating the motor or in the case of synchronous motors, may not reach sufficient speed to pull into synchronous speed.

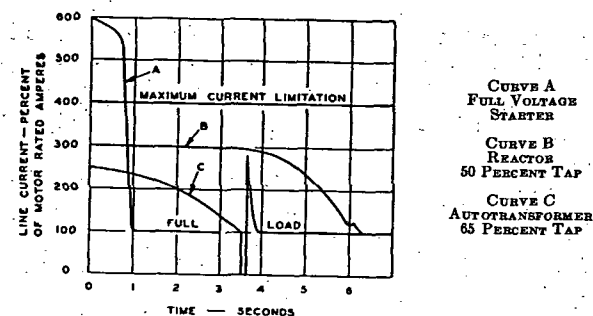


FIG. 5. STARTERS FOR MAXIMUM CURRENT LIMITATIONS

In these cases the solution may be to use the wound-rotor induction motor or some means of reducing the load such as suction dampers on compressors. Fig. 7 illustrates recommended control practice for squirrel-cage motors.

*Wound-Rotor* motors require control of both primary and secondary circuits. The primary\* control may be the same as for squirrel-cage motors, manual or magnetic, at full voltage. Secondary\* control provides means of varying secondary resistance for starting and speed control. The secondary controller should be specified for starting duty only, or for speed regulating duty. If the secondary controller is to be used for speed regulating duty, the percent speed reduction, the number of speed control points, and the type of load (variable or constant torque) should be specified. Fig. 8 illustrates recommended control practice for wound rotor motors.

*Synchronous* motor starters should provide pull-out protection, automatic synchronization or automatic stopping of the motor after pull-out, and insurance of complete starting sequence, as well as overload and low voltage protection. The control may be either magnetic or semi-magnetic at full or reduced voltage. Semi-magnetic starters provide automatic field control, but require hand operation for closing the line contactors to start and transfer to full voltage.

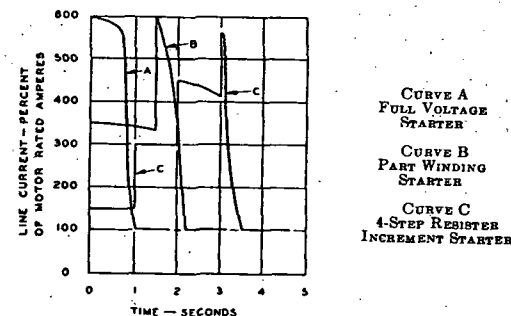
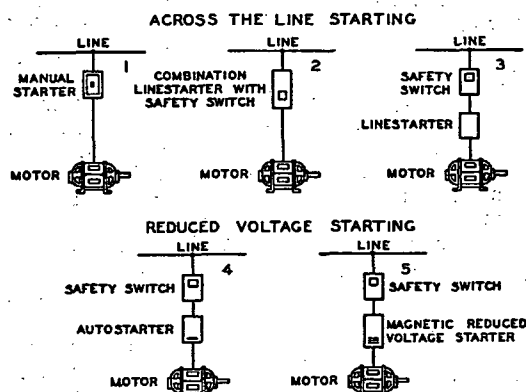


FIG. 6. STARTERS FOR INCREMENT LIMITATIONS

\* Refer to Glossary at end of chapter.

In applying reduced voltage starters to synchronous motors it should be remembered that, since these motors are started on damper windings and function during the acceleration period similarly to squirrel-cage motors, the starting torque varies as the square of the applied voltage. Consideration should be given to insure development of sufficient motor torque to accelerate the load.

**Multi-Speed** control may be either manual or magnetic, and at full or reduced voltage. When using automatic magnetic control with two-, three-, and four-speed separate winding or consequent pole motors, control may be obtained from a remote point by means of a push button master switch. The various speeds of the motor are obtained from the master switch by simply depressing the correct push button. This is known as selective speed control. It is commonly used in the smaller theater installations where the fan and motor are located backstage and the speed control is located in the lobby.



Arrangements 2, 4 and 5 provide automatic push-button starting.

FIG. 7. RECOMMENDED CONTROLS FOR SQUIRREL-CAGE MOTORS

Multi-speed motor controllers may be provided with compelling relays which make it necessary for the operator to press the first speed button before regulating the motor to the desired speed. This insures that the motor is always started at low speed before adjusting to a higher speed.

Timing relays which provide for automatic acceleration may be used for control. With this feature the motor will always start at low speed and automatically accelerate to the desired speed. Decelerating relays may be used to reduce the shock effect of the braking action on the motor and drive when the speed is reduced from a higher to a lower speed.

**Single Phase** motor control usually consists only of a line starter, either manual or magnetic. In some cases it is desirable also to provide a disconnect switch. Fig. 9 illustrates the recommended controls.

### MOTOR RATING

The rating of an electric motor depends upon the total temperature which the motor attains under operating conditions. This total temperature depends on both the ambient temperature and the temperature rise of the motor. As motor temperature rise is in turn determined by the ability of the motor to dissipate heat, circulation to the motor should not

be restricted. Improper selection of motors with regard to temperature ratings may result in high motor operating temperatures and accompanying reduction in motor life.

### FUNCTIONS OF CONTROL EQUIPMENT FOR MOTORS

In general, control equipment for all types of motors should provide (1) means of disconnecting the motor from the power supply, (2) means for starting the motor, (3) overload protection for the motor, (4) protection against low voltage, and (5) means for varying the motor speed.

Full voltage starting for motors is preferable because of its lower first cost and simplicity of control. Except for d-c machines, most motors are mechanically and electrically designed for full voltage starting. The starting inrush current, however, is limited in many cases by regulations of power companies because of the voltage fluctuations which may be caused by heavy current surges. It is therefore often necessary to reduce

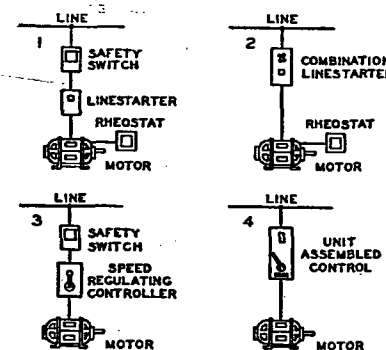


FIG. 8. RECOMMENDED CONTROLS FOR WOUND ROTOR MOTORS

the starting current below that obtained by across-the-line starting. The power supplier should be consulted to determine the allowable inrush current for any given location.

The choice between full voltage and reduced voltage starting is governed almost entirely by inrush current limitations. The starting torque of all motors varies with the starting current, and it is therefore necessary to insure that the motor is supplied with sufficient current to develop enough torque to accelerate the load.

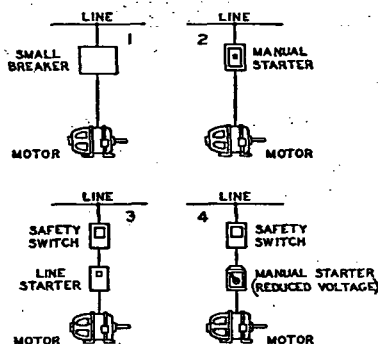
In present practice overload protection of motors is obtained by use of thermal overload inverse time limit type protection. The usual setting of such protection devices is not to exceed 125 percent of rated full load current for open 40 C rise motors, and not to exceed 115 percent of rated full load current for all other motors, the element tripping after a definite interval of time. The *National Electrical Code* requires the addition of fuses or circuit breakers to protect the overload elements from severe short circuit currents.

Two types of protection are available against low voltage at the motor terminals. One type, called low voltage release, permits the motor line contactor to drop out on low voltage and to close again when the voltage returns to normal, thereby restarting the motor when the abnormal condi-



tion is ended. The second type, called low voltage protection, causes the motor line contactor to drop out on low voltage, but prevents restarting when the voltage returns to normal except by the action of an operator. This latter type of protection is desirable where it is necessary for the operator to make initial starting adjustments on the machine.

Manual control for an alternating or a direct current motor is usually located near the motor. When so located an operator must be present to start and stop or change the speed of the motor by operating the control mechanism. Manual control is sometimes employed only as a device to give overload protection, and another device is employed to start and stop the motor. Manual control is used particularly on small motors which operate unit heaters, small blowers, and room coolers in an air conditioning system. In other cases manual control in the form of drums, when used with multi-speed motors, is used only as a speed setting device, while the



Arrangements 2, 3 and 4 are optional for motors up to 7½ hp, 220 volts.

FIG. 9. RECOMMENDED CONTROLS FOR SINGLE PHASE MOTORS

starting and stopping functions operate automatically through thermostats and pressure switches.

Because of the increasing complexity of air conditioning systems, the equipment is operated preferably by automatic control, and less dependence is placed on manual operation and regulation.

Automatic control of motor starters may be accomplished by the use of remote push button stations, by a thermostat, float switch, pressure regulator, or other similar pilot devices. An added advantage of automatic control is that the main wiring for the starter may be installed near the motor, while the starter may be operated by a remote control device.

## GLOSSARY

### General Definitions

**NEMA** is the abbreviation for the *National Electrical Manufacturers Association*.

**AEIC** is the abbreviation for the *Association of Edison Illuminating Companies*.

**EI** is the abbreviation for the *Edison Electric Institute*.

**Speed Regulation** (d-c motors) is the change in speed between no-load and full-load, expressed in percent of full-load speed; for example, a motor having a no-load speed of 1200 rpm and a full-load speed of 1140 rpm would have a speed regulation of 5.26 percent.

**Slip** (a-c induction motors) is the difference between the motor speed and synchronous speed expressed in percent of synchronous speed, e.g., a 1200 rpm motor operating at 1140 rpm would have a slip of 5 percent.

**Torque** is an expression of the turning effort developed by the motor at the shaft, and is usually expressed in ounce-feet for fractional horsepower motors, and in pound-feet for motors of larger ratings.

**Primary** is the term usually applied to the high voltage or line side of a transformer or motor. In the case of the wound rotor motor the primary is the stator winding.

**Secondary** is the term usually applied to the low voltage or load side of a transformer or motor. In the case of the wound rotor motor the secondary is the rotor winding.

## NEMA Classification of Motor Enclosures

**Open motors** (40 C rise, rated load, 50 C rise, service factor load) are self-ventilated machines having no restriction to ventilation other than that necessitated by mechanical construction.

**Guarded motors** (50 C Rise) have all ventilating openings limited in size by either design of structural parts, perforated covers or screens preventing direct access to live or rotating parts.

**Semi-Guarded motors** (50 C rise) have the ventilating openings in the top half of the frame only protected by perforated covers.

**Drip Proof motors** (50 C rise) are so constructed that drops of liquid or solid particles falling on the machine at any angle not greater than 15 deg from the vertical, cannot enter the machine either directly or by striking and running along a horizontal or inclined surface.

**Splash Proof motors** (50 C rise) are so constructed that drops of liquid or solid particles falling on the machine or coming toward it in a straight line at any angle not greater than 100 deg from the vertical, cannot enter the machine either directly or by striking and running along the surface.

**Totally Enclosed Non-Ventilated motors** (55 C rise) are so constructed as to prevent exchange of air between inside and outside of the case, but are not air tight and are not equipped with external cooling means.

**Totally Enclosed Fan-Cooled motors** (55 C rise) are similar to totally enclosed, non-ventilated machines, except that exterior cooling is provided by means of a fan or fans integral with the machine.

**Explosion Proof motors** (55 C rise) have an enclosing case designed to withstand an explosion of a specified gas or vapor which may occur within it, and to prevent ignition of the gas or vapor surrounding the motor by sparks, flashes, or explosions of the gas or vapor which may occur within the machine casing.

**Dust Explosion Proof motors** (55 C rise) have an enclosing case designed and constructed so as not to cause the ignition or explosion of an atmosphere of the specific dust, or to cause ignition of dust on or around the machine. (Proper overload protection and cleanliness are required for successful operation).

**Water Proof motors** (55 C rise) are so constructed as to exclude water applied in the form of a stream from a hose.

## Motor Speed Classifications

A **Constant Speed** motor is one in which the speed remains practically constant with changes in load; e.g., a d-c shunt wound motor or a-c squirrel-cage motor with low slip.

A **Varying Speed** motor is one in which the speed varies with the load, usually decreasing when the load increases; e.g., a d-c series motor or an induction motor with large slip.

An **Adjustable Varying Speed** motor is one in which the speed can be adjusted gradually, but when once adjusted for a given load will vary in considerable degree with change in load; e.g., a shunt wound d-c motor adjusted by armature resistance control.

An **Adjustable Speed** motor is one in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load; e.g., a d-c shunt motor with field resistance control. The standard ratings for open type, adjustable speed motors, having a speed range of 3 to 1 and greater are in accordance with the following:

- (1) A standard continuous horsepower rating at 150 percent of minimum speed with a temperature rise of 40 C.
- (2) The next higher standard continuous horsepower rating at 3 times minimum speed with a temperature rise of 40 C.

- (3) Between 150 percent of minimum speed and 3 times minimum speed, the standard continuous horsepower rating with a temperature rise of 40 C will vary with the speed along a straight line connecting these two horsepower ratings. No further increase in horsepower is recognized above 3 times minimum speed.
- (4) Below 150 percent of minimum speed the lower continuous horsepower rating (see preceding item 1) will apply with a temperature rise of 50 C.  
*Example:* 20/25 hp, 400 to 1600 rpm. This motor may be rated 20 hp, 40 C at 600 rpm and 25 hp, 40 C from 1200 to 1600 rpm. Between 600 and 1200 rpm the rated horsepower increases directly with speed from 20 to 25 hp.
- (5) Motors may also be rated 1 hour with temperature rise of 50 C with the higher horsepower rating (see preceding item 2) throughout the entire speed range.  
*Example:* 20/25 hp, 400 to 1600 rpm. This motor may be rated 25 hp, 50 C 400/1600 rpm; 1 hour.

### Mechanical Modifications

*Vertical Mountings* are available for such applications as pumps and agitators. This type of application may require a special umbrella-type hood to protect against dripping liquids.

*Flanged Mountings* are available for use where motors are built in as part of machines. Motors may also be supplied with flush plate mountings, suitable for close coupled pump and similar applications.

## CHAPTER 41

### SOUND CONTROL

Unit of Noise Measurement, Apparatus for Measuring Sound, General Problem, Kinds of Noise, Noise Transmitted Through Ducts, Design Room Noise Level, Noise Generated by Fans, Natural Attenuation of Duct System, Duct Sound Absorbers, Air Supply Noises, Cross Transmission Between Rooms, Controlling Vibration from Machine Mountings

IN ventilating and air conditioning a building or a room, consideration must be given to the effect of the mechanical system on the acoustics of the space conditioned. It is important to consider also that the use of air conditioning often permits keeping the windows closed, thus giving relief from certain external noises, but at the same time increasing the necessity of providing adequate sound control.

It is assumed that in a given space the architect and acoustical engineer have produced a room or rooms which are satisfactory for speech, music, or other uses. The ventilating engineer's sole function is to ventilate and air condition these rooms properly so that they will be physically comfortable without adding any acoustical hazards.

### UNIT OF NOISE MEASUREMENT

According to an international standard, the *decibel (db)* is the unit for expressing sound pressure levels. The *sound pressure level*, in decibels, is given by the relation:

$$db = 20 \log_{10} \left( \frac{P}{0.0002} \right) \quad (1)$$

where  $P$  = the sound pressure in dynes per square centimeter.

The reference pressure (0.0002 dynes per square centimeter) is a sound pressure which is slightly less than the threshold of audibility, at the frequency of 1000 cycles per second, for the person of average hearing. This reference point is approximately the minimum sound pressure that would be audible in a very quiet room to an observer having acute hearing. The ear is essentially a pressure operated device; hence, the sensation of loudness, or magnitude of sound is governed by the sound pressure existing at the point of reception.

The sound level meter measures sound level pressure, the measurement being expressed as *sound level* on a decibel scale with zero corresponding to the reference pressure of 0.0002 dynes per sq cm at 1000 cycles. In the higher ranges of the decibel scale, approaching 120 db, the sensation is one of feeling, and at higher levels the sensation becomes painful.

Associated with sound pressure level is the *sound intensity level*, expressed in decibels above a standard reference intensity. Sound intensity is the average rate of sound energy transmitted through a unit area normal to the direction of propagation, commonly expressed in watts per square centimeter. The *sound intensity level*, in decibels, is given by the relation:

$$db = 10 \log_{10} \left( \frac{I}{10^{-16}} \right) \quad (2)$$

where  $I$  = the sound intensity in watts per square centimeter.

The reference intensity is  $10^{-16}$  watts per square centimeter, coinciding with the reference pressure of 0.0002 dynes per sq cm or  $2 \times 10^{-4}$  microbar. A microbar is the unit of pressure commonly used in acoustics, one microbar being equal to one dyne per sq cm.

The relationship of the decibel scale to sound pressure and sound intensity is shown in Table 1. A stated sound level in decibels, under standardized procedure, will thus be related to a threshold of 0.0002 dynes per square centimeter, or to a threshold of  $10^{-16}$  watts per sq cm. The standardization upon terminology, procedures and reference levels may be found in Standards<sup>1</sup> published by the *American Standards Association*.

#### APPARATUS FOR MEASURING SOUND

The measurement of sound or noise is conventionally made by means of a sound-level meter<sup>2</sup> consisting of a microphone, an amplifier, a variable attenuator, weighting networks, and an indicating meter which reads directly in decibels. The approved sound-level meter must comply with the specifications of the American Standard for Sound Level Meters for Measurement of Noise and Other Sounds, Z24.3-1944, approved and published by the *American Standards Association*. The meter is designed to indicate sound level above the standard reference level. Three measuring networks are generally provided: (1) flat response, (2) 70 db network and (3) 40 db network. The various networks are approximations of the equal-loudness contours relating intensity and frequency sensation response of the normal human ear.<sup>1</sup> Where there are no specific codes which specify the particular network to be used, general practice would indicate use of the 40 db network for sound levels up to about 55 db, the 70 db network for sound levels from about 55 db to 85 db, and the flat response network for higher levels. When sound level measurements are stated, the specific weighting network used, i.e., 40 db, 70 db or flat response, should always be reported. Complexity in design and calibration, and variations in component parts of the sound level meter impose some deviation from design objective response. Allowable deviations in response or acceptable tolerations recognized in the Standard, vary from  $\pm 2$  db in the 1000 cycle range to  $\pm 5$  db, or more, below 100 cycles and above 1200 cycles per second.

#### GENERAL PROBLEM OF SOUND CONTROL

The problem confronting the air conditioning engineer is to design a system which will operate without increasing the noise level in the conditioned space. It is therefore necessary:

1. To determine the noise level existing without the equipment.
2. To ascertain the noise level which would exist if the equipment were installed without sound control.
3. To provide as a part of the installation, sufficient sound control appliances and treatment to reduce the sound level due to the installation to a sound level at least three decibels, and preferably five decibels, below that found in Item 1.

To accomplish this the engineer should have information of three kinds:

1. A knowledge of the noise levels currently considered acceptable in various rooms, in order that he may have a basis on which to proceed.

TABLE 1. DECIBEL SCALE VS. SOUND PRESSURES AND SOUND INTENSITIES

| DECIBEL LEVEL | PRESSURE<br>dynes per sq cm | INTENSITY<br>watts per sq cm | DECIBEL LEVEL | PRESSURE<br>dynes per sq cm | INTENSITY<br>watts per sq cm |
|---------------|-----------------------------|------------------------------|---------------|-----------------------------|------------------------------|
| 0             | 0.000200                    | $1.000 \times 10^{-16}$      | 40            | 0.0200                      | $1.000 \times 10^{-13}$      |
| 1             | 0.000224                    | $1.259 \times 10^{-16}$      | 50            | 0.0631                      | $1.000 \times 10^{-11}$      |
| 2             | 0.000252                    | $1.585 \times 10^{-16}$      | 60            | 0.200                       | $1.000 \times 10^{-10}$      |
| 3             | 0.000282                    | $2.000 \times 10^{-16}$      | 70            | 0.631                       | $1.000 \times 10^{-8}$       |
| 4             | 0.000317                    | $2.520 \times 10^{-16}$      | 80            | 2.00                        | $1.000 \times 10^{-6}$       |
| 6             | 0.000399                    | $4.000 \times 10^{-16}$      | 90            | 6.31                        | $1.000 \times 10^{-7}$       |
| 8             | 0.000503                    | $6.310 \times 10^{-16}$      | 100           | 20.0                        | $1.000 \times 10^{-6}$       |
| 10            | 0.000631                    | $1.000 \times 10^{-15}$      | 110           | 63.1                        | $1.000 \times 10^{-5}$       |
| 20            | 0.00200                     | $1.000 \times 10^{-14}$      | 120           | 200.0                       | $1.000 \times 10^{-4}$       |
| 30            | 0.00631                     | $1.000 \times 10^{-13}$      |               |                             |                              |

2. A knowledge of the nature and intensity of the noise created by the various parts of the equipment.

3. A knowledge of how, when necessary, to vary and control the noise level between the equipment and the conditioned space.

In addition, the engineer should have sufficient information to predict the levels produced by noises which may be transmitted by the duct system from one conditioned space to another, or from an outside space to the conditioned space. In either case, the designer must know the probable noise level at the point where the noise originates. From this he can compute the attenuation or transmission loss required in order to bring this level down to that required in the conditioned space. If there is likelihood of direct transmission through a duct, the attenuation required may be computed as shown in section Noise Transmitted Through Ducts. If the transmission is through dividing walls, it will be necessary to refer to published data on losses through standard building constructions.<sup>3</sup>

Information concerning the sound levels created by ventilating and air conditioning equipment such as fans, motors, air washers and similar items, has not yet been completely established. However, numerous manufacturers are in a position to supply such data for many of their products. Additional information is being collected. Uniformity in method of test and presentation of sound measurement data for fans, has been standardized in the Sound Measurement Test Code for Centrifugal and Axial Fans, developed by the *National Association of Fan Manufacturers*. The Code prescribes that the sound level shall be measured by the flat response network of the sound-level meter. Readings on the 40 db and 70 db networks may also be taken and reported, but the flat response reading is required to comply with the Code requirement. General practice is to use the *slow* or damped needle reading of the meter. The *fast* or undamped needle of the indicating meter generally reads one to two db lower than the *slow* or damped meter needle. The same Code prescribes a method of determining the sound level reading at each of seven stations, spaced at 5 ft from the outside of the fan housing, and located in a horizontal plane passing through the fan shaft. The sound level of the fan is the average of the seven readings. The level so determined is valuable primarily for comparative purposes rather than absolute values. Of more value to the design engineer would be the sound level at the fan outlet and at the beginning of the distribution duct system.

The technique of sound measurement in a moving air stream of ap-

preciable velocity has not yet been mastered, although it is a subject of current investigation. Development tests indicate that the sound level at the fan outlet is in the order of 10 to 15 db higher than the average value determined by the seven-station traverse around the fan. Where sound treatment of a distribution duct is required, the initial level should be taken as approximately 12 decibels higher than the reported Code rating sound level.

### KINDS OF NOISE

In solving a sound problem, it is desirable to consider, separately, the several means by which noise reaches the room. This avoids to some extent the necessity of knowing the noise level at the source, and instead, places the emphasis on ascertaining the level at the point where the sound enters the room.

The noise introduced into a room or building by ventilating or air conditioning equipment may be divided into two general kinds, depending on how it reaches the room:

1. Noise transmitted through the ducts.
  - a. From equipment such as fans, motors, pumps, sprays, etc.
  - b. From outside, and transmitted through duct walls into air stream.
  - c. From duct wall vibrations, transmitted into air stream.
  - d. From air currents, including eddying noises.
  - e. Cross talk and cross noises between rooms connected by the same duct system.
  - f. Noise produced by the grilles.
2. Noise transmitted through the building construction.
  - a. From machine mountings as vibration.
  - b. From equipment through room wall surfaces.

The next step in the solution of this problem is to present data and discuss methods whereby solutions of the noise problem can be obtained when the allowable room noise level, and the path through which the noise reaches the room, are known.

### NOISE TRANSMITTED BY AIR THROUGH DUCTS

Operation of an air distribution system results in the generation of noise which may be transmitted by air through the ducts to the ventilated or conditioned room. The transmission of this noise may be controlled by the proper application of sound absorptive material within the ducts. The application of the absorptive material is a problem in balancing the room noise level requirements against the intensity of the noise generated. The four steps in the problem are:

1. Determination of acceptable room noise level resulting from the operation of the equipment.
2. Determination of noise level generated by the equipment.
 

Add 5 decibels to the difference between items 1 and 2 to obtain the overall noise reduction required between the equipment and the room. In the discussion which follows, reduction of noise will be referred to as *attenuation* of noise.
3. Determination of the natural attenuation of the duct system.
4. Selection of the proper sound treatment for the duct system.

The difference in decibels between the overall attenuation required and the natural attenuation (3) is the additional sound attenuation to be provided by absorptive materials installed in the duct system, or by special constructions designed to absorb sound. Experience has shown, for example, that where ventilating requirements permit, introduction of an expansion chamber or a change in area in the duct will frequently provide further reduction in low frequency noise.

TABLE 2. TYPICAL SOUND LEVELS\*  
Weighted Network Response

| Rooms                                                        | SOUND LEVEL IN DECIBELS<br>TO BE ANTICIPATED |                |      |
|--------------------------------------------------------------|----------------------------------------------|----------------|------|
|                                                              | Min.                                         | Representative | Max. |
| Sound Film Studios.....                                      | 10                                           | 14             | 20   |
| Radio Broadcasting Studios.....                              | 10                                           | 14             | 20   |
| Planetarium.....                                             | 15                                           | 20             | 25   |
| Residence, Apartments, etc.....                              | 33                                           | 40             | 48   |
| Theaters, Legitimate.....                                    | 25                                           | 30             | 35   |
| Theaters, Motion Picture.....                                | 30                                           | 35             | 40   |
| Auditoriums, Concert Halls, etc.....                         | 25                                           | 30             | 40   |
| Churches.....                                                | 25                                           | 30             | 35   |
| Executive Offices, Acoustically Treated Private Offices..... | 30                                           | 38             | 45   |
| Private Offices, Acoustically Untreated.....                 | 35                                           | 43             | 50   |
| General Offices.....                                         | 50                                           | 60             | 70   |
| Hospitals.....                                               | 25                                           | 40             | 55   |
| Class Rooms.....                                             | 30                                           | 35             | 45   |
| Libraries, Museums, Art Galleries.....                       | 30                                           | 40             | 45   |
| Public Buildings, Post Offices, etc.....                     | 45                                           | 55             | 60   |
| Court Rooms.....                                             | 30                                           | 35             | 45   |
| Small Stores.....                                            | 40                                           | 50             | 60   |
| Upper Floors Department Stores.....                          | 40                                           | 50             | 55   |
| Stores, General, Including Main Floor Dept. Stores.....      | 50                                           | 60             | 70   |
| Hotel Dining Rooms.....                                      | 40                                           | 50             | 60   |
| Restaurants and Cafeterias.....                              | 50                                           | 60             | 70   |
| Banking Rooms.....                                           | 50                                           | 55             | 60   |
| Factories.....                                               | 65                                           | 77             | 90   |
| Office Machine Rooms.....                                    | 60                                           | 70             | 80   |
| VEHICLES                                                     |                                              |                |      |
| Railroad Coach.....                                          | 60 <sup>b</sup>                              | 70             | 80   |
| Pullman Car.....                                             | 55 <sup>b</sup>                              | 65             | 75   |
| Automobile.....                                              | 50                                           | 65             | 80   |
| Vehicular Tunnel.....                                        | 75                                           | 85             | 95   |
| Airplane.....                                                | 75                                           | 80             | 90   |

\* These values are tentative. More detailed measurements by D. F. Seacord, Bell Telephone Laboratories (*Journal Acoustical Society of America*, Vol. 12, pp. 183-187, 1940) give average values and standard deviations of room noise in residences, offices, stores, factories, etc., in large American cities.

<sup>b</sup> For train standing in station, a level of about 45 db is the maximum which can ordinarily be tolerated.

### DESIGN ROOM NOISE LEVEL

Measurements of sound levels in various types of rooms and locations have been observed by numerous investigators. However, close agreement upon these values has not been realized, and more detailed measurements are needed to accurately establish the normal sound levels in occupied spaces and enclosures subject to sound analysis and control. Typical sound levels, of a tentative nature, based upon earlier determinations, are listed in Table 2. The levels listed are weighted levels by the 40 db or 70 db network, depending upon the range of level existing. Levels taken upon the flat response network may be from 5 db to 20 db higher, as governed by the predominating frequencies which may influence the weighting level.

Table 3 lists sound levels based upon more recent surveys than Table 2, and upon the basis of the flat response network. The flat response network offers a more logical correlation of space sound level to fan sound level which, under present practice, is reported upon basis of the *flat response* reading.

The values listed were determined with the air conditioning or ventila-

TABLE 3. AVERAGE SOUND CONDITIONS IN VARIOUS TYPES OF ROOMS AND BUILDINGS\*

Flat Response Network

| TYPE OF ROOM OR BUILDING                                                                                                                                                                                                                             | DECIBELS                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| Broadcasting studios.....                                                                                                                                                                                                                            | 20-30<br>(very quiet)       |
| Residences, churches, libraries, apartments, auditoriums, executive offices, class rooms.....                                                                                                                                                        | 40-55<br>(quiet)            |
| Hospitals, court rooms, quiet offices, show rooms, small retail stores, tea rooms, hotel dining rooms, foyers, upper floors of department stores, recreation rooms.....                                                                              | 45-60<br>(moderately quiet) |
| Banking rooms, beauty salons, barber shops, general offices, restaurants, main floors of department stores, cocktail lounges, dairy bars, tap rooms, billiard halls.....                                                                             | 55-70<br>(average)          |
| Gymnasiums, transportation waiting rooms, drug stores, grocery stores, cafeterias, super markets, recreation halls, post offices, swimming pools, locker rooms, garages, service stations, dance halls, laundries, dry cleaners, bowling alleys..... | 65-80<br>(moderately noisy) |
| Warehouses, office machinery, field houses, hangars, skating rinks, loading platforms, packing plants, factories, machine shops, foundries, forge shops, round houses, steel mills.....                                                              | 75-100<br>(noisy)           |

\* Values based on recent surveys.

tion equipment out of operation, unless such equipment presented no acoustical addition to normal conditions. The windows and doors were closed to simulate the conditions of normal occupancy. In Table 2, minimum, representative and maximum levels are given for each type of space, classified as shown in the following paragraph. In Table 3, the minimum to maximum range is shown, with the same general classification.

**Minimum sound level** refers to spaces within well-constructed buildings, typified by double windows, carpeted floors, and acoustically-treated walls and ceilings. In such spaces heavy upholstered furniture is also usually used.

**Representative sound level** refers to spaces within average construction with average furnishings, and exposed to external sounds typical of the locality in which the space is usually found.

**Maximum sound level** refers to (1) any space within inexpensive construction where bare furnishings are used, and where noise is normally not an important factor, or (2) spaces in close proximity to very intense street traffic or industrial noise.

In general, if the sound level in the space resulting from the operation of the air conditioning equipment only, is equivalent to, or less than, the typical level (from Tables 2 or 3 or, better still, determined by actual site measurement) the installation will prove satisfactory. If the space level and the equipment level are equal and heard together, the resultant level will be 3 db higher than either space or equipment level alone. However, to minimize possible annoyance due to introduction of single or distinctive frequency components from the equipment, it is desirable to design for an equipment sound level of at least 5 db below the typical space level.

#### NOISE GENERATED BY FANS

Noise generated by fan wheels may be divided into two classifications, rotational noise and vortex noise. The rotational noise may be described

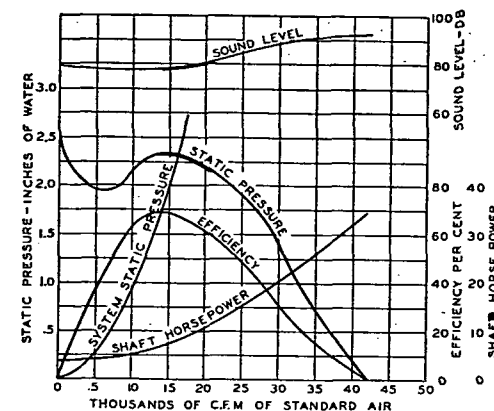


FIG. 1. SOUND LEVEL CHARACTERISTICS OF TYPICAL CENTRIFUGAL, MULTI-BLADE VENTILATING FAN

as that due to the thrust and torque applied to the air. Vortex noise is that due to the shedding of vortices from the blade, and is dependent on the angle of attack, velocity, air turbulence, and blade shape. Vortex noise is due to pressure variations on the blade as a result of variations of air circulation. Given the noise level at the outlet or inlet of one type of fan construction under specific conditions of size, tip speed, and total pressure, the noise levels at other values of tip speed, total pressure, and size may be approximated by the relationships:

1. For constant size and point of rating, the noise level of a fan will increase with increasing speed.

$$db \text{ (change)} = 50 \log_{10} \left( \frac{RPM_2}{RPM_1} \right) \quad (3)$$

2. For constant pressure and tip speed, the noise level of a given type of fan will increase with increasing fan size.

$$db \text{ (change)} = 20 \log_{10} \left( \frac{Size_2}{Size_1} \right) \quad (4)$$

Fan size refers to wheel diameter, housing height or some dimension that is directly proportional to linear units. Fan sizes based on arbitrary systems or systems of preferred numbers, have no significance.

The noise of a given fan is not constant at constant speed if the air delivery changes due to change of resistance. In general, a backward curved blade fan is lowest in noise at or near the point of maximum efficiency; a forward curved blade fan at or between the point of maximum efficiency and shut-off; an axial flow fan at or between the point of maximum efficiency and free delivery. The noise level of a double width fan may be taken as 3 db higher than for a similar single width fan operating under the same conditions of speed and pressure.

The sound level characteristic curve of a typical ventilating fan of the centrifugal multi-blade type is shown in Fig. 1. The accented portion of the curves denotes the range of minimum sound emission. The selection and application of the fan should be made within such good application range where quietness of operation is of major consideration. The various types of fans available possess individual sound level characteristics throughout their range of possible operation. Recourse to standard

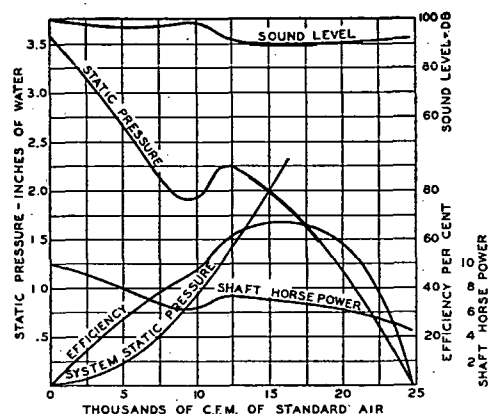


FIG. 2. SOUND LEVEL CHARACTERISTICS OF TYPICAL VANEAXIAL FAN

test rating information should be made to arrive at the sound emission of a particular type.

In general, that size of fan which is so selected as to operate at or near peak static efficiency, will also provide the lowest sound level attainable with the particular type and design of fan.

The characteristic trend of the sound level curve of a typical vaneaxial fan, adaptable to moderate pressure ventilation requirements, is shown in Fig. 2. The sound level of a particular fan is primarily governed by the operating speed required to produce a desired delivery against the system static pressure. Fig. 3 illustrates the variation of fan sound level in decibels with operating speed, the fan operating in connection with a conventional fixed system. The influence of high static pressures is evident in increased operating speed and higher sound level.

The range of sound levels to be experienced in fan application is widespread due to volumetric and pressure requirements which extend over a broad field. Fig. 4 illustrates the general scope of sound levels of centrifugal ventilating fans over a wide range of volumetric capacities and static

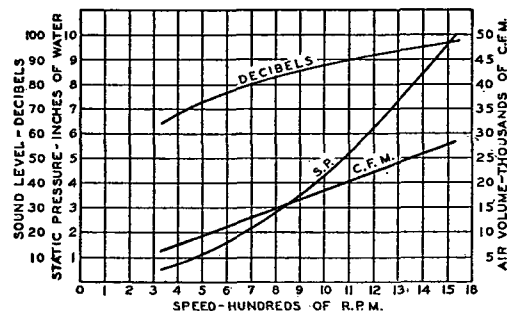


FIG. 3. RELATION OF SOUND LEVEL TO OPERATING SPEED OF A CENTRIFUGAL VENTILATING FAN

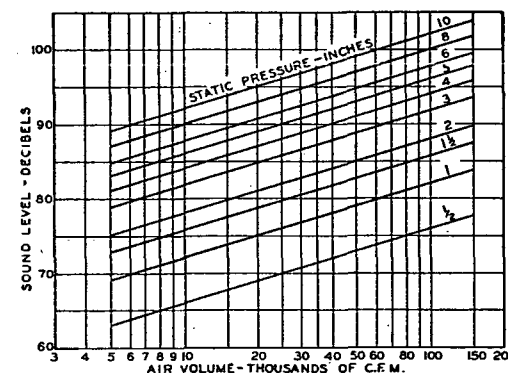


FIG. 4. TYPICAL SOUND LEVELS AT POINT OF MINIMUM SOUND EMISSION FOR CENTRIFUGAL VENTILATING FAN

pressures. The sound levels are based upon a general average of the sound emission that can be anticipated from the several types of fans adaptable to ventilating and air conditioning duties. The sound levels are typical of the centrifugal fans as a class, and specific types may exhibit sensible departure from the charted values. Exact application should be based upon applicable test data derived from the particular equipment under consideration.

#### NATURAL ATTENUATION OF DUCT SYSTEM

**Straight Sheet Metal Ducts.** The attenuation of sound in straight sheet metal ducts is a function of the length, shape, and size of the duct.<sup>4</sup> Attenuation values are given in Table 4. In general this attenuation is so negligible, except for long runs, that it may be disregarded for all practical purposes.

**Elbows and Transformations.** Due to reflective interference, attenuation will take place at elbows and transformations. The magnitude of the attenuation will depend on the size and abruptness of the elbow or transformation as shown in Table 5.

When the area of a duct increases abruptly, an attenuation of noise level takes place in the duct. In duct design practice the total area of the branch ducts is greater than the supply duct. Similarly with outlets, the area of the outlet, plus the area of the duct after the outlet is greater than the duct area before the outlet. Therefore in an outlet run, attenuation occurs in the duct as it passes each outlet. Table 6 gives the db reduction for various ratios of total branch duct and outlet area to supply duct area.

**Grilles to Room.** The large abrupt change in area between the grilles and the surfaces within a room results in an appreciable noise attenuation.

TABLE 4. ATTENUATION IN STRAIGHT SHEET METAL DUCT RUNS

| DUCT   | SIZE, IN. | ATTENUATION PER FT. db |
|--------|-----------|------------------------|
| Small  | 6 x 6     | 0.10                   |
| Medium | 24 x 24   | 0.05                   |
| Large  | 72 x 72   | 0.01                   |

TABLE 5. ATTENUATION OF ELBOWS<sup>a</sup>

| ELBOW           | SIZE IN. <sup>b</sup> | ATTENUATION<br>PER ELBOW, db |
|-----------------|-----------------------|------------------------------|
| Very small..... | 2 wide                | 3                            |
| Small.....      | 3 to 15               | 2                            |
| Medium.....     | 15 to 36              | 1.5                          |
| Large.....      | 36 plus               | 1                            |

<sup>a</sup> The attenuation in vanned elbows should be considered the same as in elbows having the same dimensions as the radius of curvature of the vanes. If the vanes are lined for the purpose of damping any vibrations in them, one third may be added to the attenuation values listed.

<sup>b</sup> These attenuation values are based on elbows having a center line radius 1.5 to 2 times the diameter or width of the duct. The attenuation will be greater if the ratio is less than 1.5 and less when the ratio is greater than 2.

This attenuation is a function of the total grille area (supply and return) and the total sound absorption of the room in *sabins*. (The sound absorption of a room in *sabins* is the summation of the products of each surface of the room measured in square feet multiplied by its corresponding absorption coefficient. The *sabin* is a unit of sound absorption equivalent to the absorption of one square foot of a totally sound-absorbent surface). The attenuation is given in Equation 5 as:

$$db \left( \begin{array}{l} \text{Attenuation between} \\ \text{grilles and room} \end{array} \right) = 10 \log_{10} \frac{\text{Total Room Absorption in Sabins}}{\text{Total Grille Area}} \quad (5)$$

Values in Table 7 approximate the attenuation for various rates of air change, and general types of room surfaces.

#### DUCT SOUND ABSORBERS

The difference between the required sound attenuation and the natural attenuation must be supplied by the proper sound treatment of the ducts.

#### Selection of the Absorptive Material

When a sound wave impinges on the surface of a porous material, a vibrating motion is set up within the small pores of the material by the alternating sound waves. As the ratio of the cross-sectional area of the pores to their interior surface is small, the resistance to the movement of air in the pores is large. This viscous resistance within the pores of the material, converts a portion of the sound energy into heat. The decimal fraction representing the absorbed portion of the incident sound wave is called the absorption coefficient. Considerable absorption may also result, particularly in the low frequency range, from the flexural vibrations of the duct. In the selection and application of the absorptive material, the following points should be considered:

TABLE 6. ATTENUATION AT DUCT BRANCHES OR OUTLETS

| $\frac{\text{BRANCH DUCT + OUTLET AREA}}{\text{SUPPLY DUCT AREA}}$ OR $\frac{\text{SUM OF BRANCH AREAS}}{\text{SUPPLY DUCT AREA}}$ | ATTENUATION<br>PER<br>TRANSFORMATION, db |
|------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| 1.00                                                                                                                               | 0.0                                      |
| 1.20                                                                                                                               | 0.8                                      |
| 1.35                                                                                                                               | 1.3                                      |
| 1.50                                                                                                                               | 1.8                                      |
| 1.75                                                                                                                               | 2.5                                      |
| 2.00                                                                                                                               | 3.0                                      |

1. For the absorption of the low frequencies below 500 cycles per second the material should be at least 1 to 2 in. thick. Thin materials, particularly when mounted on hard solid surfaces, will absorb the high frequencies and reflect the low.

2. In order to provide as much low frequency noise absorption as possible by means of flexural vibration, it is desirable to fasten the absorptive panels discontinuously. This result may be attained to some extent by spot cementing, but better results are obtained when it is possible to fasten the absorptive panels to furring strips, leaving an air space behind. However, the exact resonance characteristics of the panels, and thus their absorption, are so unpredictable that flexural vibration cannot be relied upon for a specific value of attenuation.

Requirements for a good sound absorption material are: (1) high absorption at low frequencies;<sup>5</sup> (2) adequate strength to avoid breakage; (3) fire resistance and compliance with national and local code requirements; (4) low moisture absorption; (5) freedom from attack by bacteria

TABLE 7. APPROXIMATE ATTENUATION BETWEEN GRILLES AND ROOM

| OUTLET<br>VELOCITY<br>FFM | AIR CHANGE<br>MIN. | LIVE ROOM <sup>b</sup><br>$\alpha = 0.05$<br>db | MEDIUM<br>ROOM <sup>c</sup><br>$\alpha = 0.15$<br>db | DEAD<br>ROOM <sup>d</sup><br>$\alpha = 0.25$<br>db |
|---------------------------|--------------------|-------------------------------------------------|------------------------------------------------------|----------------------------------------------------|
| 500                       | 5                  | 11                                              | 16                                                   | 18                                                 |
|                           | 10                 | 14                                              | 19                                                   | 21                                                 |
|                           | 15                 | 16                                              | 21                                                   | 23                                                 |
|                           | 20                 | 17                                              | 22                                                   | 24                                                 |
| 750                       | 5                  | 13                                              | 18                                                   | 20                                                 |
|                           | 10                 | 16                                              | 21                                                   | 23                                                 |
|                           | 15                 | 18                                              | 23                                                   | 25                                                 |
|                           | 20                 | 19                                              | 24                                                   | 26                                                 |
| 1000                      | 5                  | 14                                              | 19                                                   | 21                                                 |
|                           | 10                 | 17                                              | 22                                                   | 24                                                 |
|                           | 15                 | 19                                              | 24                                                   | 26                                                 |
|                           | 20                 | 20                                              | 25                                                   | 28                                                 |
| 1250                      | 5                  | 15                                              | 20                                                   | 22                                                 |
|                           | 10                 | 18                                              | 23                                                   | 25                                                 |
|                           | 15                 | 20                                              | 25                                                   | 27                                                 |
|                           | 20                 | 21                                              | 26                                                   | 28                                                 |

<sup>a</sup> Average absorption coefficient for the room.

<sup>b</sup> Live room-average absorption coefficient 0.05. Bare wood or concrete floor—hard plaster walls and ceiling—minimum of furniture.

<sup>c</sup> Medium room-average absorption coefficient 0.15. Carpeted floor, upholstered furniture, hard plaster walls and ceiling or bare room with acoustically treated ceiling.

<sup>d</sup> Dead room-average absorption coefficient 0.25. Heavy carpeted floor. Walls and ceiling acoustically treated. Upholstered furniture.

and algae; (6) low surface coefficient of friction; (7) particles should not fray off at the higher design velocities; and (8) freedom from odor when either dry or wet.

With every application, the use of sound absorptive material should be considered in the dual function of insulation and sound absorption. It has been shown theoretically<sup>6</sup> that the reduction (in decibels per linear foot) of sound transmitted through a duct lined with sound absorbing material, is related in a rather complicated manner to the size and shape of the duct, to the frequency of the sound, and to the sound absorbing characteristics of the lining. Experimental evidence likewise indicates that there is no simple formula involving the variables which will apply accurately to all cases. However, it may be stated generally that the attenuation in decibels at a given frequency is directly proportional to the length of



lined duct. It decreases as the cross-sectional area increases, and increases as the aspect ratio is increased.

The noise reduction varies to a considerable extent with the frequency of the sound. In calculating noise reduction, consideration should be given both to the comparative efficiency of the duct lining material at different frequencies, and to the frequency distribution of the noise to be quieted. In the case of fan noise, it is recommended that calculations be based upon the predominant frequency component in the fan sound level spectrum. Normally, most of the sound energy is in the region of this frequency, which generally corresponds to the blade frequency and is equal to  $\text{rpm} \times \text{no. of blades} \div 60$ .

Where the noise reduction is calculated upon the basis of the fundamental frequency component, the treatment indicated as required should be ample for the harmonics which are more easily absorbed than the fundamental. In quieting noise due to air turbulence and eddy currents where high frequencies predominate, the frequency 1024 should be used.

Since ventilating system noise contains many frequencies, an exception should be noted to the previous statement that attenuation in decibels is directly proportional to length of duct. Most sound absorbent materials are more efficient at high frequencies than at low frequencies. In consequence, the attenuation in the first five or ten feet of lined duct will be greater because the high frequencies are being absorbed. Thereafter, since low frequencies will be predominant, the overall noise attenuation per foot will gradually be less.

#### Duct Lining

By far the most commonly used method of obtaining sound absorption in ventilating systems is to line the duct with absorbing material. It is usually more convenient to line all four sides of the duct, but a lining on one side over a longer length of the duct will, in general, give the same effect for the same area of applied acoustical material. Subject to certain restrictions, the attenuation of a fully lined duct to single-frequency sounds may be expressed by the approximate Equation 6:<sup>7</sup>

$$R = 12.6L \frac{P}{A} a^{1.4} \quad (6)$$

where

$R$  = attenuation, decibels.

$L$  = length of lined duct, feet.

$P$  = perimeter of duct, inches.

$A$  = cross-sectional area of duct, square inches.

$a$  = absorption coefficient of lining.

This formula was empirically developed for a set of duct sizes ranging from 9 x 9 in. to 18 x 18 in., for cross-sectional dimension ratios of 1:1 to 2:1, for frequencies between 256 and 2048 cycles, and for absorption coefficients between 0.20 and 0.80. The duct lining material used was 1 in. rock wool sheet. In Table 8 are listed the absorption coefficients of a material of this type in one-half and one inch thickness.

It is also possible to calculate the absorption by a very complicated mathematical theory.<sup>8,9</sup> Such calculations are in substantial agreement with Equation 6. This equation may be in error when applied to other

TABLE 8. ATTENUATION DATA FOR TYPICAL 1 IN. AND  $\frac{1}{2}$  IN. THICK DUCT LINING BOARD

| FREQUENCY<br>cycles per<br>second | 1-INCH THICKNESS                 |           |                     | $\frac{1}{2}$ -INCH THICKNESS    |           |                     |
|-----------------------------------|----------------------------------|-----------|---------------------|----------------------------------|-----------|---------------------|
|                                   | Absorption<br>Coefficient<br>$a$ | $a^{1.4}$ | Attenuation<br>$db$ | Absorption<br>Coefficient<br>$a$ | $a^{1.4}$ | Attenuation<br>$db$ |
| 128                               | 0.29                             | 0.17      | $2.1 L \frac{P}{A}$ | 0.13                             | 0.06      | $0.8 L \frac{P}{A}$ |
| 256                               | 0.51                             | 0.39      | $4.9 L \frac{P}{A}$ | 0.25                             | 0.15      | $1.9 L \frac{P}{A}$ |
| 512                               | 0.70                             | 0.60      | $7.6 L \frac{P}{A}$ | 0.40                             | 0.28      | $3.5 L \frac{P}{A}$ |
| 1024                              | 0.80                             | 0.73      | $9.2 L \frac{P}{A}$ | 0.72                             | 0.63      | $7.9 L \frac{P}{A}$ |
| 2048                              | 0.79                             | 0.72      | $9.1 L \frac{P}{A}$ | 0.78                             | 0.71      | $8.9 L \frac{P}{A}$ |

types of duct lining and to duct sizes and shapes greater than those specified. An empirically-derived chart<sup>10</sup> representing the average experimental data on a number of different types of materials, is shown in Fig. 5. Since individual materials vary, the curves of Fig. 5 are given only as representing the best available averages for duct sizes of cross-sections from 6 x 6 in. to 48 x 48 in. The dotted lines are plotted from Equation 6 and show that the slope is materially different from the average values.

#### Rectangular Cells (Plate or Cell Absorbers)

If the length of duct from the main duct to the grille is shorter than the length of lining indicated by Equation 6, the duct may be subdivided into smaller ducts as shown in Fig. 6, or it can also be even more subdivided by an egg-crate construction. In such a construction in which all the subdivided ducts are the same size, sound will be equally absorbed down each channel. It is, therefore, only necessary to calculate the sound attenuation of an individual channel. For this, Equation 6 is adequate.

When the number of splitter plates or cell partitions is large, the percentage free area of the gross duct size may be materially reduced. This leads to a further sound attenuation. Values of the attenuation possible, due to this cause, are given in Table 9.

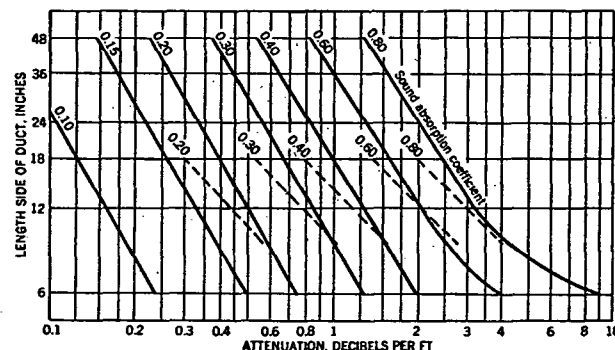


FIG. 5. SOUND ATTENUATION FOR VARIOUS ABSORBING DUCT LINERS

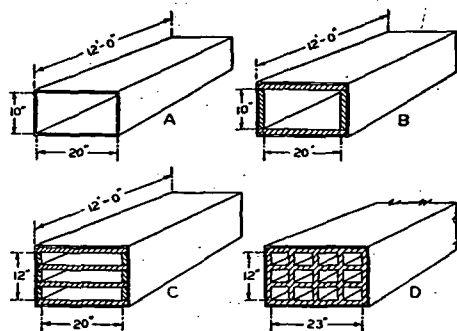


FIG. 6. ACOUSTIC TREATMENT OF DUCTS

- A. Unlined metal duct.  
 B. Absorption lined duct (Case 1).  
 C. Splitter plate type absorber (Case 2). (Channels 20 in. x 3.33 in. inside).  
 D. Cell type absorber. (Cells 5 in. x 3.33 in. inside).  
 1 in. thick absorption material in all cases.

### Sample Calculations for Duct Treatment

**Example 1:** An air conditioning installation is to be installed in a small theater. Determine the necessary sound treatment for the air distribution system to provide a satisfactory noise level in the theater utilizing these conditions:

|                                                                                           |         |
|-------------------------------------------------------------------------------------------|---------|
| Fan tip speed 4000 fpm, total pressure 1.25 in. ....                                      | 77 db   |
| Acceptable room noise level (Table 2) .....                                               | 40 db   |
| Required attenuation .....                                                                | 37 db   |
| <b>Solution:</b> Natural attenuation of supply duct.                                      |         |
| Sheet metal duct 50 ft long 48 in. x 36 in. (Table 4) 50 x 0.01 .....                     | 0.5 db  |
| Elbows, two size 48 in. x 36 in. (Table 5) 2 x 1 .....                                    | 2.0 db  |
| Attenuation grilles to theater air change 10 min (Table 7) outlet velocity 1000 fpm ..... | 22.0 db |
| Total natural attenuation .....                                                           | 24.5 db |

Difference between required and natural attenuation, 37 minus 24.5, is 12.5 db. This attenuation must be supplied by sound treatment in the duct, either in the form of duct wall lining or rectangular cells of the plate or cell absorber arrangement.

A similar analysis of the return duct system shows that 15 db attenuation is to be furnished by absorptive material. An inspection of the installation shows that the lining of the plenum on the suction side of the fan would prove the most economical, where it would secure the dual function of heat insulation and sound absorption.

**Example 2:** A 10 x 20 in. duct is connected to a private office space in a quiet location. Determine the length of lining necessary to attenuate average fan noise satisfactorily, using a lining material of a type to which Equation 6 applies, and having an absorption coefficient of 0.40 at 256 cycles. Assume that the duct is only 12 ft long as shown in Fig. 6, and that a 30 db reduction is required in this length.

**Solution:**

**Case 1.** (No splitters, duct lining only). From Equation 6,

$$R = 12.6 \times 12 \times \frac{60}{200} \times 0.40^{1.4} = 13 \text{ db.}$$

TABLE 9. END REFLECTION OF PLATE OR CELL ABSORBERS

| Percentage free area of absorber ..... | 50 | 40 | 30 | 25 | 20 |
|----------------------------------------|----|----|----|----|----|
| Attenuation db .....                   | 1  | 2  | 4  | 5  | 6  |

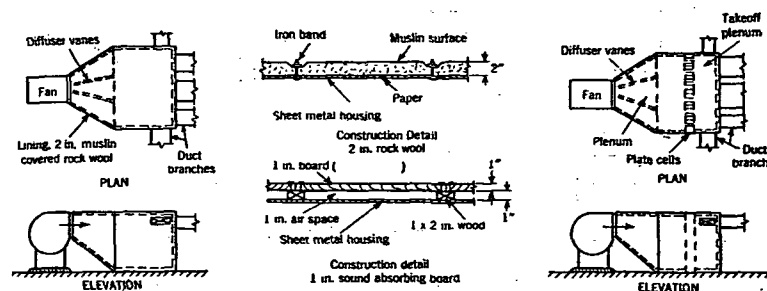


FIG. 7. ABSORPTION PLENUMS WITH AND WITHOUT SOUND CELLS

**Case 2.** (Two 1 in. splitter plates, 3 channels each 20 in. x 1/2 in.). From Equation 6,

$$R = 12.6 \times 12 \times \frac{46.7}{66.7} \times 0.40^{1.4} = 29 \text{ db.}$$

Additional attenuation may be obtained by using additional splitter plates or use of egg-crate arrangement of absorbing material and application of Equation 6.

### Plenum Absorption

In systems where individual ducts are directed to a number of rooms, and sound treatment is required in every duct, a sound absorption plenum on the fan discharge as shown in Fig. 7 will often prove the most economical arrangement. The absorption in the plenum may be approximated by Equation 7.

$$db \text{ (Attenuation)} = 10 \log_{10} \frac{\text{Plenum Absorption in Sabins}}{\text{Area Fan Discharge}} \quad (7)$$

The area of the plenum should be at least ten times as great as the fan discharge area. The plenum should be lined with 2 in. of muslin covered rock wool blanket, or 1 in. sound absorbing board preferably nailed to wood strips on the inside of the plenum. With such a lining the plenum is particularly effective in reducing low frequency fan noise. The absorption of the plenum in sabins is the sum of the products of each interior area of the plenum measured in square feet multiplied by its corresponding absorption coefficient.

### Outlet Sound Absorbers

Outlet sound absorbers are rectangular or plate cells installed directly behind an outlet or they may be the lining of a pan or plaque outlet. They are particularly effective in the elimination of high frequency whistles which are generated by air flow in the ducts. They are also employed in large systems with long runs where only a few outlets near the fan require treatment. Frequently outlet cells are the only means of correcting existing noisy installations, as the duct sections directly behind the outlets may be the only sections accessible for treatment. (See Fig. 8).

### AIR SUPPLY OPENING NOISES

When air is introduced into a room through a grille or register at a constant velocity, sound energy is being introduced into the enclosure at

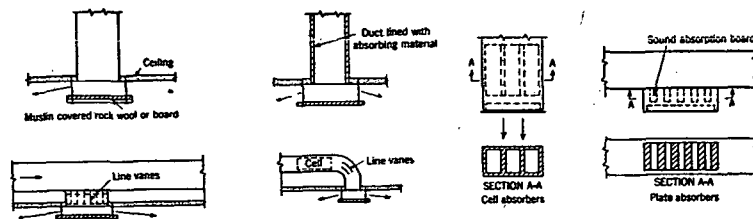


FIG. 8. OUTLET CELLS FOR PAN OUTLETS OR GRILLES

a constant rate.<sup>11</sup> Due to partial reflection at the boundaries of the enclosure, the intensity of sound at any point in the space builds up to some maximum value. In a large room at a point remote from the source of sound (the supply opening) the intensity can be shown to be substantially proportional to the rate at which sound energy is generated, and inversely proportional to the number of sound absorption units (sabins) in the room. It would thus appear that doubling the sound absorption of the room would halve the intensity and result in a noise level decrease of 3 db.

Grille noise is similar in character to fan vortex noise. Knowing the noise level at the face of a grille for a given grille blade setting, the noise will vary as given in Equation 8 where  $V$  is the velocity of the air through the grille.

$$db \text{ (change)} = 50 \log_{10} \left( \frac{V_2}{V_1} \right) \quad (8)$$

For a change in blade setting Equation 9 applies, and in this case the total pressure is measured directly behind the face of the grille. For a typical air conditioning grille the noise level at the grille face may be approximately 48 db with a total pressure behind the grille of 0.1 in.

$$db \text{ (change)} = 25 \log_{10} \left[ \frac{(\text{Total Pressure})_2}{(\text{Total Pressure})_1} \right] \quad (9)$$

The resultant room noise level can be approximated by Equation 10.

$$\text{Room Level} = \left[ \text{Noise Level at Face of Grille} \right] - 10 \log_{10} \frac{\text{Total Room Absorption in Sabins}}{\text{Total Grille Area}} \quad (10)$$

#### Grille Selection

In practice the allowable total sound and the required air flow are usually known, and it is desired to determine the maximum allowable velocity. In comparing sound ratings of various grilles several factors must be known if the information is to be properly applied:

1. The threshold intensity on which the decibel ratings are based.
2. The distance from the grille at which data were taken.
3. If stated as sound level versus velocity for a given grille, the *core area* (not nominal area) must be known.
4. The sound absorbing characteristics of the test room.
5. Whether or not corrected for test room sound level; if not, the room level (without grille noise) must be known.
6. Methods used for recording data. (Characteristics of sound meter).

Since total sound and air flow are both functions of velocity and area, the solution of the problem implies a trial and error method. It has been

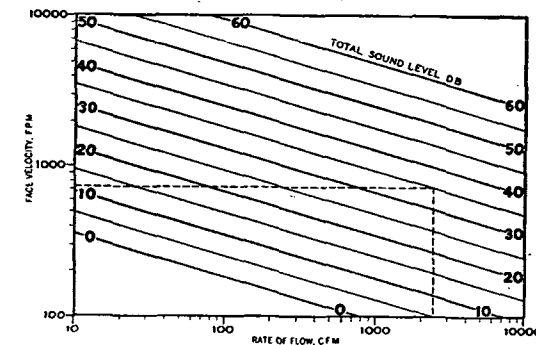


FIG. 9. AIR FLOW AND SOUND LEVEL CHART

found possible to present these data with sufficient practical accuracy as a family of uniform curves, as illustrated in Fig. 9, which are based on these assumptions:

1. Threshold intensity =  $10^{-12}$  watts per square centimeter.<sup>1</sup>
2. Microphone location 5 ft from lower edge of supply opening on a line downward at 45 deg, and in a plane bisecting the supply opening perpendicularly.
3. Where data are given as sound level versus velocity, the rating is per square foot of core area.
4. The room is assumed to have 100 sabins absorption.
5. Plotted data are sound levels of *supply openings only*, correction having been made for test room level.
6. Data taken with a direct reading sound-level meter with frequency weighing network intended to approximate the response of the human ear.

If the published ratings are in terms of decibels per square foot, correction must be made for area to secure the total sound level of supply openings of more or less than one square foot area from Equation 11.

$$\text{Decibel Addition} = 10 \log_{10} A \quad (11)$$

where

$A$  = core, square feet.

With Fig. 9 it is possible to find directly the velocity in feet per minute which will give a predetermined total sound at a predetermined rate of flow expressed in cubic feet per minute. The values used are arbitrarily chosen for the purpose of discussion, and do not necessarily represent data referring to any particular design of air supply opening. A correction chart is shown in Fig. 10 for a room having a sound absorption other than 100 sabins.

**Example 3:** Determine the core area (see Chapter 31) of an air supply grille which will maintain a noise level of not more than 40 db in a room having 100 sabins of sound absorption, if an air volume of 2400 cfm is required to maintain the proper air conditioning.

**Solution:** Assuming a grille noise rating of at least 5 db below the noise level of the room, Fig. 9 shows that the limiting grille velocity for a total sound level of 35 db is about 725 fpm, and the core area becomes fixed at  $2400 \div 725$  or 3.31 sq ft.

If the room absorption had been greater, the previously selected velocity of 725 fpm would be safe, since the sound level reduces. If the room absorption had been 200 sabins, a correction of plus 1.3 should be made by reference to Fig. 10, and the

permissible velocity becomes that corresponding to a total sound level of 36.3, or approximately 800 fpm.

If the room had been highly reflective with an absorption of less than 100, the correction would be much more important. For instance, for a room of 35 sabins, a correction of minus 3 db should be made, and the maximum velocity corresponding to the 32 db total sound level would be approximately 600 fpm.

Where more than one supply opening must be considered, the problem is more complicated. If a similar supply opening is added in a far corner of a highly absorbent room, the change in noise level at the 5 ft station at the first supply opening is small; however, if the room is small, or highly reverberant or both, the intensity at the 5 ft station may be almost doubled and the noise level increased nearly 3 db thereby. The simplest method of handling this problem is to treat the room as though all the air were being supplied by one supply opening. Thus, if two outlets, each supplying 1000 cfm are used, the value 2000 cfm should be used with Fig. 9. Although this method may place an unwarranted limit on velocity when used in a large room, it is seldom that such a room has a noise level low enough to justify a more complicated, though more exact procedure.

In general, return grilles are selected for velocities about half the supply velocity, and when this is done, they may be neglected in sound computations. However, if supply and return grilles are the same size, resulting in the same face velocity, they must be treated as two supply openings. That is, if 1000 cfm are supplied and exhausted through grilles of the same area, 2000 cfm must be used in the solution with Fig. 9.

#### CROSS TRANSMISSION BETWEEN ROOMS

Ducts serving more than one room permit cross talk between the rooms and should be lined with acoustical material. Where the rooms are close together and the ducts short, the ducts should be sub-divided to provide ample acoustical treatment. Lagging material similar in character to acoustical board, when placed on the outside of ducts, serves to prevent noise, originating outside the ducts, being carried inside the ducts and into the air stream.

A case where outside lagging is desirable occurs when ducts originate at the fan in the equipment room and pass through this room on the way to the room being conditioned or ventilated. Unless the ducts are lined, some of the mechanical noise from air in the equipment room may be transmitted through the wall of the duct into the air stream, and thereby carried into the room. In such cases, that portion of the duct which is exposed to the sounds in the equipment room should be lagged with material, such as cork, pipe covering or other sound damping material, to prevent the sound from entering the duct at this point. Numerical data are not available to permit a simple and practical calculating procedure to determine thickness of covering which should be used for this purpose.

Laboratory measurements have shown that the loss through a sheet of No. 22 gage metal is 24 db. When a sheet of rock wool insulation 1 in. thick and weighing 1.4 lb per square foot is added to this, the insulation value is increased to 29 db. In general, however, adding a layer of insulation or pipe covering does not materially increase the sound insulation value unless the material is dense, or unless it is surfaced with another sound impervious layer such as metal or board. Standard reference books should be consulted for sound insulating properties of various materials. Inside lining material, used in the case previously mentioned, would serve as an absorber of the sound transmitted through the duct walls, and thus act as a

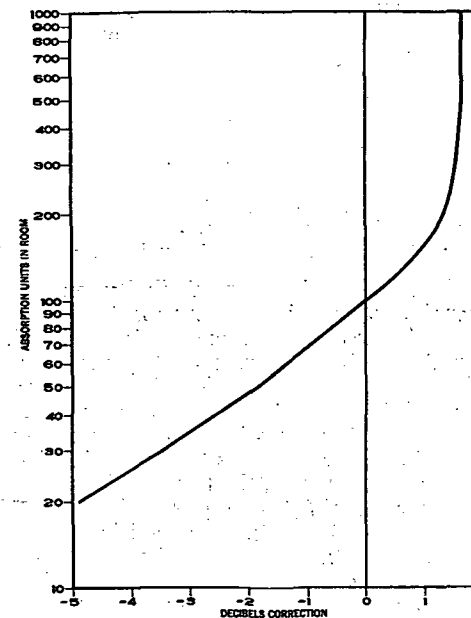


FIG. 10. ROOM ABSORPTION CORRECTION CHART

means of preventing the transfer of noise into the air stream. Inside lining may also be used in ducts to absorb noise which reaches the air stream from equipment such as fans, sprays and coils; noise due to eddying currents set up by elbows, dampers and similar obstructions; and noise transmitted from room to room where there is a common duct system.

#### CONTROLLING VIBRATION FROM MACHINE MOUNTINGS

It is impossible to select equipment which will operate without producing some mechanical noise and, since the equipment must be mounted in a building, it is probable that a part of this noise will be transmitted to the building to such a degree as to make noisy conditions in the rooms which are to be air conditioned.

Much of this noise may be transmitted by the duct if it is rigidly connected to the fan outlet. It is common practice to make the connection between the fan and the duct with a canvas sleeve which effectively restricts noise at this point. Noise may also enter the building through the mounting of the motor and the fan. Flexible mountings should be provided in all installations, but these mountings must be carefully designed so that they will actually reduce the energy transmitted between the machinery and the supporting floor. If a flexible material is used, it is desirable to investigate the installation so that it is not short-circuited by through bolts which are improperly insulated, and by electrical conduit which is not properly broken and is attached both to the equipment and to the building. The flexible mounting, if improperly engineered, may actually increase the energy transmitted between the equipment and the supporting floor.

In the proper isolation of vibration, which is usually in the lower range

of frequencies and does not include the *airborne* vibrations known as sound, there is one basic formula which is important in the solution of the problem. It is the formula of transmissibility as governed by the equation:

$$T = \frac{1}{\left(\frac{f}{f_n}\right)^2 - 1} \quad (12)$$

where  $T$  = transmissibility of the support.  
 $f$  = frequency of the vibratory force.  
 $f_n$  = natural frequency of the machine unit on its support (damping = 0).

Equation 12 shows that the transmissibility approaches unity for disturbing frequencies considerably lower than the natural frequency of the mounting. As the disturbing frequency is increased, the transmissibility is also increased until at the resonant frequency, where  $f = f_n$  the transmissibility becomes infinite. This is not true in practice because all materials have some internal damping effect. However, operating at or very close to the resonant frequency is always serious as forces and stresses may be multiplied 10 to 100 times. As the disturbing frequency becomes greater than the natural frequency, the transmissibility becomes a smaller quantity, and at the value of  $f/f_n = \sqrt{2}$  it again has the value of unity. Beyond this point true isolation is first accomplished. At a ratio of 3 to 1 for  $f$  to  $f_n$  the isolation is effective enough for practical application, and experience and economical design have shown that a ratio of 5 to 1 is good. For high speeds, higher ratios for  $f$  to  $f_n$  are easily attained and give better results for effective vibration control, but for the lower speeds as experienced with compressor work the higher ratios become uneconomical.

For a given installation, the speed of the compressor is fixed by the specifications; therefore the value of  $f$  is fixed. That leaves only  $f_n$  to be determined, and that is accomplished by the choice of mounting material and design for the support of the machine. It is well to keep in mind that when trying to isolate vibration, no attempt should be made to isolate the driving and driven piece of equipment separately. The two should be mounted on a rigid frame, and then the entire assembly isolated according to the rules presented in this chapter.

The value of  $f_n$  can be controlled by the flexibility of the machine support, and when the deflection of the machine support is proportional to the load applied (such as with springs or nearly so with rubber in shear) the value of  $f_n$  can be determined by Equation 13:

$$f_n = \frac{1}{2\pi} \sqrt{\frac{g}{d}} \quad (13)$$

where  $g$  = gravitational constant.  
 $d$  = static deflection of supporting material.  
 $f_n$  = natural frequency of the machine unit on its support (damping = 0).

By the use of Equation 13 a set of curves may be plotted as shown in Fig. 11. The first line  $AB$ , plotted as the critical frequencies for the various static deflections, is a curve showing the worst possible conditions or resonant conditions.

Plotting another curve  $CD$ , which is  $\sqrt{2}$  times curve  $AB$ , shows the area  $MCDN$  in which the resilient material or mounting does more harm

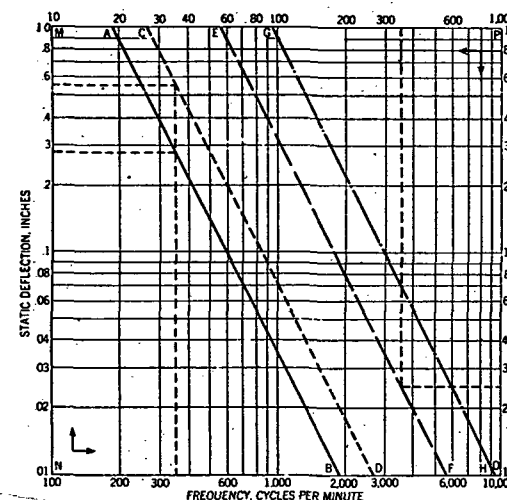


FIG. 11. STATIC DEFLECTION FOR VARIOUS FREQUENCIES

than good. Plotting curves  $EF$  (3 times curve  $AB$ ) and  $GH$  (5 times curve  $AB$ ) shows area  $EGHF$  which represents efficient and economical isolation. Area  $GPOH$  is excellent isolation, but for all except the highest speeds, becomes rather uneconomical because of the large deflections required.

**Example 4:** An electric motor driven compressor unit is to be isolated. The compressor is partially balanced and operates at a speed of 360 rpm. The speed of the motor is 1160 rpm, and it is belt connected to the compressor. Total weight of the compressor and motor is 4500 lb.

**Solution:** The minimum disturbing frequency to be isolated is 360 cycles per minute. Assume that the desired ratio of forced to natural frequency is 3 as a minimum, and that 5 is desired. The desired natural frequency of the mounting is  $360 \div 5 = 72$  cycles per minute.

From Fig. 11 a deflection of 7 in. is required to attain a natural frequency of 72 cycles per minute. This value may be obtained from critical curve  $AB$  for 72 cycles, or from curve  $GH$  (5 times critical) for 360 cycles. For the minimum ratio of 3 the deflection would be 2.5 in.

The next step is to determine the total weight to be supported by the springs. For low speed partially balanced compressors, it has been found necessary to add a foundation weighing 2 to 3 times the weight of the motor and compressor, in order to maintain the machine movement below 0.03 in.

|                      |           |
|----------------------|-----------|
| Compressor and motor | 4,500 lb  |
| Concrete foundation  | 9,000 lb  |
| Total                | 13,500 lb |

Practical application dictates the number of springs to be used, which is based on the design of the machine foundation and the supporting floor structure. However, it is desirable to design for at least 8 springs and one or two spares for cases of unknown weights. As many as 50 springs have been used on one installation. The distribution of the springs must be balanced against the masses to be supported, otherwise the foundation design and supporting structure determine the location of the springs.

The choice of the material used in the design of the resilient mounting is also important. For the slow-speed type compressor, a common speed found in practice is 360 rpm. For speeds below this, isolation should not be attempted except under careful supervision. Referring to Fig. 11, it is

found that for 360 rpm the static deflection required for a ratio of  $f/f_n$  of 3 to 1 (line *EF*) is 2.5 in., and for a ratio of 5 to 1 (line *GH*) it is 7 in. For these values of deflection the only choice of material is the coil spring. This is also true for speeds up to about 700 rpm. In consideration of the transverse spring constant (so as to maintain good ratios among the various degrees of freedom) experience has shown that the spring should be designed with a *working height* equal to 1.0 to 1.5 times the outside diameter. A long spring of small outside diameter has very low transverse rigidity, and therefore requires some additional means of preventing side drift of the unit, and on very sensitive applications this may tend to destroy the isolation efficiency. For speeds of 700 to 1200 rpm the required deflections range from 0.22 in. to 1.75 in. For these conditions rubber in shear serves as a rather satisfactory material if protected from oil. For speeds higher than 1200 rpm cork specially made for vibration damping can be applied with good results. These limitations are by no means absolute, because certain liberties may be taken without impairing the result if all possible degrees of freedom have been taken into account in the design of the installation.

When a machine unit is properly isolated it will have a definite amount of movement which is determined by the ratio of the unbalanced forces to the total mass of the machine. If this resultant machine movement is too great for the necessary connections or the satisfaction of the customer, it can be reduced only in two ways without destroying the quality of the isolation; first, adding mass or dead weight to the machine (such as concrete) common in the application of low speed, partially balanced machinery; second, accurately balancing (both statically and dynamically) all moving parts so as to eliminate the vibration at the source. This latter method is the best engineering practice and is the modern trend. However, even with well balanced machinery, installed in the vicinity of quiet offices, it is usually necessary to isolate properly the equipment to prevent the transmission of vibration likely to cause complaints.

Where limitation of machine movement is desired during the starting and stopping periods, the application of friction or hydraulic damping will serve without seriously interfering with the efficiency of the isolation.

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## CHAPTER 42

### ELECTRIC HEATING

Resistors, Heating Elements, Electric Heating Units, Applications of Electric Heat, Types of Electric Heating Systems, Equipment and Installation Methods, Calculating Capacities, Heating Water by Electricity, Induction and Dielectric Heating, Power Problems

**E**LECTRICITY as a source of heat represents thermal energy in a refined form, easily applied to space heating by a variety of methods, and readily distributed and controlled. However, it usually is more expensive on a direct-heat-equivalent basis than heat from conventional fuels, and for economical service requires careful application in the design of system, adaptation of building structure, choice of control devices, and in method of operation by the user. For special applications and particularly when used to supplement heating systems of other types, the compactness, simplicity, responsiveness, accuracy of control, safety, and other characteristics of electric heating may carry greater weight in choice of method, than operating expense or initial investment.

The basis of all electric heating methods and devices, except so-called heat pumps, is in the power-to-heat conversion constant: 1 kilowatt equals 3413 Btu per hr. Because ratings of electric heating equipment are expressed in terms of watts input and volts at the terminals, heating capacity calculations are translated directly to electric power requirements without the necessity of considering ampere currents or ohm resistances.

Definitions of *Resistor*, *Heating Element*, *Electric Heating Unit* and other terms applying to heating practices will be found in Chapter 1.

It is strongly recommended that compliance with the National Electrical Code and approval by *Underwriters' Laboratories Inc.*, or other recognized certifying agency, be required in the specifications for all equipment, materials, and construction used in electric heating systems.

### RESISTORS AND HEATING ELEMENTS

Electric resistors usually are composed of metal alloys such as nickel-chromium wire or ribbon, or non-metallic compounds containing carbon formed into rods or other shapes. Heating elements may have resistors either in the form of exposed coils mounted on insulators or of metallic conductors embedded in a refractory insulating material, encased in a protective sheath of metal. Fins or extended surfaces may be used to add heat-dissipating area. Elements are made in many forms, such as wires, strips, rings, tubes, plates and panels. Strip elements are used for clamping to surfaces requiring heat transfer by conduction, in some types of convection air heaters, and in low-temperature radiant heaters. Ring and plate elements are common in electric ranges and many small air heaters. Metal or oxide conductive films on glass and ceramics have been applied, usually in the form of panels. Tubular elements may be immersed in liquids, and when cast into metal or formed into coils, are used in water heaters, electric ranges and air heaters.

Cloth fabrics, woven from flexible resistor wires and asbestos or glass

fiber thread, are employed for many low-temperature purposes such as heating pads, blankets, aviators' clothing, and some radiant panel heating installations.

Special incandescent lamps are used as heating elements in certain applications where radiant heat alone is desired. These may have tungsten or carbon filaments as resistors, and are designed to produce maximum energy in the infra-red portion of the spectrum.

### ELECTRIC HEATING UNITS

In general, an electric heating unit is considered to be a structure containing one or more heating elements, electric terminal connections or leads, electrical insulation, and a frame, casing or other supporting means, all assembled together into a unit. There are many varieties, designated by such characteristics as shape and size of housing, material and arrangement of heating elements, operating temperature of resistors, ratio of radiant to convective heat delivery, directional control for radiation, natural or forced convection air circulation, thermostatic or manual control, and electric load-limiting features.

So-called *electric unit heaters* include a built-in fan which circulates room air over heating elements; they are employed for the same uses as other forms of unit heaters (steam, hot water, gas, oil), if conditions are favorable to electric heating. They are especially adaptable for supplemental heating, for small occupied rooms in otherwise unheated buildings and for unattended equipment enclosures in which temperature must be maintained above freezing. Location and arrangement of such unit heaters are discussed in Chapter 25. The typical wiring connection for a heater with single-phase power supply, shown in Fig. 1, has a safety thermal trip wired in series with the magnetic contactor, thermostat, and manual switch.

Forced-air duct heaters have collar frames designed to fit into rectangular cross-section ducts, within which are mounted closely nested resistors all wired to the terminal connections. Choice of resistor type and spacing depends on requirements for heat transfer to the air and on obtaining low air-flow resistance.

### APPLICATIONS OF ELECTRIC HEAT

Until recently the predominating applications of electric space heating have been for convenience service, such as: (a) to supplement an existing system, locally, at times when the main system is shut down, (b) for local use, where the main system may be inadequate, (c) for temporary service requirements, (d) for special conditions involving separate or remote control, (e) for isolated locations, (f) where minimum initial cost is the dominant factor. Some of these requirements are readily satisfied with portable heating units. However, complete electric heating systems are now finding wide application, mainly in residences, but also in many commercial and industrial establishments.

Small electric duct heaters or compact strip heaters are useful in balancing heat distribution in central fan heating systems operated with steam and hot water, and in improving temperature and humidity control for summer air conditioning. Such heaters can be installed in branch ducts or behind the air inlet grilles in each room.

In control of heating systems, employing electric units of the forced-air duct or similar types, a basic difference between electric heating and

steam should be taken into account. Steam is approximately a constant-temperature source of heat, at any given pressure, and a change in air quantity flowing over steam coils does not greatly alter the temperature of the coil surface. The amount of steam condensed (heat input) varies in proportion to the air volume, but the surface temperature of the steam coils remains about the same. Electric heat is quite different, having a constant rate of energy input. If the air flow over electric heating elements is changed, but no change is made in the electric power input, there will be a corresponding change in temperature of the air delivered. This occurs because the electrical energy input remains constant, and the surface temperature of the heating elements will vary as is necessary to compel the air to accept all the heat.

Thus, with electric heat the total heating effect is constant unless some compensating action is performed by controls. Automatic variation of

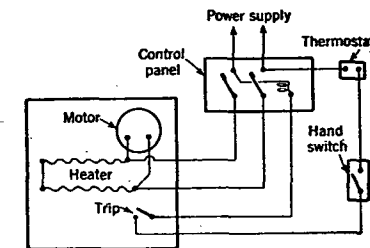


FIG. 1. WIRING DIAGRAM FOR UNIT HEATER

the electrical heat input synchronized properly with the air flow, can be successfully accomplished by certain special methods of control. By-pass dampers as used with steam units cannot control electric heat.

### TYPES OF ELECTRIC HEATING SYSTEMS

The principles employed in electric house heating for heat transfer and distribution, and for temperature control and cyclic operation, and the variety of equipment that has found application, outnumber those for systems utilizing fuel. This can be ascribed to the inherent adaptability of electric energy for transmission, conversion and regulation, and more importantly to the relatively high unit cost in terms of thermal equivalent as compared with fuels traditionally used for house heating; this necessitates and justifies greater attention to efficient utilization.

Types of electric heating equipment and complete heating systems in current use are listed in Table 1. The sequence shown is for convenient reference only, and does not indicate the relative extent of use, quality of performance, or installation cost and operating expense. Installations of all types listed are in successful operation, but performance and cost depend in large measure on proper application to the local conditions.

### EQUIPMENT AND INSTALLATION METHODS

#### Convactor with Metallic Resistors

Standard heating units for wall mounting, of either recessed or surface type, are made with resistors of incandescent bare-wire or low-temperature



(black) types and the general construction already described. A metal inner liner or reflector, usually placed between resistors and casing, provides a secondary air passage to promote circulation and reduce casing surface temperature at the rear. Depending on ratio of horizontal to

TABLE 1. PRINCIPAL TYPES OF ELECTRIC HOUSE HEATING SYSTEMS

- A. Radiators, Convectors, Unit Heaters—Built-In and Portable
  1. Metallic resistor, high- or low-temperature
  2. Glass unit with metal frame
  3. Baseboard-type resistor
  4. Resistor with fan, including unit heater
  5. Resistor with focusing radiation reflector
  6. Steam radiator with immersion electric element
  7. Resistor unit placed in window-type air-conditioner
- B. Panel-Type Installations
  1. Ceiling panel
    - a. Rigid composite panels containing electrically conductive rubber
    - b. Flexible composite sheets containing embedded metallic filaments or conductive rubber
    - c. Electric conductors embedded in plaster on lath
  2. Wall panel
    - a. Rigid panels, as for ceilings
    - b. Flexible sheets, as for ceilings
  3. Floor panel
    - a. Electric conductors embedded in concrete slab
    - b. Soil heating cable under ceramic tile
- C. Central Hot-Water Systems
  1. Water from electric heater pumped to radiators or convectors in rooms
  2. Same, with thermal storage for off-peak operation
  3. Fuel-fired boiler converted to electricity
- D. Central Warm-Air Systems
  1. Resistance-element bank in housing or air duct
  2. Fuel-fired furnace converted to electricity
- E. Heat-Pump Systems
  1. Warm-air distribution through ducts, like D-1
  2. Hot-water distribution, like C-1 or 2
  3. Radiant panels, like B-1 or 2, but with embedded tubing to act as refrigerant condenser
  4. Modification of window-type air conditioner by addition of refrigerant reversing valve and controls

vertical dimension, pattern of face grille, and arrangement of resistors and deflector, the convection heat delivery constitutes between 40 and 60 percent of total output.

Ratings usually are from 1000 to 8000 watts (3400 to 27,300 Btu per hr) with some models down to 500 and up to 15,000 watts. Voltages are the standardized values between 110 and 240. Similar models equipped also with air circulation fans of axial type, are available; these give convection heat delivery up to 80 percent. Other types, using the same components but without a fan, are arranged as *floor furnaces* to be installed

between floor joists. A manual switch and thermostat integral with the unit are optional.

Portable units of the foregoing types, except floor furnaces, are obtainable with plug-in extension cords for convenience and occasional service. Ratings are 500 to 1200 watts at 110 volts; special models rated up to 5000 watts are also made, but can be used only on branch circuits having special wiring and receptacles.

### Convector Type Unit

The location of built-in electric heating units of convector type, generally along the exterior walls beneath or alongside windows, is governed by the same principles that determine arrangement of steam and hot-water convectors, with respect to movement of warm and return air. Positions on interior walls are sometimes permissible, so long as interference from opened doors and from furniture placement is avoided. A thermostat of high-sensitivity type and a conveniently located manual switch are recommended for each unit or at least each room.

### Radiant Convector Unit

Glass electric heating units, sometimes designated as radiant panels, depend on the heating effect produced by passage of current through a thin coating of conductive material fused to one face of a panel of  $\frac{1}{4}$ -in. thick special glass. The conductive layer may be sprayed-on aluminum or *printed* metallic oxide patterned to form a grid several thousandths of an inch thick, or fused-on material to give a uniform coating less than 0.0001 in. thick over the entire active face of panel. Normal glass operating temperatures are 300 to 400 F, with maximum permissible temperature around 650 F.

Electric wiring connections are made to the panel coating at its opposite extremities by wires soldered to the coating, by metal strips held in place with springs, or by other methods that assure low electrical resistance. The panel is supported on insulators within a metal frame which also carries a reflector behind the glass and is arranged to provide space for air circulation. A protective guard prevents accidental contact with the hot glass.

Glass units have standardized ratings, usually 1000 watts; with smaller units extending down to 200 watts, for the common voltages ranging between 110 and 240 volts. Starting current for some types exceeds running current by 10 and by 50 percent. Frame sizes vary from about 30 x 24 in. for 1000-watt size to 42 x 6 in. for 300-watt baseboard model; frame types are for either recessed or surface mounting. Thermostats integral with the frame assembly are optional. Portable units equipped with plug-in extension cords are of similar construction.

### Baseboard Type Unit

Metal casing proportioned to resemble and replace the conventional wood baseboard along plastered or masonry walls, contains 2 or 3 resistors placed horizontally, one above another. These usually are of low-temperature type, with ratings 80 to 120 watts (270 to 400 Btu per hr) per linear foot of baseboard unit, at 240 volts. The maximum surface temperature is 140 to 160 F. The vertical dimension is 6 to 8 in. above floor line, and the projection from face of plaster about 1.5 in. Placement within the room and method of control follow the same principles that apply to hot-water type baseboard installations described in Chapter 23.

Another type of baseboard unit has glass panels 6 to 8 in. high and 30 to 42 in. long, with surface operating temperature kept below 250 F.

#### Resistor with Focusing Reflector

An example of the focusing-reflector-type heating unit is the copper-bowl parabolic or circular *glow* heater for portable use. This has an incandescent wire-coil resistor on a conical ceramic core, screwed into a lamp-type central receptacle. Usual ratings are 600 and 1000 watts for 110 or 120 volt service. Heat emitted by radiant effect is 75 to 85 per cent of total delivery.

For permanent installation, low-temperature focusing units are made with tubular resistors mounted within sectional trough-type reflectors resembling industrial fluorescent lighting fixtures. They may be suspended from ceiling or bracketed from a wall. Rated capacities are 500 to 1500 watts per linear foot of unit. Installations of this kind are mainly in public and industrial buildings, to handle the perimeter heat loss at windows, doors or wall openings. In a modified form, such units are employed for infra-red heating and drying in industrial processes.

#### Steam Radiator with Immersion Element

For portable use, radiators (convectors) of light-weight 2-column construction are equipped with an immersion element screwed into a bottom opening at one end. Usually, after charging with water and antifreeze compound the radiator is sealed. A safety valve or thermal relief plug is provided, to protect against excessive pressure in case heat dissipation is unduly curtailed by clothing, bedding or other insulating material placed over the unit. The steam-and-water intermediate heat-transfer medium has no effect on overall thermal efficiency, but gives the unit operating characteristics adapted for certain applications.

Many recent models of window-type air conditioners are provided with resistors, enabling them to be used also for heating service in moderate weather. Electric input for heating is usually kept the same as for cooling. Consequently, the units normally give only convenience heating and are intended for use at times when the main heating system is shut down.

#### Ceiling Panel-Type Installations with Conductive Rubber

Panels of laminated construction containing electrically conductive rubber, with rating of 22 watts (75 Btu) per sq ft, for 115 and 230 volt service, are built in standard sizes 3 x 4 ft, 4 x 4 ft, and 4 x 6 ft. They consist of a layer of special rubber about  $\frac{1}{4}$  in. thick sealed between layers of phenolic resin-impregnated electrical insulating paper. The assembly is covered on each side with a sheet of aluminum foil. Overall thickness is  $\frac{1}{8}$  in.; weight is 0.4 lb per sq ft. Metal strips embedded along edges of the rubber sheet serve as potential leads. Electric terminal blocks are provided on each panel and standard raceway mouldings are furnished for wiring connections. An earlier type of construction using asbestos-board backing to form rigid panels  $\frac{1}{4}$  in. thick has been discontinued.

Under normal operating conditions that cause cycling under thermostat control, the surface temperature is about 100 F. When panels are turned on in a cold room or with continuous operation, the maximum temperature reached is 120 F.

The position of panels on the ceiling of a room should be as near as possible to exposed walls, especially at windows and doors, to counteract

cold-wall effect and to keep the occupants never farther than 3 ft horizontally from a heated area. The preferred location is with the terminal-block edges close to the walls and with 1-ft spaces between panels. Since it is not permissible to cut heating panels, the entire pattern for ceiling must be planned in advance both for appearance and for economy. Attachment to ceiling plaster, plaster-board or other smooth surface is made by a special adhesive applied on the ceiling along a  $1\frac{1}{2}$  in. fastening margin, provided around the four sides of each panel, which carries a dry adhesive tape bonded to the panel. Lighting fixtures must not be fastened or cut into the active area of a panel.

Adequate thermal insulation above panels is mandatory to protect all wiring from excessive temperature and to assure economical heating service. The minimum thickness of mineral or fiber insulation (glass or rock wool, cellulose fibers, loose asbestos, etc.) is 4 in. at top story and 2 in. for intermediate floors, whereas 6 in. and 3 in., should be the minimum corresponding thicknesses of expanded mica insulation.

A thermostat of high sensitivity type with an integral manual cut-off device should be provided in each room. To obtain economy of operation, a time switch or clock is advocated for lowering the room temperature to 55 F at night or when rooms remain unoccupied.

#### Ceiling Panel-Type Installations with Embedded Conductors

Resistors or *cables* for embedding in plastered ceilings to form panel-type heating installations are electrically insulated with a special compound resistant to high temperature, water absorption, aging effects, and chemical action with plaster, cement and soil. Cable units are furnished in standardized lengths between 20 ft and 1000 ft, rated from 50 to 3000 watts per unit, for 120, 220 and 240 volts. They have an outside diameter about  $\frac{1}{2}$  in., the maximum safe operating temperature is about 165 F, and the test voltage is 2500. Non-heating leads 8 ft long are attached to each unit, allowing the unit to be terminated at thermostats or in switch boxes without causing erratic operation of thermostat by heat from cable. Units are identified in regard to rating, by label and by color code. It is not permissible to alter the length of cable or leads, nor to install any cable unit lacking a visible identification label.

For plastered ceilings, the lathing used is of gypsum or other non-metallic fire resistant type. The cable is temporarily secured to lath with strips of  $\frac{3}{4}$ -in. cotton tape spaced not over 16 in. apart. Each element is tested immediately after fastening on lath, for completeness of circuit and for insulation resistance of at least 100,000 ohms measured to adjacent plaster or structural members.

The minimum spacing between cable passes or turns should be  $1\frac{1}{2}$  in. Leads from cable to junction boxes should be placed in loom. A clearance of at least 2 in. is required from any metal lath, such lath being permissible only for reinforcement along corners at walls. Clearance is likewise necessary at any metal objects, and this applies also to non-heating leads, as a precaution against magnetic hum. Cables must be kept away from local areas of ceiling that would be additionally heated by recessed or surface-type lighting fixtures. All general wiring for power and light is run above thermal insulation over the heat panel areas, or at least 4 in. above the heated ceiling surface.

Plaster should be applied in three coats with the first coat trowled in the same direction as the elements. A superfine sand finish is recommended, since a putty finish coat has a tendency to crack. While new

plaster is drying out, the range and rate of temperature changes (either increase or decrease), should be kept low. Vermiculite or other insulating plaster must not be used, since it causes cables to overheat.

Thermostats should be of high sensitivity type with a manual switch and have other characteristics like those described for conductive rubber panel installations.

### Electric Wall Panels

Although less common than ceiling or floor panel systems, walls may similarly be utilized for electric panel heating. However, possibility of damage to the electrical conductors or to their insulation, from nails driven for hanging pictures and from building alterations, as well as radiation interference caused by furniture placement and interior decorations, requires consideration. Care must be exercised to assure compliance with any applicable codes or safety regulations.

### Electric Floor Panels

Resistor cables of the same types which are used for ceiling panels are employed also for floor panel systems in concrete slabs. The thickness of the concrete slab is usually made a minimum of 3 in. when placed directly on soil. Precautions to be observed in construction of floor slabs for panel heating are covered in Chapters 12 and 24. Cement finish  $1\frac{1}{8}$  in. thick is poured and trowled above the cables. They are stapled at the specified spacing to wood nailing strips laid on the rough concrete slab. It is desirable that cables be secured in place either with a  $\frac{1}{8}$  to  $\frac{1}{4}$ -in. layer of cement wash or thinned grout before the final  $1\frac{1}{2}$ -in. cement or ter-razzo finish is applied, or by tacking at 2 ft intervals with daubs of cement, plaster-of-Paris, strips of masking tape or other non-conductive material. When the slab is made of light-weight insulating concrete, cables should be secured by tape or cord stapled directly to the slab as in the case of plastered ceilings. With monolithic finish, nailing strips are omitted and the cable is strung on frames with nail spacers; frames are removed when enough concrete has been poured to hold the cable in place. If desired, magnesite flooring, asphalt tile or wall-to-wall carpeting may be used on the floor.

Spacing between adjacent turns or loops of cable, and clearance from reinforcing steel bars or other metal bodies embedded in concrete, for prevention of magnetic hum, are the same as for plaster ceilings. Non-heating leads should have rigid conduit between the wall outlet box and floor. They terminate beneath the surface of the final coating. Porcelain or phenolic bushings to separate the leads should be placed with the leads pass from raceway into the slab. Cable circuits should be tested for continuity during the time they are being laid and again while the top concrete layer or cement finish is being poured.

Under ceramic tile floors, the cables are embedded in grout before tiling is laid. In the case of bathrooms, laundry rooms, basements subject to flooding, or other locations where wet floor conditions are likely, soil heating cable of lead-sheathed or other special water- and corrosion-resistant types may be required under local regulations.

### Central Hot-Water Systems

Heating systems of hot-water type using conventional radiator or convector units, discussed in Chapter 22, may be operated electrically by means of heat exchangers containing immersion elements (resistors) of

the required capacity. Control of the resistor circuit by a thermostat within the exchanger is usually desirable. The water holding capacity of exchanger should be made sufficient to minimize frequency of cycling of the heavy electric load from the resistor, and for safety. Resistors may be interlocked with the circuit of the water circulating pump, so that they can be energized only when circulating pump is in operation under control of the room thermostat.

For off-peak operation, where rate schedules for electric power make this desirable, a water heating tank of large storage capacity is employed. The system may be designed for a maximum water temperature of 250 to 275 F at pressures of 60 to 75 psig. An automatic valve is required to provide 140 to 160 F temperature at the pump, by mixing hot water from the tank outlet with cool water from the return main. Another method for heat delivery employs the *flash* principle, withdrawing water at high storage temperature into a low-pressure separating chamber where steam is obtained as a result of the pressure reduction; however, power for pumping is substantially greater with this steam-accumulator method. In practice, tanks up to 1200 gal with immersion elements of 25 to 30 kw have been used for installations with design heat requirements up to 90,000 Btu per hr. Thermal insulation on the tank piping must have low heat transmission in order to cut down the daily and seasonal standby losses. Design of such off-peak systems requires careful analysis of all factors, both thermal and economic. High investment, space required for equipment, and other practical considerations tend to limit the application of this type of electric heating.

### Central Warm-Air Systems

These systems usually employ heaters consisting of resistors mounted in a frame or housing, as mentioned under Electric Heating Units earlier in this chapter. In many cases, arrangement of the supply and return duct system can be planned advantageously to facilitate future addition of equipment for summer air conditioning.

### Conversion of Existing Heating Systems

Changeover of existing conventional fuel-type house heating systems to electric operation, by substituting resistors in place of the fuel equipment in the combustion chamber of a warm-air furnace or boiler, is seldom desirable. Excessive thermal losses from such central equipment and lack of adequate refinements in the distribution facilities and controls, will usually cause high operating cost. However, where heat delivery into the system is accomplished by a steam or hot-water coil assembly located within a duct system, replacement or supplementing with a bank of resistors like those employed in electric unit heaters is sometimes advantageous. A case of this kind occurs where standby heating is needed to maintain safe or comfortable temperature in isolated rooms, during emergency conditions or when the normal electric service for lighting and motors is not in use.

### Heat Pump Systems

Where summer air conditioning is wanted in addition to heating, the heat-pump type of all-year system, which utilizes a refrigeration compressor unit in conjunction with a central-plant installation, is finding a number of applications. It reduces electric input demand and consumption for heating to about one-half or one-third that with the resistance method, the reduction depending mainly on temperature level of the heat source

used and on the type of heat distribution system and its controls. In general, the conditions most favorable to heat pumps occur where, due to climate or operating requirements, the compressor capacities needed both for heating and for cooling service are the same, or nearly so. Customary methods of conveying the heat output from heat pumps to the space served are indicated in Table 1. The main types of heat pumps and the characteristics of heat sources utilized are discussed in Chapter 37.

Some recent models of window-type air conditioners are being equipped for operation as heat pumps. They have refrigerant reversing valves and controls, provided either at the factory or optionally by the installing contractor. Such units are intended for between-season or convenience heating only, since they do not give good performance when the outdoor temperature falls below 35 to 40 F, and they lack means for defrosting the evaporator coil.

In the case of heat pumps using air as heat source, it is shown theoretically and found in practice that heat delivery capacity falls off rapidly as outdoor temperature decreases, whereas the heat requirement increases directly with indoor-outdoor temperature difference. Deficiency at temperatures below the *balance point* can be made up by supplementary electric resistance elements, but this adds disproportionately to power demand. Moreover, seasonal energy consumption by such resistance heating, per kilowatt of demand established, is much less than for the heat-pump cycle itself, and the combination gives load characteristics unfavorable to the utility company for rendering low-cost electric service. An alternative provision for cold-weather peaks is thermal storage in chemical salts and by other devices; such processes are still in the development stage.

The installed cost of residential heat-pump systems is two to three times that of resistance types. However, in practically all cases the summer air-conditioning service obtained with conventional heat pumps is as valuable to the user as the winter heating. Resistance heating systems, except the minority using mechanical air circulation through ducts, do not lend themselves to consolidation with summer air conditioning features, and consequently, an independent cooling installation is necessary. Heat pumps thus have an advantage over such dual systems.

### CALCULATING CAPACITIES

The procedure outlined in Chapter 12 for calculating the heating load should be used for electric systems. Load expressed in Btu per hour is converted to kilowatts by the divisor 3413 Btu per kilowatt. All the energy applied to a resistor transforms itself into heat, unaffected by temperatures of the surrounding air and of surfaces receiving radiated heat. However, both electric power input and heat output are directly affected by voltage at the resistor terminals, being proportional to square of the voltage. Thus, a resistor rated 1000 watts at 240 volts, if used on a circuit at 220 volts, delivers 840 watts or 16 percent under the rated value, while at 208 volts the shortage is 25 percent.

Selection of proper indoor and outdoor temperatures for design of electric heating systems is more critical than for those using fuel, since in case the installed heating capacity is found deficient, the only recourse is to add more electric heating units or to bring the supply voltage up to the permissible maximum. On the other hand, fuel-operated systems ordinarily

permit raising the rate of combustion somewhat above the nominal rating, although there may be some penalty on efficiency, operating or maintenance expense, or overall performance.

Indoor temperatures usually specified are shown in Table 2 of Chapter 12, subject to the indicated notation concerning effect of radiant or panel heating. Moreover, allowance is required for radiation effect of cold surfaces if there are large windows, and for the continuing trend toward adoption of higher indoor temperatures. Concerning outdoor temperature for design, attention is directed in the case of electric heating systems to the cautionary remarks relating to winter climatic conditions in Table 1 of Chapter 12. Judgment must be exercised in choice between values *In Common Use* and *TAC 97.5 Percent Basis*, which show differences as large as 15 deg for some cities. If indoor temperature is taken at 70 F, it may be inadvisable to select outdoor temperature as high as the TAC 97.5 percent value.

The arbitrary addition of a percentage *safety margin* on the calculated heating load or on the specified rated capacity of heating units to be installed, is not recommended, especially in case the outdoor temperature for design is taken at or near the *In Common Use* value instead of *TAC 97.5 Percent Basis*. Such practice increases the peak electric demand and usually the cost of electric service. It also tends to produce excessive on-and-off cycling, impaired temperature regulation, and needless voltage variation or *flicker* disturbances with bad effect on lighting and other electric devices.

Many electric heating systems are of decentralized type, with a thermostat provided on each convector or for each room as recommended by manufacturers of such heating equipment. This practice compensates for variability of heat contributed by auxiliary sources such as sunshine, lighting and appliances. It also gives opportunity for *diversity* of power demand, i.e., the non-coincidence of electric load from all the convectors, panels or heating units of an installation. Manual switches are also commonly provided in such decentralized installations to permit cutting off heat or reducing temperature in rooms when not occupied. Such decentralized operation, advocated as an economic measure with electric heating, requires that consideration be given to adequate capacity for warm-up, as against the uniform-temperature operation with a fully centralized system.

It is essential that buildings intended to be heated electrically should be well constructed, with adequate thermal insulation having impervious vapor barriers, and with storm windows or double-glazed window units and weather stripping to minimize heat loss and air infiltration. Open fireplaces should be eliminated wherever possible, because they induce excessive infiltration. The relatively high electric cost for thermal energy, about \$6.00 per million Btu at \$0.02 per kwh, for example, as compared with about \$1.20 for oil at \$0.12 per gal when utilized with 70 percent efficiency, gives economic justification for substantial expenditure to reduce heat consumption. The large majority of dwellings heated economically by electricity have heat factors (quotient of seasonal energy consumption in kilowatt hours, divided by degree-days and by volume of gross heated space expressed in thousands of cubic feet) between 0.2 and 0.3. The features necessary to hold consumption within these limits result in construction that for 5000 degree-day climate with 0 F outside design temperature, gives a calculated heating load of 4000 to 5000 Btu per hr per 1000 cu ft gross volume. Heat factors up to 0.4 are not uncommon, but

experience shows that such high heat requirement may result in excessive operating cost.

### HEATING WATER BY ELECTRICITY

Electric water heaters for hot-water service in residences and commercial buildings are predominantly of the automatic storage type. These generally have a cylindrical tank mounted vertically, with a primary electric heating element or resistor near the bottom and a secondary unit located within the upper one-quarter of the tank. Water heaters of single-heating-unit type have an element only at the bottom. The first cost of automatic electric heaters is somewhat higher than that of fuel-fired types, owing to the need for larger tank storage to compensate for the limitation of recovery rate, since for economical electric service the connected load should be kept low. Large tank capacity is necessary also with off-peak operation, where there are low electric rates for this class of service.

Instantaneous heaters are used in special cases only, because of the high electric power input required, for example, 15 kw to deliver 1 gpm with 100 deg temperature rise.

Capacities of household automatic storage-type water heaters, as partially standardized within the electrical industry, range from 30 to 140 gal nominal tank capacity with input 1600 to 7000 watts. Wattage input ratings of two-unit heaters are based on approximately 30 watts per gallon of tank capacity for secondary unit and 20 watts for primary unit. Single-unit heaters have tank sizes up to 80 gal with an input of 4000 watts, the ratings being based on 50 watts per gallon. The schedule of heater capacities shown in ASA Standard C72.1-1949 is reproduced in Table 2.

The wattages listed in Table 2 are minimum recommended values for continuous service. Some departure from the standardized watts-per-gallon ratios is to be expected, as experience indicates that increased hot-water use with automatic laundry machines and dishwashers may call for larger heating units than have heretofore been found desirable. With off-peak operation the watts-per-gallon ratio likewise must be raised.

Rated voltage for water heaters is 240 volts, with a range 220 volts minimum to 248 volts maximum, but specified test performance is required to be met only at the 236 volts taken as normal design voltage. Thermostats controlling the heating units are normally set for 150 F, with upper limit of adjustment range of 170 to 180 F.

Heating units are of three general types, all of which give approximately the same service efficiency if selected to suit the operating conditions, as follows:

1. Immersion element, inserted horizontally through a threaded or flanged opening in side of tank.
2. Strap-on unit, externally mounted directly against the tank shell and held in close contact by a band or strap encircling the tank.
3. Side-arm or *outside circulation* unit, consisting of a vertical cylindrical housing or heat exchanger which contains an immersion heating element, connected by pipes into top and bottom of the storage tank.

For the third type, which is less commonly used, thermostats separate from the heating units are mounted within the storage tank.

A fourth type of heater, applied only in exceptional cases and for large installations with alternating current, employs the water itself as a re-

sistor in which electrodes are immersed. Close temperature regulation and compensation for the effect of variable amount and composition of solids and gases in the water are difficult to obtain with small unattended heaters of this kind. The electrode type of construction has in the past been used also for generating steam in so-called electric boilers, mainly for industrial plants; however, in only few instances today is electric energy obtainable at cost low enough to make it competitive with fuel-fired boilers for steam production.

Tanks of electric heaters are regularly constructed to withstand a 300 psig hydrostatic test pressure and are rated for a safe working pressure of 127.5 psig. Materials in contact with the water are selected to resist corrosion caused by solid and gaseous impurities occurring in some locations. It may be desirable also to provide *sacrificial metal* anodes of magnesium, zinc or alloys to protect the tank and its piping connections. A safety relief valve of pressure-actuated type must be included; it may optionally be actuated also by internal temperature. A heat trap at the hot-water

TABLE 2. STANDARD RATED CAPACITIES OF ELECTRIC WATER HEATERS

| TANK SIZE<br>GALLONS |            | RATED INPUT, WATTS |           |                    |
|----------------------|------------|--------------------|-----------|--------------------|
|                      |            | Two-Unit Heater    |           | Single-Unit Heater |
| Nominal              | Range      | Primary            | Secondary |                    |
| 30                   | 30 to 35   | 600                | 1000      | 1500               |
| 40                   | 35 to 45   | 750                | 1250      | 2000               |
| 52                   | 45 to 55   | 1000               | 1500      | 2500               |
| 66                   | 55 to 70   | 1250               | 2000      | 3000               |
| 80                   | 70 to 90   | 1500               | 2500      | 4000               |
| 110                  | 90 to 115  | 2000               | 3000      |                    |
| 120                  | 115 to 135 | 2500               | 4000      |                    |
| 140                  | 135 to 175 | 3000               | 4000      |                    |

outlet, if not provided by manufacturer within or outside the tank shell and inside the insulated jacket, may be placed in the external piping. The trap consists of vertical pipe at least 6 in. long having downward flow, to retard circulation of hot water within the distribution piping system under standby conditions.

Occasionally, an uninsulated tempering tank is installed ahead of an electric water heater, enabling the cold inlet water to absorb heat from the basement or room air—if conditions are such that objectionable sweating does not occur. The practice of connecting a tempering tank with a fire-box coil, the electric heater then furnishing heat only when there is deficiency from the boiler or furnace, is not recommended.

Delivery performance efficiency of heaters meeting the electrical-industry standard 24-hour operation test is 90 percent minimum, which allows 10 percent for thermal loss through the jacket insulation. In service, the quantity of water withdrawn from an automatic storage heater has considerable influence on overall efficiency. With increasing quantities, service efficiency rises and approaches the upper limit fixed solely by the jacket thermal loss; on the other hand, if little or no water is drawn, efficiency approaches zero since no useful work is done. Hence oversizing

a water heater by having too large a tank impairs the service efficiency. Excessive heating-unit wattage causes undesirably high electric demand. Undersizing of heaters obviously results in inadequate and unsatisfactory hot-water service.

Selection of electric heater capacity for residences is made by reference to rating tables which take into account the number of occupants, number of bathrooms or plumbing fixtures, and presence of appliances such as laundry equipment, dishwashers, and the like. Information of this kind is in Chapter 49 and in design manuals issued by the electric utility industry and by heater manufacturers. For commercial applications, the hourly hot-water requirements must be analyzed and the best combination of tank capacity and heating element rating determined, with due consideration of electric power demand created in relation to the user's other electric demands.

A common type of electric service for water heating is the so-called

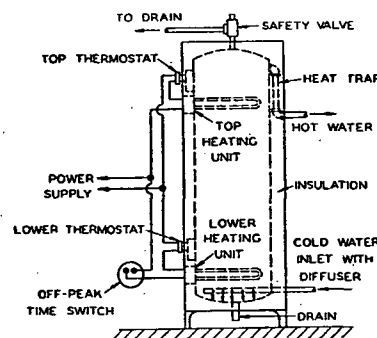


FIG. 2. DOMESTIC HOT-WATER HEATER FOR OFF-PEAK SERVICE

*off-peak* service under which the charge for energy consumed during designated hours is lower than for normal or unrestricted service. With this system, the operation of heaters is confined to such hourly intervals during the 24 hours as will (a) avoid creating peak electrical demands by the customer in excess of the demand resulting from the customer's other uses of electricity, or (b) keep the water heating load off the electric utility system during peak hours. In general, Case (a) occurs where rate schedules contain a demand charge component, and Case (b) where a special low rate applies to off-peak consumption. Water heater circuits are controlled with relays actuated by an electric-clock mechanism or by a *carrier-current* impulse impressed at suitable intervals on the electric distribution system, or by an automatic load-limiting type of control.

One arrangement of domestic hot-water heater for off-peak service, shown in Fig. 2, has the lower heating unit under control of an off-peak switch. Upper unit is connected directly to the line, so that in case the reserve of hot water becomes depleted, the top thermostat brings its heating unit into operation only until the upper portion (usually about 25 percent) of tank contents reaches the thermostat temperature.

Water heaters employing the heat-pump principle are now in limited trial use, obtaining annual performance factor (sometimes called coefficient

of performance) approaching 2.5. This value represents the ratio of useful heat delivered, to the direct heat equivalent of total electric input. The predominant models have tank capacity of approximately 55 gal, hermetic type compressors rated  $\frac{1}{4}$  or  $\frac{1}{2}$  hp, and small circulating fans. So-called *vagrant* heat occurring within the basement or utility room is generally the heat source. In some cases there is secondary benefit from dehumidifying, and an appreciable cooling effect is produced. Present limitations include high initial cost, low recovery rate, restricted maximum temperature, and necessity of condensate drain connections, compared with conventional electric resistance-type and fuel-fired water heaters.

### INDUCTION AND DIELECTRIC HEATING

These methods, employed for industrial processes requiring extreme speed or close control of heat location, do not lend themselves to space or water heating. However, since they are sometimes proposed for consideration, the operating principles are described briefly.

Any electrically conducting material placed in an alternating magnetic field develops eddy currents that generate heat. The rate of internal heating is so high that conduction away from the zone to be treated does not unduly lower the temperature. The field is created by coils connected to an alternating-current power source such as motor-generator set, a mercury arc, or an electronic-tube or spark-discharge oscillator, producing frequencies usually between 250 and 10,000 cycles per second, but for some applications up to 500,000 cps. The coils are generally copper tubes through which cooling water is circulated. Induction heating apparatus must be specifically designed for each application such as melting metals, brazing, heat treating internally or in zones, and surface hardening without oxide scale formation or distortion.

Dielectric heating, for materials that are non-conductors of electricity and are poor thermal conductors, requires a high-frequency electrostatic field produced at high voltage and very high frequencies reaching 50 million cps. The method is well adapted to continuous-flow production process including manufacture of bonded plywood, drying of deep-pile fabrics, dehydration of granular or crystalline materials, and sterilization of foods.

### POWER PROBLEMS

#### Rates for Electric Service

The cost of electricity varies due to several factors. The main elements are the annual charges, including taxes, on capital invested and those expenses necessary to keep the electric utility system at all times in a state of *readiness to serve* the load. The cost of generating the energy is secondary. Electricity is not stored, but must be produced instantaneously when and as required by the user. Consequently, the time of power use, both daily and seasonally, and relation between rate-of-use or demand and the energy consumed within a period (load factor) have large effects on costs and the rates charged. Special low rates sometimes are available during certain prescribed *off-peak* hours of use, when the system load is low.

Space heating is a load whose magnitude is determined basically by weather, and is affected to a much lesser extent by the electric customer's use of his premises. Most of the heating loads in a region occur simultaneously, thereby tending to create peaks for which the capacity of the electric system must be adequate. Accordingly, rates contain in one way



or another, charges both for demand and energy. Demand may be indicated directly by a demand meter or be derived from manufacturers' rating data shown on nameplates of the heating equipment. In block-type rates, where demand is not specifically mentioned, it is in part reflected by higher charges per kilowatt-hour in the earlier blocks.

#### Control of Electric Demand

To obtain electricity for space heating at minimum cost, it is necessary to keep the user's kilowatt demand as low as possible, by provisions in original design of the installation and by judicious methods of operation. Excess heating capacity should be avoided, but without jeopardizing satisfactory performance in cold weather. A variety of control methods can be applied to minimize both demand and consumption. Decentralized control with a thermostat in each room or on each heating unit, together with manual switch to cut off any unoccupied room, is one method. Sequence switching whereby electric service to individual rooms or circuits is shifted in rotation by an automatic timing device and sequence is modified by outdoor thermostat or by total electric load, is another.

Load-limiting controls of several types have come into use. These are generally arranged to measure the customer's total power demand, which for a residence may be grouped as lighting and miscellaneous appliances, refrigerator and water heater, cooking range, and the space heating system. When the demand exceeds a preset value, one or more heating circuits are cut off progressively in rooms least affected by the interruption. Experience shows that with electric floor or ceiling panel heating, temperature drop occurs slowly, at the rate of about 1 deg per hour for concrete slabs and 2 deg for plaster construction or rigid panels properly backed with thermal insulation. Moreover, electricity consumed by lighting, appliances and cooking ranges is contributing some useful heat at such times.

Another form of limiting control for 120/240-volt 3-wire circuits provides complete or sequence transfer of space heating units from 240 volts to 120 volts, thereby reducing the electric input to one quarter whenever the total load or general-service component exceeds a preset limit. This method lends itself to use of an outdoor thermostat actuating a relay, whereby in mild weather the entire heating system operates at 120 volts and with lengthened cycles obtains more uniform room temperature. For reducing temperature at night, if desired, a clock-operated master thermostat can be provided to lower the heating-system voltage. On some electric utility systems, centralized control by means of a pilot-wire or carrier-current actuating a relay is applied to house-heating installations.

With any type of control, time-delay relays should be used in order that upon restoration after an emergency service interruption or whenever a master thermostat calls for heat, the individual circuit or units will come on non-simultaneously over a period of a few minutes. This is advisable especially for types of resistor units that have a power input, when cold, as much as 50 percent above the rated value at normal operating temperature.

#### Operating Costs

The range of electric costs for house heating, on residential rate schedules typical of country-wide conditions, is from something over two cents per kilowatt-hour where house-heating consumption comes mainly on the

bottom step of a block-type residential rate, to as little as half that figure in areas served by large hydroelectric systems. Since the range of heat factors for houses of differing construction types with various methods of resistance electric heating and with a variety of occupancy is likewise more than 2-to-1, costs of house heating for dwellings of the same size in similar winter climates may vary through a range of nearly 5-to-1. However, an

TABLE 3. RELATION OF RESISTOR VOLTAGE TO HEAT DELIVERY

| CONDITION                                | VOLTS   | HEAT DELIVERED<br>% |
|------------------------------------------|---------|---------------------|
| Electric system, nominal value           | 120/240 | 103.3               |
| For design of equipment, at terminals    | 118/236 | 100                 |
| Range, as basis for design               |         |                     |
| Minimum                                  | 110/220 | 86.8                |
| Maximum                                  | 124/248 | 110.5               |
| On secondary distribution system         |         |                     |
| Favorable zone, as to voltage conditions |         |                     |
| Minimum                                  | 110/220 | 86.8                |
| Maximum                                  | 125/250 | 112.0               |
| Tolerable zone                           |         |                     |
| Minimum                                  | 107/214 | 82.2                |
| Maximum                                  | 127/254 | 116.8               |
| Emergency conditions                     | 90/180  | 58.3                |

8000-cu ft house can be heated with 8000 kilowatt-hours of electrical energy annually in 5000 degree-day climate, if a heat factor of 0.2 is attained by means of good construction and adequate insulation.

#### Voltage Requirements

The preferred nominal system voltage at point of electric utilization by equipment, for single-phase 3-wire systems necessary with space heating, is 120/240 volts, as stipulated by standards of the electrical industry (*EEI* publication R-6 and *NEMA* publication No. 117 issued May 1949). For household heating appliances mentioned in the standards, such as air heaters, water heaters, and cooking ranges, the *equipment voltage rating for design* is specified as 118/236 volts, and the range of *voltages to be used as a basis of design* extends from 110/220 minimum to 124/248 maximum. However, naturally variations exist from time to time in the conditions at different points in any secondary distribution system and will affect both voltage level and range of fluctuations. Under emergency conditions on electricity supply systems, voltages of the order of 90/180 may be encountered. Heat delivery by resistors with these voltage values, expressed in percent of rated delivery with the normal 118/236 volts (at terminals) is given in Table 3.

Voltages stipulated for secondary distribution systems are at point of service entrance to the building; the drop of voltage in the house supply wiring to terminals of the heating equipment may be 2 to 3 percent, thus reducing heat delivery by some 5 to 8 percentage points below the *favorable zone* and *tolerable zone* values included in the last column of Table 3. Ac-



cordingly, it is necessary the designers of electric heating installations obtain specific information from the local electric utility company on both existing and anticipated future conditions at the location, before specifying the capacity and voltage for equipment, wiring and controls.

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### CHAPTER 43

## CORROSION AND WATER FORMED DEPOSITS, CAUSES AND PREVENTION

Definitions, Classification and Characteristics of Water, Causes and Prevention of Scales and Sludges, Causes and Prevention of Slimes, Underwater Corrosion, Atmospheric Corrosion, Buried Pipe Lines, Handling Water Treating Chemicals, Legal Regulations

THE surfaces of heating and ventilating equipment that are in intimate contact with water sometimes are affected by the chemical characteristics of contacting waters to such an extent that prohibitive amounts of insoluble materials are formed or corrosion ensues at an insufferable rate. To avoid or to correct such troubles; it is desirable that heating and ventilating engineers have a general appreciation of industrial water chemistry. The principal purpose of this chapter is to provide those criteria by which the average engineer may judge whether a problem is one that will yield to rather simple remedies, or will require the skill of an experienced water technologist.

### DEFINITIONS

The following definitions for water-formed deposits, corrosion, and closely allied terms have been proposed:

**Water-Formed Deposits.** A water-formed deposit<sup>1</sup> is any accumulation of insoluble material derived from water or formed by the reaction of water upon surfaces in contact with water.

Deposits formed from or by water in all of its phases may be further classified as scale, sludge, corrosion products, or biological deposits.

**Scale.** Scale<sup>1</sup> is a deposit formed from solution directly in place upon a confining surface. It is a deposit which will retain its physical shape when mechanical means are used to remove it from the surface on which it is deposited. Scale, which may or may not adhere to the underlying surface, is usually crystalline and dense, frequently laminated, and occasionally columnar in structure.

**Sludge.** Sludge<sup>1</sup> is a water-formed sedimentary deposit. It usually does not cohere sufficiently to retain its physical shape when mechanical means are used to remove it from the surface upon which it deposits. Sludge is not always found at the place where it is formed. It may be hard and adherent, and baked to the surface on which it has been deposited.

**Biological Deposits.** Biological deposits<sup>1</sup> are water-formed deposits of biological organisms or the products of their life processes. Biological deposits may be microscopic in nature, such as slimes, or macroscopic, such as barnacles or mussels. Slimes are usually composed of deposits of a gelatinous or filamentous nature.

**Corrosion.** Corrosion<sup>2</sup> is destruction of a metal by chemical or electrochemical reaction with its environment. In the corrosion process, the reaction products formed may be soluble or insoluble in the contacting environment. Insoluble corrosion products may deposit at or near the attacked area, or be carried along and deposited at a considerable distance from the attacked area.

**Corrosivity.** Corrosivity<sup>3</sup> is the capacity of an environment to bring about destruction of a metal by the process of corrosion. Corrosivity is a property of the environment, but it has no significance until the metal in question is specified.

### CLASSIFICATION AND CHARACTERISTICS OF WATER

For industrial use there is no accepted conventional classification of water. Rather, each industry usually develops a body of ideas applicable to its own water problems.<sup>4</sup> For heating and ventilating engineers, it is perhaps most convenient to distinguish between mineralized waters and condensates.

#### Mineralized Waters

All the waters found in streams, wells, lakes, and the ocean are mineralized. The same is true of all municipal supplies even though they may have been treated. For a given area, ground waters are likely to be more highly mineralized than are surface waters. Conversely, surface waters

TABLE 1. MINERAL ANALYSES TYPIFYING COMPOSITION OF WATERS AVAILABLE AND USED INDUSTRIALLY IN THE USA

| SUBSTANCE              | UNIT              | LOCATION OR AREA <sup>a,b</sup> |       |     |       |     |     |     |     |        |
|------------------------|-------------------|---------------------------------|-------|-----|-------|-----|-----|-----|-----|--------|
|                        |                   | (1)                             | (2)   | (3) | (4)   | (5) | (6) | (7) | (8) | (9)    |
| Silica                 | SiO <sub>2</sub>  | 2                               | 6     | 12  | 37    | 10  | 9   | 22  | 14  | .....  |
| Iron                   | Fe                | 0                               | 0     | 0   | 1     | 0   | 0   | 0   | 2   | .....  |
| Calcium                | Ca                | 6                               | 5     | 36  | 62    | 92  | 96  | 3   | 155 | 400    |
| Magnesium              | Mg                | 1                               | 2     | 8   | 18    | 34  | 27  | 2   | 46  | 1,300  |
| Sodium                 | Na                | 2                               | 6     | 7   | 44    | 8   | 183 | 215 | 78  | 11,000 |
| Potassium              | K                 | 1                               | 1     | 1   | ..... | 1   | 18  | 10  | 3   | 400    |
| Bicarbonate            | HCO <sub>3</sub>  | 14                              | 13    | 119 | 202   | 339 | 334 | 549 | 210 | 150    |
| Sulphate               | SO <sub>4</sub>   | 10                              | 2     | 22  | 135   | 84  | 121 | 11  | 389 | 2,700  |
| Chloride               | Cl                | 2                               | 10    | 13  | 13    | 10  | 280 | 22  | 117 | 19,000 |
| Nitrate                | NO <sub>3</sub>   | 1                               | ..... | 0   | 2     | 13  | 0   | 1   | 3   | .....  |
| Dissolved Solids       |                   | 31                              | 66    | 165 | 426   | 434 | 983 | 564 | 948 | 35,000 |
| Carbonate Hardness     | CaCO <sub>3</sub> | 12                              | 11    | 98  | 165   | 287 | 274 | 8   | 172 | 125    |
| Non-Carbonate Hardness | CaSO <sub>4</sub> | 5                               | 7     | 18  | 40    | 58  | 54  | 0   | 295 | 5,900  |

<sup>a</sup> All values are parts per million of the unit cited to nearest whole number (see Reference 5).

<sup>b</sup> Numbers indicate location or area as follows:

- |                                                            |                                           |
|------------------------------------------------------------|-------------------------------------------|
| (1) Catskill supply—New York City                          | (6) Well Water—Maywood, Illinois—2090 ft. |
| (2) Swamp Water (Colored) Black Creek, Middleburg, Florida | (7) Well Water—Smithfield, Va.—330 ft.    |
| (3) Niagara River (Filtered) Niagara Falls, New York       | (8) Well Water—Rosewell, N. Mexico        |
| (4) Missouri River (Untreated) Average                     | (9) Ocean Water—Average                   |
| (5) Well Waters—Public Supply—Dayton, Ohio—30-60 ft.       |                                           |

are more likely to be contaminated with municipal sewage and trade wastes. Virtually all mineralized waters also contain biological organisms.

**Mineralogical Characteristics.** The character and amount of extraneous inorganic materials—including deleterious gases—dissolved and suspended therein, describe the mineralogical characteristics of any water. Revealing such information is the function of a mineralogical chemical analysis.

The analyses in Table 1 disclose the composition of the public water supplies used by about 45 percent of the total population of the cities, in the United States, having more than 20,000 inhabitants.<sup>5</sup>

All values recorded are in terms of parts per million.\* This is the approved standard terminology for reporting the results of mineral analyses.<sup>6</sup> Values reported in the other terms commonly used may be converted into the standard form by using the factors listed in Table 2.

Data for dissolved gases or pH values have been omitted in Table 1 because even waters of the same mineral contents may vary widely in these respects. Unpolluted natural waters usually have pH values within the range 5 to 8, depending upon their free CO<sub>2</sub> contents. Polluted waters,

\* Parts per million are hereinafter abbreviated ppm. A part per million signifies a unit weight of material per million unit weights of the solution.

TABLE 2. CONVERSION FACTORS FOR WATER ANALYSES

| TO CONVERT                 | INTO | MULTIPLY BY |
|----------------------------|------|-------------|
| Grains per U. S. gallon    | ppm  | 17          |
| Grains per Imperial gallon | ppm  | 14 1/4      |
| Grams per liter            | ppm  | 1000        |
| Mg per liter               | ppm  | 1           |

which include those derived from wells or swamps in marshy ground, may have pH values well below 5.

**Biological Characteristics.** The slime-forming organisms are mostly lower plants, grouped by botanists into the phylum thallophyta. This group is distinguished by the absence of leaves, roots, or stems from the mosses, ferns, and seed plants which comprise the three other phyla of the plant kingdom.

The thallophyta (see Table 3) are divided into algae, which can synthesize chlorophyll for the production of sugar, and the fungi which lack chlorophyll, and must therefore secure already synthesized carbohydrates.

All thallophyta are of universal distribution and many of them are slime forming. Of the five divisions of algae, only three (the green, the blue-green, and the diatoms) are found in fresh water. Of the five divisions of fungi, all may occur in fresh water, the principal slime formers being indicated in Table 3.

The methods of analysis commonly used in the sanitary examination of a water have, as their principal object, to identify and count pathogens.

Most slime-forming organisms are not pathogens. When a water is subjected to a biochemical analysis for the purpose of evaluating its slime producing characteristics, tests, widely different from sanitary bacteriological tests, must be made. Tests upon the water itself are seldom satisfactory, and true indications of the sliming characteristics of a water can only be determined by the analysis of deposits on surfaces having a temperature close to the temperature of the final design equipment. The results of such a test are commonly reported in the manner illustrated in Table 4.

#### Condensates

All condensates result from the chilling of water vapor. Such chilling may result from natural causes, thus producing *dews, sweats, rain, and snow*, or from artificial causes, as in steam condensing equipment, producing condensate or return water.

TABLE 3. PRINCIPAL SLIME FORMERS

| PHYLA | ROUGH DIVISION OF PHYLA                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Algae | Single celled, sometimes forming slimy sheets.<br>Many celled in either sheets or fronds.                                                                                                                                                                                                                                                                                                                                                                                   |
| Fungi | <i>Bacteria</i> (Schizomycetes) frequently forming slimy surface coatings.<br><i>Slime Molds</i> (Myxomycetes) forming slimy sheets as one stage of their life history.<br><i>Sac fungi</i> (Ascomycetes) of which one division, the yeasts, occasionally form slimy aggregates.<br><br>The alga-like fungi ( <i>Phycomycetes</i> ) and the stalked fungi ( <i>Basidiomycetes</i> ) rarely form slimes but their filaments may hold together the slimes of other organisms. |

TABLE 4. PLANT WATER SUPPLIED FOR EXAMINATION

|                                                     |                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| WATER SUPPLY—                                       | 200 feet deep well—average water temperature 53 F—water is producing a brown stain in plumbing fixtures.                                                                                                                                                                                                              |
| SAMPLE—                                             | The sample was scraped from the surface of the shell and tube condenser of No. 2 Freon Compressor on the meat chilling room. The sterile sample bottle was filled one-half with deposit and the balance with circulating water. No preservative was added—pH at time of collection was 7.4.                           |
| ANALYSIS REQUIRED—                                  |                                                                                                                                                                                                                                                                                                                       |
| MACROSCOPIC <input checked="" type="checkbox"/>     | MICROSCOPIC <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                       |
| BACTERIOLOGICAL <input checked="" type="checkbox"/> | ORGANIC CONTENT <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                   |
| PROBLEM—                                            | A 25-ton Freon-12 Compressor has head pressure about 10 lb higher than during initial operation, without change in water temperature. Deposits have been observed on heat exchanger surfaces. It is desired to know the nature of these deposits and if they are the cause of this increased head pressure.           |
| MACROSCOPIC EXAMINATION—                            | Heavy brown flocculant material settles rapidly in clear water. pH—7.3 Odor—woody, mouldy.                                                                                                                                                                                                                            |
| MICROSCOPIC EXAMINATION—                            | INORGANIC MATERIAL—small amount white crystals.<br>AMORPHOUS MATERIAL—small amount—brown.<br>IRON BACTERIA—profuse growth of crenothrix—(Photo usually included).                                                                                                                                                     |
| CULTURAL EXAMINATION                                | SABOURAUD'S AGAR<br>1. Aerobic gram positive spore-forming rod with mucoid sheaths. (Photo usually included).<br>2. Short gram negative coccibacilli (Photo usually included).                                                                                                                                        |
| TOTAL COUNT                                         | 100,000 organism/cc.                                                                                                                                                                                                                                                                                                  |
| ORGANIC CONTENT (by WEIGHT, DRY BASIS)—60%          |                                                                                                                                                                                                                                                                                                                       |
| DISCUSSION—                                         | The presence of common slime-forming organisms in the deposit combined with high organic content indicates that the deposit is bacterial in origin. Heat transfer reductions would be caused by such a deposit. These deposits, combined with crenothrix, can cause corrosion of both ferrous and non-ferrous metals. |
| RECOMMENDATIONS—                                    | It is recommended that the water be treated at the suction side of the deep well pump with chlorine in quantities sufficient to maintain a free chlorine residual of 1.0 ppm at the discharge of the shell and tube cooler. This treatment can be scheduled on an intermittent basis.                                 |

In the heating and ventilating field, the biological characteristics of condensates are likely to be of concern *only* where the condensate is used as cooling water in recirculating systems. The deleterious gas contents of condensates, however, very often create serious corrosion troubles.

The data in Table 5 typify the chemical composition of the atmosphere in rural and metropolitan areas, and of stack gases when various types of common fuels are used. The curves in Fig. 1 disclose the solubility of the major deleterious gases present in such atmospheres in otherwise pure water, when the partial pressure of the gas is one psia.

The most common deleterious gases entrained by steam are oxygen and

TABLE 5. DATA TYPIFYING THE DELETERIOUS GAS CONTENT OF DIFFERENT ATMOSPHERES

| Name of Gas        | Chemical Formula | AIR          |                        |              |                        | FLUE GASES   |                        |              |                        |              |                        |
|--------------------|------------------|--------------|------------------------|--------------|------------------------|--------------|------------------------|--------------|------------------------|--------------|------------------------|
|                    |                  | RURAL        |                        | METROPOLITAN |                        | BITUM. COAL  |                        | FUEL OILS    |                        | NATURAL GAS  |                        |
|                    |                  | % by Vol-ume | Partial Pres-sure psia | % by Vol-ume | Partial Pres-sure psia | % by Vol-ume | Partial Pres-sure psia | % by Vol-ume | Partial Pres-sure psia | % by Vol-ume | Partial Pres-sure psia |
| Oxygen.....        | O <sub>2</sub>   | 21           | 3.143                  | 21           | 3.143                  | 2            | 0.299                  | 7            | 1.048                  | 10           | 1.497                  |
| Carbon Dioxide.... | CO <sub>2</sub>  | 0.03         | 0.004                  | 0.06         | 0.009                  | 15           | 2.245                  | 13           | 1.946                  | 10           | 1.497                  |
| Sulphur Dioxide..  | SO <sub>2</sub>  | None         | None                   | 0.003        | 0.004                  | 0.07         | 0.010                  | 0.03         | 0.004                  | 0.0001       | 0.0015                 |

carbon dioxide. In rare instances, hydrogen sulphide, sulphur dioxide, or ammonia are present.

In most steam condensing equipment,<sup>7,8</sup> the non-condensable gases entrained with steam accumulate so that the amount present in the vapor space is several hundred times higher than in the incoming steam and the amount dissolved in the condensate may therefore approach, or even exceed for short periods, the amount entrained by the steam.

### CAUSES AND PREVENTION OF SCALES AND SLUDGES

Scales may be formed on surfaces of equipment in contact with water, and sludges in the body of the water, by the separation from the water of dissolved or suspended solids. According to the nature of a particular

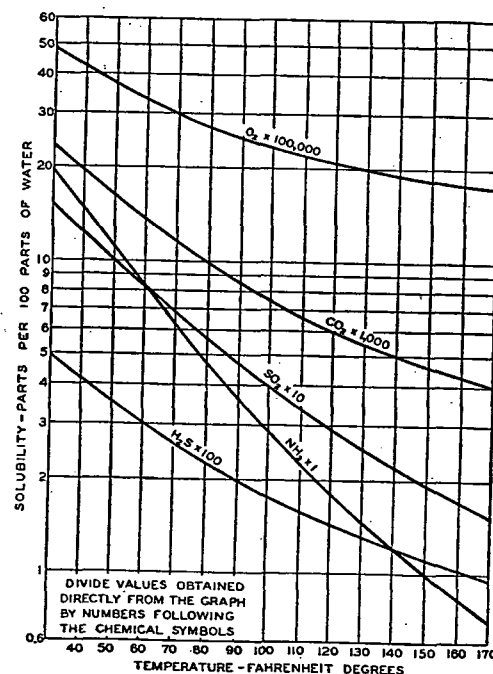


Fig. 1. SOLUBILITY OF GASES AT PARTIAL PRESSURE OF 1 PSI

piece of equipment and the method of its operation, such separation may be promoted by one or more than one, of several factors:

- The concentration of solids may be increased by the evaporation of water.
- The dissolved solids may be rendered less soluble in the water by changes in temperature.
- Conditions may favor the decomposition of unstable compounds with the formation of less soluble compounds.

Figs. 2 and 3 show that the solubilities of both calcium carbonate and calcium sulphate decrease with the rising temperature within a moderate range of temperatures. Surfaces transferring heat into water, such as

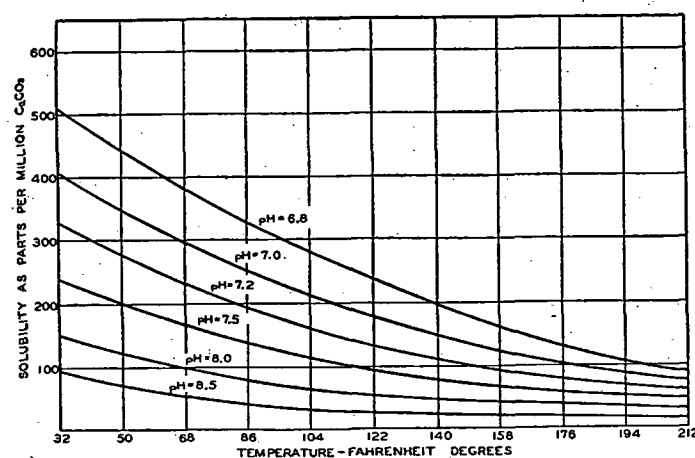


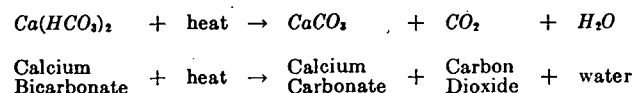
FIG. 2. SOLUBILITY OF CALCIUM CARBONATE IN DISTILLED WATER CONTAINING CARBON DIOXIDE

(pH Values at Approximately 73 F)

Fig. 2 Adapted from (1) *Ind. & Eng. Chem.*, 20 (1928) 1197—by Baylis. (2) *J.A.C.S.* 50 (1929) 2086—Frear & Johnson.

condensers and coolers, are more susceptible to scale and sludge formation than are the cold parts of the same system using the same water.

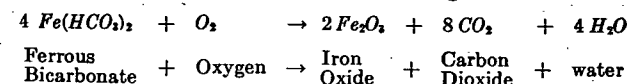
The most common of the unstable soluble salts are the bicarbonates of calcium, magnesium, and occasionally iron. Under conditions favoring the removal of carbon dioxide, as when the water is strongly aerated or when it is boiled, the bicarbonates are readily converted to the relatively insoluble carbonates. The type of scale most usually encountered is calcium carbonate (often called alkalinity) from the decomposition of calcium bicarbonate according to the following chemical reaction:



Conversely, carbonates are readily converted to the more soluble bicarbonate by the addition of carbon dioxide or other acidic materials. This explains the increase in the apparent solubility of calcium carbonate

at decreasing pH values (increasing concentration of hydrogen ion) shown in Fig. 2, the carbonate really going into solution largely as bicarbonate.

In special cases, primarily with well waters possessing a high natural iron content, deposition of iron oxide from the decomposition of ferrous bicarbonate takes place according to the following reaction:



Low water velocity in heat transfer equipment often causes sludges to settle out in the tubes. This has the same effect on heat transfer as scale

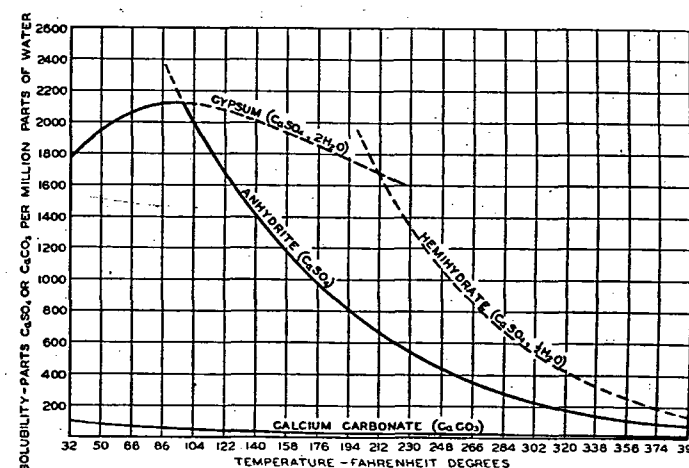


FIG. 3. SOLUBILITY OF CALCIUM SULFATE AND OF CALCIUM CARBONATE FOR COMPARISON

(CaCO<sub>3</sub> in Equilibrium with Normal CO<sub>2</sub> Content of the Atmosphere)

Fig. 3 Adapted from Bull. No. 15, *Univ. of Mich.* Formation and Properties of Boiler Scales by P. E. Partridge.

formation. When this occurs, increasing the water velocity often cures the condition.

It is sometimes desired to evaluate the tendency in a particular water toward the separation of calcium carbonate, which may be desirable as a means of establishing a corrosion-resistant film on metal surfaces, or in other circumstances may be undesirable because of the impedence of the calcium carbonate film to heat transfer. This tendency is indicated approximately by the Langelier Index,<sup>9</sup> which is obtained by subtracting the actual pH of a particular water from the pH at which it is estimated precipitation of calcium carbonate would just begin. This estimate may be made by the use of Fig. 4.

There are various expedients which may be employed for avoiding or mitigating difficulties due to scales:

- The water may be treated before use to remove elements such as calcium, magnesium, and iron, which form relatively insoluble compounds. In the various softening processes this removal of these elements is accompanied by the addition of other elements, particularly sodium, the compounds of which are relatively soluble.
- The water may be treated within the equipment to promote the separation of

dissolved solids as sludges, rather than as scale which is, in most cases, more objectionable.

c. The increase in total solids, due to the evaporation of water, may be controlled by the displacement, continuously or intermittently, of some of the used water by fresh supply.

d. Substances, such as the polyphosphates, having the property of inhibiting the precipitation of calcium carbonate from solutions supersaturated with it, may be added.

e. The *pH* of the water may be lowered (hydrogen ion concentration raised) to reduce the tendency for precipitation of carbonate. This is permissible only to such an extent as will not cause a serious increase in rate of corrosion.

The choice of the best expedient or combination of expedients must be made for each type of equipment, and will be affected by operating and water considerations. Item c above must be used, regardless of which other items are used, for all recirculating water systems from which evaporation takes place.

### Once-Through Equipment

Where abundant supplies of water are available at low cost, the cooling water may pass through the equipment once, undergoing a rise in temperature. Little difficulty from scale should be encountered if the Langelier Index is lower than +0.5, based on the highest water temperature encountered in the system. This often corresponds to a carbonate hardness of less than 200 ppm when water temperatures are lower than 100 F. However, since many municipal supplies are softened so that incipient calcium carbonate precipitation is induced, the Langelier Index is a more reliable indication of scaling tendency.

Prevention of scale in once through systems is based primarily on the adjustment of *pH*, the application of surface-active agents, or a combination of the two. Normally the addition of a few parts per million of a surface-active agent such as a polyphosphate<sup>10</sup> fed proportionately to a water with a scaling tendency is all that is required to control scale.

Where a given water does not respond satisfactorily to surface-active agents, reduction of *pH* with sulfuric acid or carbon dioxide is often employed. The *pH* is reduced only sufficiently to have it fall within the effective range of the surface-active agent. The use of acid or carbon dioxide is sometimes permitted without polyphosphates when corrosion will not be severe. In this case the *pH* is reduced so that the Langelier Index is less than +0.5. The acid or carbon dioxide must be added with care. Use of automatic *pH* controllers is required if corrosion is to be prevented.

A special case of scale from ferrous bicarbonate decomposition was mentioned previously. Ferrous bicarbonate is considerably less stable than calcium bicarbonate. The prevention of this decomposition can be accomplished by the addition of polyphosphate in low concentrations.<sup>11</sup> The use of polyphosphate in the ratio of two parts by weight to one part by weight of iron is usually most effective. The polyphosphate must be added to the water before exposure of the water to air or chlorine if effective stabilization of the iron is to occur.

### Closed Recirculating Systems

The closed recirculating system is one in which water circulates through one heat exchanger where it absorbs heat, has its temperature elevated, and circulates through another heat exchanger in which its temperature is lowered. In cold water or chilled water systems scaling is seldom a

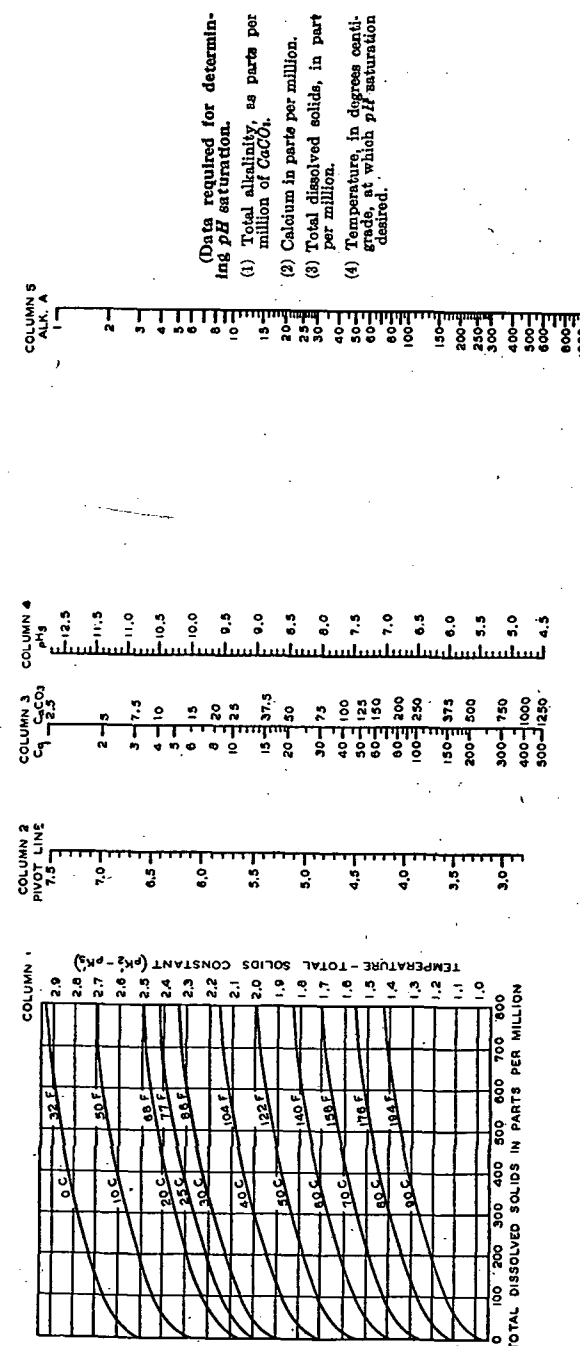


FIG. 4. GRAPH AND NOMOGRAM FOR DETERMINATION OF *pH* SATURATION BY LANGELIER'S FORMULA  
(Applicable within *pH* Range 7.0-9.5)

Based on article in Oct. 1938 issue of American Water Works Association Journal and later corrections for Tables 2 and 4 of article. Prepared for Charles P. Hoover of the Columbus, Ohio, Water Softening and Purification Plant by M. L. Riehl.

#### Instructions for Using Chart:

1. Knowing temperature and total dissolved solids, find temperature and total solids constant on Col. 1.
2. Align this constant with given value of calcium on Col. 3 of Chart, then locate point on Col. 2 of Chart (Pivot Line).

3. Align this point on Pivot Line with given alkalinity on Col. 5; read *pH* saturation on Col. 4.
- Saturation index is *pH* actual minus *pH* saturation.  
e.g. - *pH* actual, *pH* saturation. Saturation index.  
7.6 8.1  
-0.5 (corrosive)  
+0.5 (scale forming)

problem. In hot water systems scaling is seldom a problem unless there is a large amount of makeup water.<sup>12</sup> In these cases the use of surface-active agents such as polyphosphate are used.

### Open Recirculating Systems

Where water from condensers and similar equipment is passed through a spray pond or cooling tower and then returned to the equipment, there is an increase in the concentration of solids because of the evaporation of some of the water into the cooling air, and, moreover, the aeration removes carbon dioxide. Both factors promote the tendency to deposit scale.

This condition is also true for air washers during periods of operation when air is humidified. Evaporation of recirculated water occurs, causing concentrations of scale forming minerals. (There are cases, such as in New York City, where water supplies have extremely low solids content. Aeration in air washers and cooling towers causes absorption of acid gases

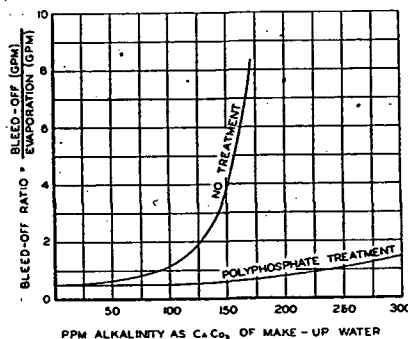


FIG. 5. RELATION OF BLEED-OFF REQUIREMENT TO  $\text{CaCO}_3$  IN MAKE-UP WATER

such as sulfur dioxide,  $\text{SO}_2$ , from the air. Serious corrosion rather than scale occurs.)<sup>13</sup>

The concentration of scale-forming minerals in open recirculated cooling water is limited by natural drift or windage loss. This is the loss of water droplets from the system. Windage losses from typical systems may be classified as follows, based on recirculating rates:

|                                              | Percent of Recirculating Rate |
|----------------------------------------------|-------------------------------|
| Evaporative Condensers and Air Washers ..... | 0 to 0.1                      |
| Mechanical Draft Cooling Towers .....        | 0.1 to 0.3                    |
| Atmospheric Cooling Towers .....             | 0.3 to 1.0                    |
| Spray Ponds .....                            | 1.0 to 5.0                    |

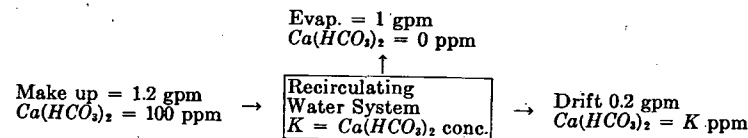
To show the effect of concentration in a typical mechanical draft system assume:

1. Recirculating Rate = 100 gpm.
2. Drift loss = 0.2 percent of recirculating rate = 0.2 gpm.
3. Evaporation Rate = 1 percent of recirculating rate = 1.0 gpm.
4. Calcium bicarbonate in make-up water = 100 ppm.
5. Calcium bicarbonate in evaporated water = 0 ppm.

### Corrosion and Water Formed Deposits, Causes and Prevention

Let  $K$  = concentration of calcium bicarbonate in recirculating water = concentration of calcium bicarbonate in drift loss.

The process of concentration in the system may be represented diagrammatically as follows:



The concentration may be obtained from the equation

$$(\text{Make Up}) [\text{Ca}(\text{HCO}_3)_2 \text{ conc.}] = (\text{Evap.}) [\text{Ca}(\text{HCO}_3)_2 \text{ conc.}] + (\text{Drift}) [\text{Ca}(\text{HCO}_3)_2 \text{ conc.}]$$

$$(1.2) (100) = (1) (0) + (0.2) (K)$$

substituting,

$$120 = 0 + 0.2 K$$

whence,

$$K = 600 \text{ ppm}$$

Therefore the concentration of calcium bicarbonate in the recirculating water equals 600 ppm. This far exceeds the allowable concentration of 170 ppm at which scaling will occur.

To correct this situation, it is imperative to provide a continuous bleed-off or blow down from the recirculating water circuit. Typical bleed-off requirements are shown in Fig. 5. Reference to the No Treatment curve shows that a bleed-off rate of 1.2 times the evaporation rate is required when a make-up water contains 100 ppm calcium bicarbonate (or alkalinity) if scale is to be prevented. Calculation by a material balance will show that the bleed-off plus drift loss will limit the calcium bicarbonate to 171 ppm.

It can be seen from Fig. 5 that very large amounts of bleed-off are required as a make-up water approaches or exceeds 150 ppm of alkalinity. When alkalinity exceeds 175 ppm, bleed-off alone is no longer effective. The use of 5 ppm or less of polyphosphate is extremely effective in reducing the required bleed-off and making possible the use of make-up waters which will not respond to bleed-off alone.

Occasionally, waters are encountered which have exceptionally high alkalinities or which develop high  $\text{pH}$  values when recirculated. The use of sulfuric acid is common in these cases to maintain  $\text{pH}$  values between 7 and 8. Polyphosphates are most always used when acid is required.

It is very important to control acid feeding carefully to avoid serious corrosion. Automatic  $\text{pH}$  controllers are often employed for such purpose.

### Heating System

In hot water heating systems or in steam heating boilers where all condensate is returned, troubles from scaling should not be severe. If necessary, sodium phosphate or sodium carbonate may be added to the water to prevent the formation of adherent calcium sulphate scale.

### Boilers and High Temperature Equipment

Where temperature exceeds 250 F, complete softening of the water is the only practical method for minimizing sludge formation. This is usually accomplished by artificial or natural zeolites (called also ion-exchange materials) or by hot-process precipitation softeners.

In boilers operating at pressures above 100 psig virtually all the calcium, magnesium, silica, iron, and manganese salts entering with the feed water are potential scale or sludge formers.

In boilers operating at 100 to 250 psig, the formation of adherent calcium sulphate (anhydrite) scales is most to be feared. Such deposits form on the *hottest* evaporative surfaces. The scale has a low heat conductivity. Even a layer of egg shell thickness may so impede the rate of heat transfer as to bring about over-heating of the metal.

The ortho-phosphates of sodium are most frequently used to prevent sulphate scales. The concentration of phosphate required is such as to cause the precipitation of calcium phosphate as sludge, thus keeping the boiling water under-saturated with respect to calcium sulphate. To a lesser extent, sodium carbonate (called also soda ash and sal soda) is also used. Most of the effective boiler compounds contain either phosphates or soda ash, or both. Certain organic materials and colloids are sometimes found to minimize scale formation. Where chemicals are introduced directly into the boiler in amounts adequate to prevent scale, sludge is formed in amounts proportionate to the calcium and magnesium salts entering with the feed water. To prevent troublesome accumulation of this sludge, as well as soluble salts, as evaporation occurs, some *blowdown* of boiler water is necessary.

### CAUSES AND PREVENTION OF SLIMES

A water containing slime-producing organisms will produce prohibitive amounts of slime *only* when the conditions of use are such as to propagate their life processes. Whenever sufficient food material from normal water or from airborne dust combines with optimum temperature conditions, such as exist on cooling surfaces and air washers, serious quantities of slime will be produced.

Some natural well waters do not contain sufficient foods to support luxuriant slime-growths. Algae, which require light for carrying on their life processes, are likely to cause difficulty in cooling towers and other areas where sunlight is abundant. The ordinary slime-forming bacteria are capable of using a wide variety of nitrogenous and cellulose material as food sources. These bacteria thrive best under dark conditions such as exist in condensers and other heat transfer surfaces. Other organisms capable of causing similar difficulties use such a wide variety of food material as algae,<sup>14</sup> iron compounds,<sup>15</sup> and inorganic sulphates.<sup>16</sup>

At present, the use of toxic chemicals and irradiation are the two general means employed in slime control. The value of ultra-violet light, used so broadly in the beverage industry, is somewhat in dispute.

Anti-fouling paints have been developed and are fairly satisfactory for the prevention of the growth of macro-organisms such as *barnacles* and *mussels*, but these paints must be renewed at frequent intervals, and are not applicable to inaccessible areas such as the inside of pipe lines and cooling towers. Satisfactory *anti-sliming* paints have *not* been found.

Names and other pertinent data relating to some of the more common chemicals used in slime control are shown in Table 6.

Chlorine is the only chemical to which is attributed the ability to destroy slime-forming organisms. The others are presumed to poison marine organisms, most of which *recover* when the chemical is not used regularly.

While chlorine is the most generally used chemical, the use of others may occasionally prove to be more practicable. Choice of the chemical is conditioned largely by the design and operation of the system.

### Open Recirculating Systems

In spray ponds and cooling towers of the open type, light-loving algae growths are likely to cause blocking of the distribution piping and troughs. These organisms are most troublesome in areas accessible to sunlight. Algae slimes are usually stringy in character.

In open recirculating systems, continuous use of small quantities of chlorine is generally most satisfactory. In once-through systems, where

TABLE 6. COMMON CHEMICALS USED FOR SLIME CONTROL

| CHEMICAL                    | TRADE NAME                                                      | PHYSICAL STATE*                        |
|-----------------------------|-----------------------------------------------------------------|----------------------------------------|
| Chlorine                    | Chlorine                                                        | Gas                                    |
| Hypochlorites               | Calcium Hypochlorites<br>Sodium Hypochlorites                   | Crystalline                            |
| Chlorinated Phenols Sodium— | Chlorophenylphenate<br>Tetrachlorophenate<br>Pentachlorophenate | Briquettes<br>Briquettes<br>Briquettes |
| Potassium Permanganate.     | Permanganate of Potash                                          | Crystalline                            |
| Copper Sulphate             | Blue Vitriol                                                    | Crystalline                            |

\* As Shipped.

large quantities of water are used, intermittent treatment a few times each day will usually result in satisfactory slime removal and chemical economies.

Neither the phenols nor copper sulphate may be used for the removal of slime already formed. For this purpose, chlorine gas is used. After being cleaned, the other chemicals may be used to prevent the reestablishment of slime in the system. The removal of green algae from a cooling tower should never be used as an indication that the true slime-forming organisms on heat exchanger surfaces have been removed. The more resistant slime formers, which so materially reduce heat transfer efficiency, will often be unaffected by treatment which completely eliminates algae.

Copper sulphate must be used with care because it can cause serious corrosion of steel in a system. It is also ineffective in alkaline water because the copper is precipitated from the water.

### Closed Once-Through Systems

In equipment where light is excluded, slime formations are due to fungi. Usually, they predominate on the heat exchange surfaces. Bacteria form thick, soft slime. Yeast and molds form tough rubbery slimes. Chlorine and hypochlorite solutions, fed intermittently, are usual preventatives.

### UNDERWATER CORROSION

When deleterious substances are present in water, the corrosivity of the solution is increased in proportion to the amount of deleterious substances present, the temperature, and usually the rate of flow of the solution over



the metal surfaces. There are other relevant factors, but their influence in general is subordinate to those mentioned. Dissolved oxygen, acid gases, and chloride salts are the corrosion accelerators most frequently encountered.

Neutral and slightly alkaline waters saturated with air, corrode iron at a rate about triple that for the same water free of air. Hot water containing oxygen will corrode iron at a rate three to four times that for the same water when cold.

Corrosion of iron decreases as the *pH* of water solutions increases, and practically ceases at a *pH* of 11. If the metal contains film forming agents, such as chromium, nickel, and silicon, or if the water contains inhibitors such as silicates and chromates, corrosion may in some instances be minimized.

Soft water, as for example the effluent from zeolite softeners, is likely to be several times more corrosive to iron than hard waters. In small installations, the use of copper or brass pipe usually is a practical expedient. Cement-lined pipe and tanks suitably resist attack.

Where the water contains slime-forming organisms, especially those bacteria that thrive on iron, chlorination of the water is imperative to inhibit tuberculation and subsequent pitting.

Bitumastic paints, applied at regular intervals upon well cleaned surfaces, will measurably prolong the life of equipment handling cold waters.

**Pipe Materials.** Brasses with 60 to 67 percent copper are dezincified in some corrosive waters, and in certain localities are not much more serviceable than galvanized iron or steel pipe. The zinc in brass pipes is leached out locally, leaving a plug of porous copper. The weakening of such pipe is especially noticeable under the threads. Dezincification is retarded by the use of silicate of soda (8 ppm added silica).<sup>17</sup>

In salt or fresh water, there is no material difference in rate of pitting of wrought iron, steel, low metalloid steels, or copper bearing steels. This is contrary to the relative performance of these metals in atmosphere.

#### Once Through Systems

Corrosion prevention in once through systems is obtained by any one of or a combination of the following methods.<sup>12</sup>

1. Forming a protective film of calcium carbonate on the metal surfaces.
2. Mechanical or chemical deaeration, or both, of the water.
3. Use of organic or inorganic corrosion inhibitors, or both, in low concentrations.

Formation of a thin protective calcium carbonate film is accomplished by adjustment of the water until the Langelier Index has a value greater than +0.5. This is rather difficult in systems which have a wide variation in temperature. Since the Langelier Index is dependent on temperature, when a water is adjusted to form a protective film on those surfaces of higher temperature, no film will form on colder surfaces. Therefore, this method of corrosion control is more applicable to large municipal distribution systems. Where heat transfer is involved, the method is usually impractical except under unusual circumstances. When this method is used, *pH* is increased by using an inexpensive alkali such as lime, caustic soda, or soda ash. Lime is usually used for waters of low calcium content. Caustic soda or soda ash are used for waters of high calcium content.

Mechanical<sup>18</sup> and chemical deaeration are not often used in once through

systems because of relatively high operating costs. Mechanical deaeration also requires the use of costly equipment. Chemical deaeration is usually accomplished by raising *pH* with caustic soda and by continuously feeding catalyzed sodium sulfite in proportion to water flow. The use of catalyzed sulfite is not permitted in water to be used for potable purposes.

There are several corrosion inhibitors such as chromate, polyphosphates, and silicates which are effective in once through systems.<sup>19</sup> Chromates are not usually used because, when maintained at an effective concentration of 300-500 ppm, their cost is prohibitive. It has been found that the use of polyphosphate at a concentration of 2-5 ppm is effective in controlling tuberculation of iron pipe and in reducing overall corrosion.

The use of chromate-polyphosphate concentrations at less than 60 ppm has also proved effective. Under no circumstances may chromates be used in potable water systems.

Sodium silicate is often used in relatively soft waters by increasing the silica content about 8 ppm. It is used primarily to reduce corrosion in potable water supply systems.

#### Open Recirculating Systems

Corrosion in open recirculating systems, such as air washers and cooling towers, is usually controlled by use of corrosion inhibitors such as chromates polyphosphates, a combination of chromate and polyphosphate, and nitrites.<sup>20, 21</sup> Mechanical or chemical deaeration is not practicable in open systems because of the high rate of aeration. It is not practicable to use high *pH* values of 11 or more in systems containing wood. High *pH* will cause serious delignification of wood. High *pH* values also prevent control of scale. Corrosion control is usually carried out in the *pH* range of 6.5-8.

Chromates are by far the most effective corrosion inhibitors. It is extremely important, however, to maintain an adequate concentration of 300-500 ppm, which is effective for most systems. If for economic reasons substantially lower concentrations are used, serious pitting corrosion may occur.

Polyphosphates are most effective in reducing tuberculation. It is not usually possible to reduce overall corrosion to anywhere near the degree possible with chromate.

Where economy of treatment is of primary importance, a substantial reduction of pitting and overall corrosion can be obtained by using as little as 60 ppm of a mixture of polyphosphate and chromate. Close control over *pH* is a requirement for good corrosion control by this process.

Sodium nitrite has not had widespread use as a corrosion inhibitor in open recirculating systems. It has been reported that difficulty may be encountered in maintaining effective concentrations. Considerable field experience is needed to further qualify this inhibitor.

#### Closed Recirculating Systems

The term Closed Recirculating System is in reality a misnomer. Except for relatively small systems, most closed systems are open because they most usually require make-up water. Recently, tests conducted on 84 closed systems indicated that more than 50 percent of the systems had one or more water changes per month because of leakage. Weekly water changes were found in more than 10 percent of the systems.<sup>22</sup> Continuous make up, of course, replenishes oxygen in the system, thus promoting

corrosion. It is imperative, therefore, that corrosion control be provided for most closed systems. The age old assumption that closed systems are closed is no longer valid.

Corrosion control is usually accomplished by (1) mechanical or chemical deaeration or (2) use of corrosion inhibitors such as chromates and nitrites.

The use of polyphosphates is not generally recommended for closed systems because they will revert to ineffective orthophosphates unless there is a large replacement of water containing polyphosphate.

Higher concentrations of chromate are usually maintained in closed systems as compared with open systems. This is primarily due to the fact that, since water losses are usually small, the cost of maintaining excess chromate as a safety factor is small.

### Treating Chemicals

Whenever chemicals are used to control scale, corrosion, algae, and slime, competent advice from a water chemist is desirable. Often factors considered irrelevant to the layman, will be of much importance in secur-

TABLE 7. QUANTITIES OF SODIUM DICHROMATE TO BE ADDED TO MAINTAIN INITIAL CONCENTRATION

| SPECIFIC GRAVITY OF BRINE TO BE STRENGTHENED | LB SODIUM DICHROMATE PER 100 LB CaCl <sub>2</sub> ADDED |
|----------------------------------------------|---------------------------------------------------------|
| 1.16                                         | 0.695                                                   |
| 1.18                                         | 0.621                                                   |
| 1.20                                         | 0.556                                                   |
| 1.22                                         | 0.502                                                   |
| 1.24                                         | 0.455                                                   |
|                                              | LB OF SODIUM DICHROMATE PER 100 LB NaCl ADDED           |
| 1.12                                         | 1.79                                                    |
| 1.14                                         | 1.47                                                    |
| 1.16                                         | 1.32                                                    |
| 1.175                                        | 1.18                                                    |

ing effective treatment. Very often troubles are created through improper use of chemicals and are more serious than if they were not used.<sup>23</sup>

### Refrigerating Systems

Corrosion in refrigerating systems is confined to surfaces in contact with brines or those in contact with the refrigerant.

**Brines.** Refrigerating brines usually are comprised of sodium chloride, calcium chloride, or calcium and magnesium chlorides. The corrosivity of dilute brines is higher than their more concentrated solutions. The corrosivity of sodium brines, other conditions being fixed, is about 1.5 times greater than brines of the alkaline earth metals.

Brines are excellent electrolytes. Contact of dissimilar metals of wide potential differences, when in contact with brines, results in rapid corrosion by galvanic action.

The leakage of air, acid refrigerants, or both, accelerates the corrosivity of brines. Ammonia precipitates calcium and magnesium salts, thus clogging the system at restricted points.

The addition of caustic soda and sodium dichromate to brine solutions to inhibit corrosion of iron, is a more or less general practice. Sodium sili-

cate and sodium phosphate are also used at times, but tests indicate they are not as effective as is sodium dichromate. It has been suggested<sup>24</sup> that 125 lb of sodium bichromate per 1000 cubic feet of calcium chloride brine, and 200 lb per 1000 cubic feet of sodium chloride brine, be added to inhibit brines; that when salt or calcium chloride is added to "strengthen" brine, sodium dichromate also be added in the amounts shown in Table 7.

**Refrigerants.** The common refrigerants, except those of the hydrocarbon type, will attack the common metals and alloys if *moisture is present*. Even a very small amount of water may cause severe corrosion with certain refrigerants. The amount required need only be sufficient to produce a water film on the metal surface.

With the halogenated hydrocarbons, complete elimination of water is much to be desired. Where ammonia is used, copper and its alloys, aluminum and zinc, are attacked especially at elevated temperatures. When sulphur dioxide is used, more than 50 ppm (0.005 percent) of water will cause appreciable corrosion of virtually all the common materials.

### Minimizing Condensate Corrosiveness

There are four expedients that may be utilized to minimize corrosion in steam condensate systems: (1) treatment of the boiler feedwater so as to eliminate deleterious gases entrained with the steam, (2) design of the condensing equipment to minimize dissolution in the condensate of the deleterious gases entrained with the steam, (3) chemical treatment of the condensate, (4) use of resistant metals.

**Boiler Feedwater Treatment.** Elimination of oxygen from boiler feedwater and, therefore, from the steam developed, can be accomplished either mechanically or chemically. In some steam generating stations, both expedients are employed.

Tests<sup>25</sup> have indicated that in small low-pressure heating boilers, where the boiler input contains less than about 50 ppm of carbonate hardness, the CO<sub>2</sub> in the steam can be controlled by adding calcium hydroxide to the boiler. In Fig. 6 are shown the equilibria conditions proposed for boilers operating at pressures up to about 5 psi gage. This expedient may *not* be used in higher pressure boilers, because of the possibilities of scale and sludge formations. In the latter, the only method used to date for treating the feedwater consists of removing the alkaline earth salts, *i.e.*, softening, and subsequent acidulation followed by deaeration at temperatures near the atmospheric boiling point of water.<sup>26</sup>

**Design of Condensing Equipment.** In the design of water heaters and comparable types of condensing equipment,<sup>27</sup> it is possible to shift the accumulation of non-condensable gases to a location away from the condensate level and, subsequently, vent these gases to the atmosphere. Venting an amount of steam equal to about one-half percent of the total steam entering the condenser is the optimum vent rate.

Venting is of little practical value when the CO<sub>2</sub> content of the incoming steam is below about 5 ppm. When the steam contains more than 5 ppm, venting provides a means of producing a condensate containing a minimum of about 3 ppm. However, even as little as 3 ppm of dissolved CO<sub>2</sub> can produce active corrosion if large amounts of condensate are flowing.

**Chemical Treatment of Condensate.** Condensates containing comparatively large amounts of oil, are practically non-corrosive, due to the protective film provided by the oil. When oil is intentionally added to con-

densate,<sup>28</sup> inadequate quantities may accelerate rather than decelerate corrosion on those surfaces not covered by the oil. Sodium silicate added to  $CO_2$ -bearing condensate has been shown to decrease, but not entirely prevent, corrosive action. It is not known whether the protection afforded by silicate solutions is due to the establishment of a protective film on the metal surface or to neutralization of the  $CO_2$  by the alkali in the silicate solution.

It has been postulated that ammonia,<sup>29</sup> cyclohexylamine,<sup>30</sup> ethylene diamine, and morpholine<sup>31</sup> will retard corrosion of condensate lines. Tests with benzylamine have also been reported.<sup>32</sup> Where copper and its alloys are involved, the use of alkaline inhibitors is believed inadvisable. The use of small amounts of sodium hexametaphosphate has been suggested

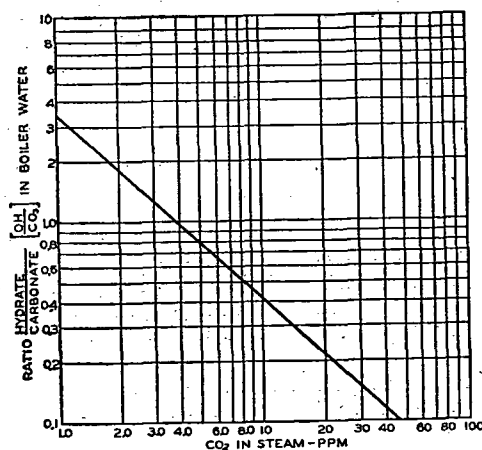


FIG. 6. RELATION OF HYDRATE/CARBONATE CONTENT IN *Hard* BOILER WATER AND  $CO_2$  IN STEAM AT ABOUT 5 PSI OPERATING PRESSURE  
(All analytical values are ppm by weight)

too, but tests<sup>33</sup> indicate that this salt accelerates rather than decelerates, the rate of attack of steel by condensate containing  $CO_2$  and oxygen. Whether chemical treatment of steam or condensate is feasible, must be determined not only upon the basis of the acuteness of corrosion troubles, but also upon the uses to which the steam or condensate is put.

**Use of Resistant Metals.** For economic reasons, the metals known to resist corrosion can seldom be used exclusively for condensate lines in any sizable enterprise. Nevertheless, there may be instances where the use of a limited amount of the more costly, but resistant, materials can be justified. The data in Fig. 7 are the results of tests<sup>34</sup> designed to reflect the corrosion resistance of the more commonly used metals to attack by condensate containing oxygen and  $CO_2$ .

In contemplating the use of a resistant metal, as a section of a condensate line, it should be remembered that, if other conditions are *right*, corrosive attack will merely be transferred down stream in the system. Galvanic corrosion resulting from the contact of dissimilar metals in a condensate line seldom occurs. No paint or similar protective coating

has thus far proven satisfactory. Tests of cement-lined and vitreous-lined pipe have shown the linings to be readily dissolved by hot condensates.

### ATMOSPHERIC CORROSION

Most of the problems originated by atmospheric corrosion occur in connection with the fire-side of boilers and furnaces (including their flues and stacks), sewer vents, air ducts, coal and ash handling equipment. Usually such equipment is fabricated from common types of ferrous metals.

Generally little or no atmospheric corrosion occurs at temperatures higher than the boiling point of water, because at such temperatures little or no condensate is formed. If it does form at the higher temperatures, only negligible amounts of carbon dioxide and oxygen present in the

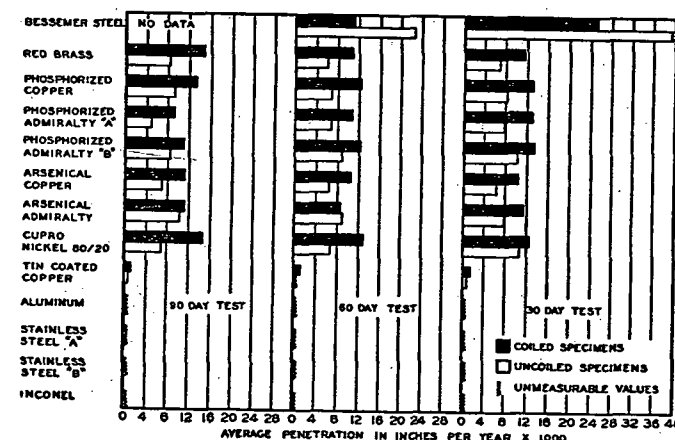


FIG. 7. COMPARATIVE CORROSION RESISTIVITY OF 10 MATERIALS EXPOSED TO CONDENSATE

atmosphere, will dissolve in the hot liquid, but sulphur gases may dissolve and cause rapid attack. Oxygen, sulphur dioxide, sulphur trioxide, and carbon dioxide are the deleterious gases most frequently accountable for corrosion in moist atmospheres.

### Coal Storage and Handling Equipment

Virtually all coals contain sulphur in the form of pyrite, and some moisture. In storage, the pyrite is likely to be decomposed by oxidation. Moisture dissolves the products of decomposition forming sulphurous and sulphuric acid. The acid solutions vigorously attack the supporting metal.

Rubber linings have been developed for coal chutes and bins to effectively resist corrosion and the abrasive action of the coal, but they are expensive.<sup>35</sup> Concrete linings for steel bunkers have also been effectively employed.<sup>36</sup>

The use of high chromium steels is not always a sure cure, especially with coals treated with dust allaying agents high in chlorides.

### Flues, Stacks, and Fire-side of Boilers

The surfaces of flues and boilers contacting the products of combustion, seldom experience corrosive attack when the equipment is in operation.

Breechings, smoke hoods and canopies in contact with flue gas may, however, be subject to attack during the warming-up period of an appliance, or when the rate of operation is so low that the temperature of the flue gas is below the dew-point. It is common practice to use cast-iron or acid resistant vitreous enameled steel in flue gas connections to appliances, to prolong the life of these parts. The shut-down period, when condensation of moisture occurs on the metal surfaces, is usually the time when most damage is done.<sup>37</sup> In those sections of the stacks where flue gas temperature drops below the dew-point, corrosion is inevitable during operation.

It is clear that where long shut-down periods are anticipated, a practical method for mitigating corrosion is to clean the surface thoroughly and to provide adequate clean, dry air circulation to prevent condensation. (See also Care of Idle Heating Boilers, Chapter 16).

Protective coatings with organic binders are destroyed rather rapidly above 400 F because of the decomposition of the organic materials. The surfaces of metals, whose temperature does not exceed 400 F, may be protected by periodically applying paints such as those specified in the following paragraphs entitled Air Ducts.

#### Air Ducts

The most practical method for protecting air duct surfaces made of steel from atmospheric corrosion, is to apply protective paints. One of the most effective protective coatings is red lead paint.

Three coats of paint should be applied, of which the first two coats should be rust inhibitive paint such as red lead paint, with the second coat tinted to a light brown color with carbon black, and the finishing coat may be red lead paint tinted to a black or brown color, black paint made according to Federal Specification TT-P-61; red iron oxide paint conforming to Federal Specification TT-P-31, or white or light tinted paint made according to Federal Specification TT-P-40.

Another paint which has had some use for priming iron and steel is zinc chromate paint.

Under some conditions, a chlorinated rubber base paint made according to Federal Specification TT-P-91 may be used for the finishing coat, particularly where the presence of highly corrosive gases or contact with strong alkaline water would injure the standard paints. Rubber base paints should be used only for the finishing coat over regular priming and second coats.

#### BURIED PIPE LINES

Lines that are cold and in intimate contact with the earth are corroded from the same causes as in mineral waters, but pitting is usually more intense due to variations in concentration of salts and oxygen in solution, acidity, drainage, and presence of solid materials (such as cinder) in contact with metal pipe. Galvanic currents, induced by contact of certain dissolved constituents in the soil, often act over a large area, and accelerate corrosion where they leave the pipe line.

Certain bacteria that thrive in the absence of oxygen have the power to obtain hydrogen and dissociate sulphates in the soil, with a resultant production of hydrogen sulfide which attacks the iron to form iron sulphide.

Stray electric currents from electric power generating stations sometimes find their way into buried steel structures, and do damage in proportion to the current density where the current leaves the metal to enter the ground.

#### Pipe Materials

Under many conditions where steel would be corroded, the use of corrosion-resistant metals other than steel may be desirable, even if greater in first costs. Wholly austenitic stainless steels are very resistant to underground corrosion. In most environments copper, red brass, and copper-silicon alloys will resist corrosion and may, at times, be used to advantage. However,<sup>38</sup> soils with a high content of organic matter, or alkaline soils in which the ratio of chlorides and carbonates to sulfate is high, may be corrosive. Copper should not be embedded directly in cinders or in tidal marshes where it may be subjected to attack by sulfur compounds. Lead<sup>39</sup> corrodes chiefly in soils deficient in oxygen or containing cinders. Because lead is corroded to a considerable extent in most soils, lead coatings applied to steels are not adequate for underground use.

Galvanized iron pipe will resist corrosion for various periods of time, depending on the soil and how long the galvanized coating lasts. The zinc used for the galvanized coating is on the electrochemical protective side of the iron, and the zinc is corroded and changed to zinc compounds before the iron is attacked. This accounts for the protection afforded by galvanized iron. Even if some protection is obtained, eventually the galvanized coatings are destroyed by chemical action and the corrosion of the steel begins.

#### Protective Coating

Protective coatings for buried pipe lines are in a class by themselves because of the unusual service conditions, and because it is not possible to maintain them by recoating when necessary. Buried steel pipe lines have been protected against corrosion with considerable success by the use of very thick bituminous coatings applied in molten condition. The best results are obtained by applying the bituminous coatings over a standard priming coat such as red lead or a bituminous paint, and for long service it has been found that after the bituminous coatings are applied, a wrapping of asbestos fabric saturated with bitumens will prevent movement and displacement of the bituminous coatings, and add greatly to the length of time satisfactory protection will be maintained.

#### Cathodic Protection

Protection is obtained by rendering the structure cathodic to the surrounding water or soil by means of a controlled difference of potential. This method, which has proved satisfactory and economical on a number of gas and oil pipe lines underground, has also been applied with some success to the protection of the inside of water storage tanks and other structures that are in contact continuously with water. Protective coatings that insulate a large portion of the metal surface will reduce very materially the total amount of protective current that must be impressed on bare anodic areas to arrest corrosion.

Because of differences in environmental conditions, it is necessary to determine or estimate the minimum current density required for each structure, and design the anode or anodes so that the necessary protection can be obtained most economically. In water having relatively high electrical conductivity such as in sea water, this is comparatively easy compared with fresh water. In the latter, the composition of the water is a major factor. It is therefore desirable to obtain an accurate estimate of the minimum current density required. The current is then controlled by the potential between the anode and the structure to be protected.

Rectifiers have generally proved to be the most practical means for supplying the necessary current for protection of surfaces in contact with neutral waters.<sup>40</sup>

### HANDLING WATER TREATING CHEMICALS

Virtually all the chemicals used in water conditioning are injurious if taken internally in large doses. Many also cause severe skin irritation. Thus, they should be handled with caution.

Caustic soda, lime, and concentrated sulphuric acid will burn the flesh. In addition, if mixed with small amounts of water, sufficient heat may be generated so that spattering occurs or the container becomes too hot to handle.

The chlorophenol compounds, even in the low concentrations used in water conditioning, have been reported<sup>41</sup> to produce dermatitis. Chrom-itch is not uncommon among workers handling chromates. The amines are said to be absorbed through the skin.<sup>42</sup> Morpholine is said to cause kidney and lung trouble when so absorbed.

Chlorine gas irritates the skin, eyes, and mucous membranes. Concentrations as low as 0.004 percent by volume in air cause dangerous illness in 0.5 to 1 hour.

When relatively large amounts of the non-gaseous chemicals are to be handled, protective clothing, including goggles, should always be provided, and a shower head or its equivalent provided at or very near the point where the chemicals are mixed. *Chemicals should always be washed from the skin with large volumes of water.*

For the handling of chlorine and chlorinators, the *U. S. Public Health Service*<sup>43</sup> stipulates the following safety requirements:

1. Suitable gas masks and a small bottle of ammonia for testing for leaks should be kept at convenient points immediately outside the room or enclosure in which chlorine is being stored or is in use. Gas masks should be inspected at regular intervals and kept in serviceable condition. Note:—All-purpose masks offer adequate protection only when the concentration of acid gases does not exceed two percent—see Safe Practices Pamphlet #64 National Safety Council.

2. Chlorinating equipment and cylinders of chlorine should be housed preferably in separate buildings above the ground level.

3. The room or building housing chlorinators in service should be maintained at a temperature above 60 F, but never in excess of the normal summer temperature. The cylinders of chlorine should be shielded, where necessary, from excessive heat or cold. Direct heat should not be applied to cylinders of chlorine, nor should hot water be poured over them or come in contact with the cylinder valve.

4. Adequate ventilation should be provided for all enclosures in which chlorine is being fed or stored.

5. All joints of tubing connecting chlorine cylinder and chlorinators should be kept absolutely tight and inspected frequently to insure tightness. Tubing should slope upward from the cylinder.

### LEGAL REGULATIONS

In a number of states, the water used for humidification, even in industrial plants, is required to meet drinking water standards insofar as bacteriological quality is concerned. A ruling of the *U. S. Department of Agriculture, Meat Inspection Division*, prohibits the use of chromate in water used for air washing when the air later contacts foodstuffs.<sup>44</sup>

There is an ever growing consciousness on the part of public health officials, of the necessity for regulations to protect potable water supplies. Attesting this is an ordinance<sup>45</sup> now in effect in Detroit, Michigan, which stipulates in part:

"No physical connection shall be maintained between lines carrying city water and pipes, pumps, or tanks supplied from any other source. Where dual supplies are necessary or desired, lines carrying city water must be protected against back flow of polluted water by an *atmospheric gap*. Secondary supplies and emergency sources shall include: surface waters from rivers, lakes, ponds, lagoons, and reservoirs; well waters both deep and shallow; any supply of water which has been stored, held, or reserved after being used for industrial purposes; cooling water, or water which has in any way been treated, processed, or has been subjected or exposed to any contamination of a bacteriological or chemical nature; and water from any other source than the city supply."

The *U. S. Public Health Service* stipulates:

"Salts of barium, hexavalent chromium, heavy metal glucosides, or other substances with deleterious physiological effects, shall not be allowed in the water supply system."

The same agency recommends that the concentration of the substances listed be held below the values cited in Table 8. The Board of Directors

TABLE 8. RECOMMENDED MAXIMUM ALLOWABLE CONTENT IN WATER SUPPLY\*

| SUBSTANCE                     | MAX. CONCENTRATION, ppm | SUBSTANCE                     | MAX. CONCENTRATION, ppm |
|-------------------------------|-------------------------|-------------------------------|-------------------------|
| Copper.....                   | 3.0                     | Arsenic.....                  | 0.05                    |
| Iron & Manganese (Total)..... | 0.3                     | Selenium.....                 | 0.05                    |
| Magnesium.....                | 125.0                   | Phenols (Total).....          | 0.001                   |
| Zinc.....                     | 15.0                    | Poly-phosphate of Sodium..... | 10.0                    |
| Lead.....                     | 0.1                     | pH Value @ 25C.....           | 10.6                    |
| Fluorine.....                 | 1.0                     |                               |                         |

\* *U. S. Public Health Service.*

of the *American Water Works Association* has accepted these values as standard for all public water supplies in the United States.<sup>46</sup> While their action is not binding, prudence dictates that no form of treatment should be used that will result in raising the concentration of the substances listed above the value cited.

Since virtually all of the permissible chemicals used for scale, slime, and corrosion control have deleterious, physiological effects if taken internally in *relatively large doses*, they should always be carefully *proportioned*. To insure this, the Detroit ordinance stipulates that the chemical feeding device must have the following major characteristics:

- "1. There shall be a visible means of checking the quantity of material being applied by the feeding device.

2. A water metering device, sealed to prevent tampering, shall be installed to measure the flow of water being treated.

3. The device shall be constructed so that in the event of back-flow or vacuums, the maximum amount of material that may be possibly back-siphoned from the device or any of its attachments or parts shall not exceed one fluid ounce.

4. Should there be a failure of the water metering device or the water supply, the feeding device shall automatically cease operating."

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## CHAPTER 44

## OWNING AND OPERATING COSTS

Fixed Charges: Amortization, Interest, Taxes, Insurance, Rent; Maintenance Costs;  
Labor for Operation; Energy and Water Costs: Operating Refrigerating  
Equipment, Condenser Water, Heating

THE total cost for the use of heating, ventilating, and air conditioning systems may be divided into two classifications. The first of these is the relatively fixed and unvarying expense of ownership, and the second is the variable and somewhat controllable expenditure for actual operation of the equipment. Owners and prospective purchasers of this equipment are particularly concerned with both since the actual expenditure is generally predicated upon the possible return on the investment resulting from increased patronage, greater efficiency on the part of the employees, meeting of competition, or the improvement and maintenance of quality in a manufactured product. These costs may be grouped under four headings: (1) *Fixed Charges*, (2) *Maintenance Costs*, (3) *Labor for Operation*, and (4) *Energy and Water Costs*.

## FIXED CHARGES

Fixed charges are the annual expenses arising from the ownership of the installation, including use of the owner's money, and protection of the equipment in the form of insurance. Such costs are usually unchanged from year to year regardless of whether the equipment is in or out of service. Fixed charges may be grouped under five headings: (1) *Amortization*, (2) *Interest*, (3) *Taxes*, (4) *Insurance*, and (5) *Rent*.

## Amortization

As air conditioning equipment becomes older, its ability or capacity to perform present and future service is reduced. Provision must be made for the owner to recover each year a portion of the initial value of the equipment as an expense to be charged against revenue, or to amortize the cost. This decrease in the value of property is usually determined by an accountant or engineer using some theoretical method and will depend upon (1) the total first cost, and (2) the amortization period.

The total first cost of an installation is the actual capital expenditure required to buy and install the air conditioning, heating, or ventilating system ready for operation. It represents the first cost of the equipment combined with additional costs incurred because of the installation of the system.

The first cost of air conditioning, heating, or ventilating systems includes the following:

1. Heat producing equipment including boilers, burners, controls, etc.
2. Heat distributing equipment including direct radiation, piping, etc.
3. Air handling equipment including fans, air heaters, air conditioners, filters, controls, etc.
4. Air distribution system including ducts, outlets, grilles, etc.
5. Refrigerating equipment including piping, pumps, etc.
6. Water conservation devices including towers, evaporative condensers, etc.



TABLE 1. COST DOLLARS PER TON FOR A COMPLETE SYSTEM, INCLUDING HEATING AND COOLING COILS, FAN, DUCTS, REFRIGERATION EQUIPMENT, TEMPERATURE CONTROLS, ETC.\*

| 1                  | 2                | 3                     | 4                               | 5                                        | 6                       | 7                      | 8       | 9       | 10              | 11      | 12                                          | 13                                  |
|--------------------|------------------|-----------------------|---------------------------------|------------------------------------------|-------------------------|------------------------|---------|---------|-----------------|---------|---------------------------------------------|-------------------------------------|
| REFRIGERATION TONS | FLOOR AREA SQ FT | AIR DISTRIBUTED CU FT | REFRIGERATION EQUIPMENT PER TON | DUCTS, FANS, HEATING COILS, ETC. PER CFM | REFRIGERATION EQUIPMENT | AIR HANDLING EQUIPMENT | TOTAL   | PER TON | PER SQ FT FLOOR | PER CFM | EVAPORATIVE CONDENSERS PER TON <sup>b</sup> | COOLING TOWERS PER TON <sup>c</sup> |
| 25                 | 8,333            | 12,500                | 250                             | 1.05                                     | 6,250                   | 13,100                 | 19,350  | 775.00  | 2.32            | 1.55    | 190.00                                      |                                     |
| 50                 | 16,666           | 25,000                | 224                             | 0.98                                     | 11,200                  | 24,500                 | 35,700  | 730.00  | 2.15            | 1.43    | 155.00                                      |                                     |
| 75                 | 25,000           | 37,500                | 212                             | 0.95                                     | 15,900                  | 35,700                 | 51,600  | 690.00  | 2.07            | 1.38    | 120.00                                      |                                     |
| 100                | 33,332           | 50,000                | 204                             | 0.92                                     | 20,400                  | 46,000                 | 66,400  | 664.00  | 1.99            | 1.33    | 90.00                                       | 52.00                               |
| 150                | 50,000           | 75,000                | 195                             | 0.91                                     | 29,200                  | 68,200                 | 97,400  | 650.00  | 1.95            | 1.30    | 60.00                                       | 50.00                               |
| 200                | 66,664           | 100,000               | 192                             | 0.90                                     | 38,200                  | 90,000                 | 128,200 | 641.00  | 1.93            | 1.28    |                                             | 48.00                               |
| 250                | 83,333           | 125,000               | 187                             | 0.88                                     | 46,800                  | 110,000                | 156,800 | 628.00  | 1.88            | 1.25    |                                             | 46.00                               |
| 300                | 100,000          | 150,000               | 182                             | 0.86                                     | 54,600                  | 129,000                | 183,600 | 612.00  | 1.84            | 1.23    |                                             | 44.00                               |
| 400                | 133,328          | 200,000               | 165                             | 0.84                                     | 66,000                  | 168,000                | 234,000 | 585.00  | 1.76            | 1.17    |                                             | 42.00                               |
| 500                | 166,666          | 250,000               | 158                             | 0.82                                     | 79,000                  | 205,000                | 284,000 | 568.00  | 1.71            | 1.14    |                                             | 40.00                               |

\* These cost figures (based on 1950 prices which may be adjusted by using current building cost index) cover only the average type of comfort air conditioning in open spaces as in department store, or for industrial air conditioning involving large areas. Where a multiplicity of small spaces must be individually controlled, as in office buildings, hotels and apartment houses, the cost of the equipment will be increased accordingly.

<sup>b</sup> Includes on 10 and 11 recent costs where well water or city water is available for condensing purposes. Where conservation of water is required, add column 12 or 13 to column 9 to obtain total cost per ton.

<sup>c</sup> Does not include cost of structural reinforcement, if required to support the weight of cooling towers or evaporative condensers.

## Owning and Operating Costs

7. Insulation of pipes, ducts and equipment.

8. Building alterations, furring-in ducts and pipes, structural work, etc.

To estimate the first cost of any system prior to installation, the best procedure is to determine the heating and cooling load, and then after thorough engineering study, select the type of system. The installed cost of systems will vary widely, depending upon the type of equipment selected, and the design of the distribution system, equipment and labor costs in the locality, demands for the particular installation, etc. A reasonable approximate cost may be determined for a selected design in a given locality from the sum of the estimated unit costs of the component parts of the system. A reasonably precise estimate of the cost of the components may be obtained from cost records of recent installations of a comparable design, or from quotations submitted by manufacturers and contractors.

Approximate costs are given in Table 1 for mechanical air handling systems including heating and cooling coils for distributing  $1\frac{1}{2}$  cfm per square foot of floor area and refrigeration equipment based upon a requirement of one ton for every 333 sq ft of floor area. Different types of service demand may change the floor area per ton of refrigeration and air volume per square foot between wide limits and, consequently the table should be used with caution.

Other first costs may be incurred because of the installation of the air conditioning or heating and ventilating system. These will include such items as electrical work, plumbing, miscellaneous piping, building alterations, cutting, patching, furring-in of ducts or pipes, foundations, structural supports, remodeling or redecorating after installation, consulting engineer's fees, licenses, and permits. As these costs vary widely no approximations are practicable. Therefore, each case must be considered individually. If a quotation can be secured from a manufacturer or contractor covering the complete job, it will usually include the items which have been mentioned.

The length of the amortization period to be used depends upon (1) the type and remaining life of the building or space for which the system is to be used; (2) the type of equipment to be employed as a part of the system; (3) the character of the business; and (4) the lease or ownership conditions.

Depreciation, due to deterioration or obsolescence, must be considered in arriving at the amortization period. Maintenance and deterioration usually have the effect of offsetting one or the other. If a long depreciation period is to be used, then the item for maintenance, repair, and the replacement of wearing parts must be greater than for a short depreciation period.

In determining the length of the amortization period, the owner's accounting practices will have considerable bearing upon the number of years used in the calculation. For taxation purposes, this period depends upon the use and the service to which the equipment is placed. At the present time indications are that varying interpretations on depreciation will be made by the *Bureau of Internal Revenue*. While most air conditioning equipment may be considered as having a normal, useful life of 20 years for depreciation purposes, no final value for depreciation should be determined without consultation with the owner's tax consultant or perhaps



referral to Schedule F which is issued by the *Bureau of Internal Revenue* and summarized in Table 2.

### Interest

The interest charged to the cost of ownership may be based upon the average interest rate for the period during which the first cost of the equipment will be amortized. While some accountants do not include interest in the annual fixed charges and consider it a negligible item, the money invested in air conditioning, heating, or ventilating equipment, must be either borrowed or diverted from the owner's funds and converted to the

TABLE 2. PROBABLE USEFUL LIFE OF EQUIPMENT\*

|                                               | LIFE IN YEARS |
|-----------------------------------------------|---------------|
| <b>1. HEAT PRODUCING EQUIPMENT</b>            |               |
| (a) Boilers.....                              | 20            |
| (b) Stokers and burners.....                  | 20            |
| <b>2. HEAT DISTRIBUTING EQUIPMENT</b>         |               |
| (a) Piping—copper.....                        | same as bldg. |
| (b) Piping—iron.....                          | 20            |
| (c) Radiation—concealed.....                  | 25            |
| (d) Radiation—direct.....                     | 25            |
| (e) Valves and specialties.....               | 10            |
| <b>3. AIR HANDLING EQUIPMENT</b>              |               |
| (a) Filters—automatic.....                    | 20            |
| (b) Heating and cooling coils.....            | 20            |
| (c) Spray humidifiers and dehumidifiers.....  | 10            |
| (d) Fans.....                                 | 15            |
| (e) Air conditioning units.....               | 10            |
| (f) Motors.....                               | 20            |
| (g) Electrical starting equipment.....        | 20            |
| (h) Pneumatic control systems.....            | 15            |
| (i) Electric control systems.....             | 15            |
| <b>4. AIR DISTRIBUTING EQUIPMENT</b>          |               |
| (a) Ductwork.....                             | same as bldg. |
| (b) Outlets, grilles.....                     | 20            |
| (c) Duct insulation.....                      | 15            |
| <b>5. REFRIGERATING EQUIPMENT</b>             |               |
| (a) Centrifugal refrigerating machines.....   | 20            |
| (b) Reciprocating refrigerating machines..... | 20            |
| (c) Motors and starters.....                  | 20            |
| (d) Piping—copper.....                        | 20            |
| (e) Piping—steel.....                         | 20            |
| (f) Pumps.....                                | 20            |
| <b>6. WATER SAVING DEVICES</b>                |               |
| (a) Evaporative condensers.....               | 15            |
| (b) Cooling towers.....                       | 15            |
| (c) Wells.....                                | 25            |

\* Taken from U. S. Bureau of Internal Revenue Schedule of Probable Useful Life, revised 1942.

purpose of making the installation. Whether it is borrowed or taken from surplus funds, the money that might have been earned as interest is properly chargeable to the operation of the system.

The formulas for computing interest and amortization are given in Table 3. This table also serves as a check list for the various items to be considered in calculating the cost of ownership and operation.

### Taxes

The taxes which may be charged to the property as a result of the improvement due to the installation of an air conditioning system will vary according to the practice of the official agencies levying property taxes.

### Insurance

Insurance against losses by fire is ordinarily secured by increasing the building fire insurance coverage to cover all or part of the first cost of installing the air conditioning and other mechanical systems. Various types of extended coverage are available for protection against a number of other types of losses.

Boiler insurance may be extended to cover the air conditioning equipment to protect against losses due to explosion, rupture of piping, and similar hazards. Since insurance rates vary widely depending upon the type of structure in which the equipment is located and the nature of the owner's business, the rates are usually set by rating organizations specializing

TABLE 3. OWNING AND OPERATING COST

| FIRST COST                                               | ANNUAL SERVICE COST                    |
|----------------------------------------------------------|----------------------------------------|
| Cost of mechanical system.....                           | Electric Power Costs                   |
| Other costs.....                                         | Fans.....                              |
| First Cost (FC)—Total.....                               | Pumps—Chilled water.....               |
| ANNUAL FIXED CHARGES                                     | Pumps—Condenser water.....             |
| Amortization—Depreciation period                         | Pumps—Well water.....                  |
| Y years.....                                             | Cooling tower fans.....                |
| Interest rate 1%.....                                    | Cooling tower pumps.....               |
| Amortization and Depreciation                            | Refrigeration machines.....            |
| FC                                                       | Miscellaneous or other.....            |
| Y                                                        | Gas.....                               |
| Interest: $\frac{Y+1}{2Y} \times i \times \text{cost} =$ | Coal.....                              |
| Taxes.....                                               | Oil—for boilers or Diesel engines..... |
| Insurance.....                                           | Steam.....                             |
| Rent.....                                                | For Direct Heating.....                |
| Annual Fixed Charges:                                    | For Ventilation—preheaters.....        |
| (Total).....                                             | For Ventilation—reheaters.....         |
| ANNUAL MAINTENANCE COSTS                                 | For Turbine driven equipment.....      |
| Replacement or servicing of air                          | For Engine driven equipment.....       |
| filters.....                                             | Sewers.....                            |
| Outside Maintenance service.....                         | Charges for discharging water          |
| Water Treatment.....                                     | into public drainage systems.....      |
| Lubricating oil and grease.....                          | Condenser water.....                   |
| Painting for corrosion protection or                     | Annual Service Costs:                  |
| other purposes.....                                      | Total.....                             |
| Replacement of worn parts.....                           | SUMMARY                                |
| Refrigerant.....                                         | Annual Fixed Charges.....              |
| Wages of engineer or operator.....                       | Annual Service Costs.....              |
| Annual Maintenance Cost—                                 | Annual Maintenance Costs.....          |
| Total.....                                               | Annual Owning and Operating            |
|                                                          | Costs—Total.....                       |

ing in this work. Exact figures on insurance cannot be determined without consultation with the owner's underwriter.

### Rent

If the equipment under consideration is to be located in rented or leased quarters, or if additional space must be rented, such expense becomes a fixed charge.

### MAINTENANCE COSTS

Maintenance charges consist of expense for labor and material necessary to make repairs and replace parts, as well as cleaning, painting, inspection, etc. for the purpose of eliminating or minimizing the need for repairs. Generally, routine maintenance labor requirements will be the function of an operating engineer or staff. If the responsibility of this group may

extend to other facilities beyond the equipment being discussed here, it is important that only an equitable share of the group's time be charged to maintenance.

Extraordinary repairs are quite often handled by separate maintenance divisions and the expense charged back to air conditioning, heating, and ventilating. In other cases, all maintenance is handled by outside service firms and the cost considered as maintenance. These costs vary considerably with factors such as the type of system and the proficiency of the installing and servicing organization. Therefore, any forecast of maintenance costs should include consideration of the equipment as a part of the engineering study. The charges should be based upon the entire period under study rather than the early years of operation when repairs may be expected to be at a minimum.

Various estimates of maintenance costs vary from 5 percent to 10 percent of the installation cost. Table 4 is based upon an average of  $7\frac{1}{2}$  percent for about a 75-ton installation. This probably would apply to most installations using high quality equipment. The maintenance cost must be

TABLE 4. APPROXIMATE MAINTENANCE COST FOR LARGE AIR CONDITIONING INSTALLATIONS, USING HIGH QUALITY EQUIPMENT\*

|                                                 | DOLLARS PER (TON)(YEAR) |
|-------------------------------------------------|-------------------------|
| Repairs for refrigeration machinery.....        | 1.07                    |
| Refrigerant.....                                | 0.40                    |
| Oil and grease.....                             | 0.11                    |
| Painting (Water boxes and dehumidifiers).....   | 0.45                    |
| Filters, clean and re-oil 4 times per year..... | 1.50                    |
| Controls, outside service.....                  | 0.26                    |
| Cleaning air conditioners.....                  | 1.38                    |
| Total.....                                      | 5.17                    |

\* Estimated for 1955.

modified for size of job and quality of equipment. With lower cost equipment, higher maintenance costs can be expected.

The accounting practices of the owner and the rules of the *Bureau of Internal Revenue* affect the charges for major overhauling or complete replacement which may restore the capital value of certain equipment items. In these cases the expenditure may not necessarily be charged as maintenance but will become a fixed charge spread over the remaining years of equipment life. Table No. 4 gives some approximate costs for maintaining large air conditioning installations using high quality equipment.

#### LABOR FOR OPERATION

In some cases with the installation of automatic equipment, operating labor may be non-existent, but where such labor is required, the cost is readily calculated. Where operators are required, the expense is often considered maintenance, but since they may have other functions which are not properly charged to operation of the air conditioning, heating, or ventilating installations the charges should be properly allocated. The cost of experienced and competent operators is well justified in medium and larger plants by economies that can be achieved in maintenance and energy costs.

#### ENERGY AND WATER COSTS

Energy costs include the costs for power, water, steam, coal, oil, etc. consumed to operate the system.

From the selected equipment and type of installation, it is possible to segregate the relatively constant power loads and the total brake horsepower. Annual power cost can then be figured from the following formula:

$$\text{annual power cost} = \frac{0.746(\text{bhp})HR}{\eta} \quad (1)$$

TABLE 5. EQUIVALENT FULL LOAD OPERATING HOURS OF REFRIGERATION EQUIPMENT USED FOR SUMMER COOLING MAY 15 TO OCT. 15\*

| APPLICATION                   | Hr OPEN FOR BUSINESS | ATLANTA | BOSTON | CHICAGO | DETROIT | LOS ANGELES | NEW ORLEANS |
|-------------------------------|----------------------|---------|--------|---------|---------|-------------|-------------|
| Barber Shops.....             | 1280                 | 1010    | 650    | 720     | 720     | 680         | 1080        |
| Department Stores.....        | 940                  | 840     | 560    | 610     | 610     | 530         | 890         |
| Drug Stores.....              | 2100                 | 1630    | 950    | 1060    | 1060    | 980         | 1790        |
| Funeral Parlors.....          | 600                  | 440     | 300    | 330     | 330     | 310         | 470         |
| Offices.....                  | 940                  | 870     | 560    | 620     | 620     | 580         | 900         |
| Restaurant (Short Hour).....  | 1290                 | 970     | 535    | 620     | 620     | 570         | 1060        |
| Restaurant (Long Hour).....   | 2100                 | 1510    | 820    | 930     | 930     | 850         | 1690        |
| Specialty Shops (5 & 10)..... | 1090                 | 800     | 530    | 590     | 590     | 560         | 860         |
| Theaters—Continuous.....      | 1500                 | 1010    | 700    | 750     | 750     | 720         | 1080        |
| Theaters—Neighborhood.....    | 900                  | 640     | 420    | 450     | 450     | 430         | 650         |

| APPLICATION                   | Hr OPEN FOR BUSINESS | NEW YORK | PHILADELPHIA | OKLAHOMA CITY | ST. LOUIS | WASHINGTON D.C. |
|-------------------------------|----------------------|----------|--------------|---------------|-----------|-----------------|
| Barber Shops.....             | 1280                 | 830      | 860          | 1020          | 890       | 940             |
| Department Stores.....        | 940                  | 700      | 720          | 840           | 750       | 780             |
| Drug Stores.....              | 2100                 | 1280     | 1330         | 1650          | 1420      | 1530            |
| Funeral Parlors.....          | 600                  | 370      | 380          | 440           | 400       | 410             |
| Offices.....                  | 940                  | 710      | 740          | 880           | 770       | 810             |
| Restaurant (Short Hour).....  | 1290                 | 760      | 800          | 980           | 830       | 880             |
| Restaurant (Long Hour).....   | 2100                 | 1170     | 1210         | 1530          | 1300      | 1400            |
| Specialty Shops (5 & 10)..... | 1090                 | 670      | 690          | 810           | 720       | 750             |
| Theaters—Continuous.....      | 1500                 | 850      | 870          | 1020          | 910       | 950             |
| Theaters—Neighborhood.....    | 900                  | 500      | 520          | 650           | 550       | 580             |

\* *Modern Air Conditioning, Heating and Ventilating*, by W. H. Carrier, R. E. Chrene and W. A. Grant Pitman Publishing Corp. 1940, p. 73).

where

bhp = brake horsepower.

H = annual operating hours.

R = power rate, dollars per kw-hr.

$\eta$  = motor efficiency (decimal).

In using Equation 1 it must be pointed out that the electric rate, R must reflect the proper combination of energy and demand rates. These vary widely between the utility companies, and sometimes the rate structure is such that it is largely the demand charge which determines the proper value of R to use in Equation 1.

#### Operating Refrigerating Equipment

In an air conditioning system the refrigerating equipment is usually the largest power consuming item to be considered. Also, the prediction

of operating cost is more difficult because the power required for summer cooling is affected by many factors of a variable nature.

Table 5 gives the equivalent full load operating hours of refrigerating equipment used for summer cooling for the period of May 15th to October 15th. This table was calculated from the following equation:

$$H_e = m(b + cf) \quad (2)$$

where

- $H_e$  = equivalent full load operating hours of refrigeration equipment used for summer cooling during period May 15 to October 15.  
 $m$  = total hours during period May 15 to October 15 that the establishment is open for business.  
 $b$  = fraction of maximum load from internal heat under average operating conditions.  
 $c$  = fraction of maximum load which is due to external sources at maximum design conditions.  
 $f$  = ratio of the number of hours for a particular city, when the outside wet-bulb exceeds 65 F, during the period June 1 to October 1 to the total number of hours during that same period. Total hours are assumed as 8 hr per day period for barber shops, department stores, funeral parlors, offices, short hour restaurants, and specialty shops, and 12 hr per day period for drug stores, long hour restaurants, and theaters.

It should be pointed out that certain southern cities may have seasons longer than the 5-month period indicated in Table 5. If it is desired to consider a longer season of operation, the ratio of full load operating hours to hours open for business is smaller; in other words, the *refrigeration load factor* is lower. This is true because the extra increment of days added will be a relatively light load, since the table already includes the more severe part of the season.

The season electrical power cost for refrigerating equipment is then given by the following equation:

$$\text{season power costs} = \frac{0.746 (\text{bhp}) TH_e R}{\eta} \quad (3)$$

where

- bhp<sub>t</sub> = brake horsepower per ton (see Fig. 1) for *average* load during period. (Due allowance should be made for poorer compressor efficiency at light load.)  
 $T$  = maximum refrigeration design load, tons.  
 $H_e$  = equivalent full load refrigeration operating time, hours (from Table 5).  
 $R$  = power cost, including demand and energy charges, dollars per kwhr.  
 $\eta$  = motor efficiency at average load (decimal).

In considering refrigeration power consumption, it should be noted that the use of weather records for a specific year may lead to large inaccuracies in estimating operating costs, since there may be wide variations from year to year, and therefore, average yearly weather records should be used rather than those for any individual year.

If the refrigeration compressor is steam turbine driven, the same general method can be followed, taking into account average water rate per brake horsepower-hour and the cost of steam.

### Condenser Water

Condenser water cost estimates can also be based on equivalent full load operating hours of the refrigeration equipment. The varying temperature of the water at its source, as well as the temperature of the discarded water, must, however, be taken into account. In general, when water is purchased, control is provided to hold the leaving water temperature (or condensing temperature) constant; and in such case the entering water temperature becomes the major variable, and the gallons per minute per ton can readily be calculated for any water temperature rise.

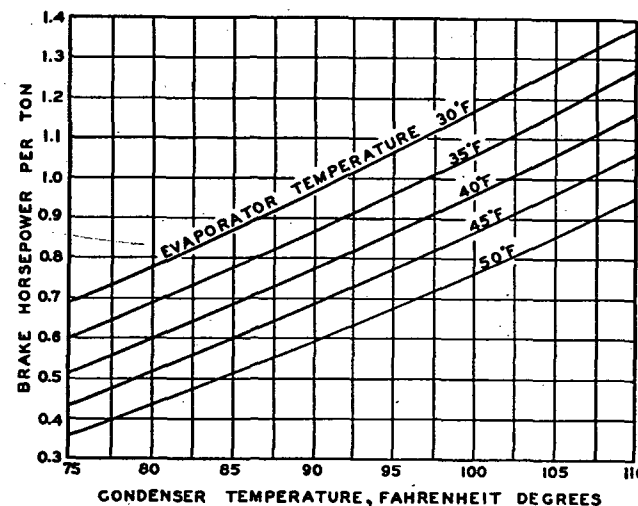


FIG. 1. TYPICAL BRAKE HORSEPOWER REQUIREMENTS FOR REFRIGERATION\*

\* Values given are representative of dichlorodifluoromethane reciprocating machines of about 25 tons capacity in air conditioning applications. Requirements of smaller machines are usually higher, and for larger machines may be lower. Values shown are for liquid refrigerant at condenser temperature (no subcooling). Subcooling of the liquid may decrease these values approximately 0.3 percent to 0.5 percent for each Fahrenheit degree the liquid temperature is lowered.

The following equation for cost of condenser water is useful:

$$B = 0.060 a TH_e C \quad (4)$$

where

- $B$  = cost of water for refrigeration during period, dollars.  
 $a$  = average gallons per (minute) (ton).  
 $T$  = tons of refrigeration at maximum design load.  
 $H_e$  = equivalent full load refrigeration operating hours (Table 5).  
 $C$  = water cost, dollars per 1000 gal.

The average gallons per minute per ton must take into account the variable water temperature. When well water is used as a source, and entering and leaving temperatures are considered constant, the average gallons per minute per ton obviously are equal to the design gallons per minute per ton. However, when the source is river or lake water, its maximum seasonal temperature will generally be reached at the same time that

the refrigeration load factor is highest. The average gallons per minute per ton should be calculated from known or estimated water temperatures, because they vary through the season. Maximum water main temperatures are given in Chapter 35, but should always be verified locally. In lieu of this tedious work, the average gallons per (minute) (ton) may be taken as 80 percent of design gallons per (minute) (ton) with reasonable accuracy, for the condition of variable temperature of entering water obtained from rivers and lakes.

Cooling towers and evaporative condensers virtually eliminate condensing water charges since the windage and evaporation losses are seldom over two or three percent of the water circulated.

The savings in water consumed often times will not in itself justify the installation of water economizing equipment since the cost for pumping and the fixed or ownership charges may be in excess of the annual cost for once through condensing operation. If operating costs are to be the basis for selection, then fixed charges should be determined when studying application of this equipment which usually has a shorter life than the other components.

Usually the primary factors influencing the installation of water conservation equipment are the lack of an adequate water supply or local regulations intended to conserve an existing water supply.

Another factor influencing the installation of such equipment is the increasing trend toward the enactment of taxes and service charges for condensing water wasted into city sewers. Certain municipalities will remit the sewer taxes or service charge if the condensing water is submetered and discharged into a storm sewer or used for process purposes.

### Heating

The method of estimating fuel consumption to balance the building heat loss is given in Chapter 18. It is important to include the fuel required to heat ventilation air as used in ventilating and air conditioning systems. In estimating fuel consumption for ventilation air, the tendency of the conventional control systems to use less than the estimated quantity of outside air in cold weather should be considered in its effect in lowering fuel consumption. In addition, the heat required to accomplish winter humidifying must not be neglected, when this feature is included in the equipment.

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## INDUSTRIAL AIR CONDITIONING

General Requirements for Manufacture, Processing and Preservation; Design Conditions and Application Data; Classification of Problems; Moisture Content and Regain; Conditioning and Drying; Chemical and Biochemical Reactions; Crystallization; Control for Machining, Polishing, and for Static Electricity Elimination; Laboratory Conditions; Calculations; Safeguarding Health and Maintaining Safety; Contaminant Control; Dilution Systems for Contaminants; Heat Storage; Radiation; Local Relief and Spot Cooling; Odors

INDUSTRIAL air conditioning is concerned with the design and application of equipment for obtaining proper conditions for (1) the manufacturing, processing, and preserving of material, equipment, and commodities; and (2) maintaining the health, safety and efficiency of workers. This chapter includes a general discussion of these conditions and also a comprehensive list of specific requirements for various types of products.

### GENERAL REQUIREMENTS FOR MANUFACTURE, PROCESSING AND PRESERVATION

In order to apply air conditioning to industrial processes, the air conditioning engineer must have a thorough understanding of the processing problems involved. Individual processes and machines are changing rapidly, and air conditions must be revised constantly to meet the new conditions.

Table 1 lists the temperatures and relative humidities required for storage of certain commodities, and for manufacturing and processing of others. In some cases the temperatures and relative humidities listed in Table 1 have no direct influence upon the product itself, but do affect the efficiency of employees, and in turn affect workmanship, uniformity and the cost of production. Sometimes, a compromise between the known optimum condition for processing and that required for worker comfort is unavoidable.

Air conditioning for industrial processes is so extensive and involved that a detailed treatment is beyond the scope of this chapter. It is possible to cover only a few salient points of the general subject. In many industries the exact conditions to be maintained are determined and known only by the manufacturer who specifies them. In other industries there is a wide variance between manufacturers' requirements, depending on results desired, experience, and cost considerations.

### CLASSIFICATION OF PROBLEMS

In general, any industrial air conditioning problem in processing may be classified under one or more of the following:

1. Control of regain.
2. Control of rate of chemical reactions.
3. Control of rate of biochemical reactions.
4. Control of rate of crystallization.
5. Control of temperature for close tolerance machining and grinding.

(Continued on page 1026.)

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING\*

| PROCESS                                           | TEMP. F | R.H. % |
|---------------------------------------------------|---------|--------|
| <b>BAKERY</b>                                     |         |        |
| Mixer (bread dough).....                          | 75-80   | 40-50  |
| Fermenting.....                                   | 75-80   | 70-75  |
| Proof box.....                                    | 92-96   | 80-85  |
| Bread oven.....                                   | 375-450 |        |
| Cake oven.....                                    | 300-430 |        |
| Bread cooler (room or tunnel) Vacuum 28.6 in..... | 70-75   | 80-85  |
| Cold room.....                                    | 40-45   |        |
| Make up room.....                                 | 75-80   | 65-70  |
| Cake mixing.....                                  | 70-75   | 65     |
| Cake mixing (sponge).....                         | 95-110  |        |
| Crackers and biscuits.....                        | 60-65   | 50     |
| Wrapping.....                                     | 60-65   | 60-64  |
| Dried ingredients, storage.....                   | 70      | 55-65  |
| Fresh ingredients, storage.....                   | 30-45   | 80-85  |
| Flour storage.....                                | 65-80   | 50-65  |
| Shortening (depending on type), storage.....      | 45-70   | 55-65  |
| Sugar, storage.....                               | 80      | 35     |
| Water, storage.....                               | 32-35   |        |
| Wax paper, storage.....                           | 70-80   | 40-50  |

## METHODS OF MIXER COOLING

1. 35-40 F water circulated through mixer jacket.
2. 15-25 F brine.
3. Direct expansion, refrigerant circulated through mixer jacket.
4. Cracked ice added to dough in mixer.
5. Cold air introduced into mixer during mixing process.
6. Cooled agitators are used in mixers.

## MIXER LOAD CALCULATIONS

Refrigeration is required to remove: excess ingredient, if any; heat generated by the heating and mixing of dough; excess heat in mixer body; heat of hydration of flour and water; and heat absorbed by mixer from atmosphere during mixing process.

Additional factors are the design and speed of mixer, consistency, kind and mass of dough.

Data Used in Calculations:

1 bbl. flour = 200 lb  
 Heat of hydration = 6.5 Btu per lb of flour  
 Specific heat of flour = 0.42 Btu per lb  
 Water is 65% of weight of flour  
 Flour is 65% of batch  
 Sponge is 60% of batch  
 Total motor output is converted to heat in the mixer.

In fermenting rooms recent practice is to use direct radiation for heating, atomizing sprays for humidifying, and gravity convection cooling surfaces for temperature reduction and dehumidifying thereby eliminating objectionable air currents.

Proof box and bread cooler conditions vary slightly for dark bread.

Cakes are sterilized by ultra-violet rays before wrapping.

| PROCESS        | TEMP. F  | R.H. %   |
|----------------|----------|----------|
| <b>BANANAS</b> |          |          |
| Ripening.....  | 68       | 90 to 95 |
| Storage.....   | 60       | 85 to 90 |
| Shipping.....  | 54 to 56 | 85 to 90 |

Forced ripening is accomplished in 4 to 5 days while slow ripening is extended to 7 to 9 days with lower temperatures.

The green fruit with a pulp temperature of 56 F is placed in a ripening room at 68 F and 90 to 95 percent relative humidity until it begins to change color. The temperature is then lowered sharply to 60 F (or slightly less) dependent upon how quickly the fruit is to be moved.

Typical refrigeration load for ripening room per carlot, with an 85 F ambient temperature:

Insulation & electric load = 0.4 ton  
 Live load = 0.9 ton  
 Pull down load (from 68 F to 60 F) = 1.6 ton

Minimum carlot—20,000 lb which represents about 300 stems.

Since bananas give off minute quantities of ethylene and possibly other gases necessary for ripening, ventilation during the early stages of ripening is undesirable.

Cooling unit to be sized to provide a complete air change every 1½ to 2 min.

\* Information in Table 1 is drawn from many sources. See bibliography at end of chapter.

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

## BANANAS (Continued)

Provide a heating system with a rated capacity to warm the fruit at a rate of not less than 2 deg per hr. Specific heat—0.9 Btu per (lb)(F deg).

Approximate rate of evolution of heat by bananas when stored at temperatures indicated:

Bananas at 54 F = 3,300 Btu (per ton) (24 hr).  
 green at 68 F = 8,360 Btu (per ton) (24 hr).  
 turning at 68 F = 9,240 Btu (per ton) (24 hr).  
 ripening at 68 F = 8,360 Btu (per ton) (24 hr).

| ROOM                          | TEMP. F  | R.H. %   |
|-------------------------------|----------|----------|
| <b>BREWING</b>                |          |          |
| Storage: Hops.....            | 30 to 32 | 55 to 62 |
| Grain.....                    | 80 max.  | 60 max.  |
| Liquid yeast.....             | 32 to 34 |          |
| Lager.....                    | 32 to 34 | 75 min.* |
| Ale.....                      | 40 to 46 | 75 min.* |
| Fermenting Cellar: Lager..... | 40 to 45 | 75 min.* |
| Ale.....                      | 55       | 75 min.* |
| Racking Cellar.....           | 32 to 35 | 75       |

\* If wooden tankage is used, otherwise humidity controlled to prevent condensation on walls and ceiling.

Wort cooled to 47 F for lager, 54 to 59 F for ale, by evaporative cooling or use of double pipe or plate type coolers with counter flow of cooling medium.

Fermentation produces 250 Btu per lb of sugar fermented. Lager fermented five days at 55 to 60 F, ale at 68 to 75 F, then cooled to storage temperature.

Bottled beer pasteurized by heating to 140 F in twenty minutes, maintaining temperature for eighteen minutes, then cooling to 80 F in twenty minutes. Canned beer requires one-third less time.

Cold water, brine, direct expansion ammonia or propylene-glycol and water solutions may be used as the cooling medium.

| PROCESS                           | TEMP. F  | R.H. %   |
|-----------------------------------|----------|----------|
| <b>CANDY (CHOCOLATE)</b>          |          |          |
| Candy centers for coating.....    | 80 to 85 | 40 to 50 |
| Hand dipping room.....            | 60 to 65 | 50 to 55 |
| Enrober room.....                 | 75 to 80 | 55 to 60 |
| Enrobing.....                     |          |          |
| Loading End.....                  | 80       | 50       |
| Enrober.....                      | 90       | 13       |
| Stringing.....                    | 70       | 40 to 50 |
| Tunnel.....                       | 40 to 45 |          |
| Packing.....                      | 65       | 55       |
| Panned specialty room.....        | 70 to 75 | 45       |
| General candy storage.....        | 65 to 70 | 40 to 50 |
| Tempering room = Ventilation only |          |          |

Tunnel discharge room requires a dew point lower than the temperature of the product leaving the tunnel.  
 During the summer months the product is usually held in the tempering room for 24 hours prior to shipping.

Recovery of sugar fly in coating kettle rooms is accomplished with the use of cyclone type dust collecting devices. Supply air to coating kettles is maintained at 85 F dry-bulb and 61 F wet-bulb temperature.

Bacteriological control is employed.

Load calculations for hand dipping rooms are based on 100 lb of 90 F chocolate per (worker) (hr).

Specific heat of chocolate = 0.30 to 0.56 Btu per (lb)(F deg).

Latent heat of fusion = 34 to 40 Btu per (lb)(F deg).

Freezing point =

Sweet milk chocolate = 86 F.

Dark chocolate = 90 to 92 F.

| PROCESS                        | TEMP. F  | R.H. %   |
|--------------------------------|----------|----------|
| <b>CANDY (HARD)</b>            |          |          |
| Manufacturing.....             | 75 to 80 | 30 to 40 |
| Mixing and cooling.....        | 75 to 80 | 40 to 45 |
| Tunnel.....                    | 55       |          |
| Packing.....                   | 65 to 75 | 40 to 45 |
| Storage.....                   | 65 to 75 | 45 to 50 |
| Tempering = (Ventilation only) |          |          |

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

## CANDY (HARD) (Continued)

Hot rooms used in the drying of jellies and gums are maintained at 120 to 150 F. A purge system using 100 percent outside air, bypassing the heating coil, is incorporated to produce rapid cooling of both the product and the room.

Cold rooms for cooling marshmallows and cast creams are maintained at 75 to 80 F with a relative humidity of 45 to 50 percent. Uniform air distribution is essential.

Standard starch drying equipment is employed.

Filtration of air is required.

| PROCESS            | TEMP. F | R.H. % |
|--------------------|---------|--------|
| <b>CHEWING GUM</b> |         |        |
| Manufacturing..... | 77      | 33     |
| Rolling.....       | 68      | 63     |
| Stripping.....     | 72      | 53     |
| Breaking.....      | 74      | 47     |
| Wrapping.....      | 74      | 58     |

| PROCESS                      | TEMP. F    | R.H.     |
|------------------------------|------------|----------|
| <b>CERAMICS</b>              |            |          |
| Refractory.....              | 110 to 150 | 50 to 90 |
| Molding room.....            | 80         | 60 to 70 |
| Clay storage.....            | 60 to 80   | 35 to 65 |
| Decalcomania production..... | 75 to 80   | 48       |
| Decorating room.....         | 75 to 80   | 48       |

Relative humidity has no effect on the manufacture of the products.

Temperature and humidity must be controlled in the decorating shop in the whiteware plants, and the decalcomania production room.

Dust control is essential, and the dust count must be held down to four million particles per cubic foot due to the danger of silicosis.

| PROCESS        | TEMP. F | R.H. % |
|----------------|---------|--------|
| <b>CEREAL</b>  |         |        |
| Packaging..... | 75-80   | 45-50  |

| PROCESS                    | TEMP. F | R.H. %   |
|----------------------------|---------|----------|
| <b>CITRUS FRUIT</b>        |         |          |
| Lemons (storage)*.....     | 58      | 84 to 88 |
| Grapefruit (storage)*..... | 60      | 88 to 88 |

\* Prior to transcontinental shipment

Careful consideration must be given to air volumes, air temperatures, humidity, ventilation and distribution.

In regions where end rot is prevalent, it may be necessary to store grapefruit at temperatures of 32 to 34 F for a period not exceeding six weeks.

Lemon and grapefruit storage requires an air conditioning system to (1) maintain a constant temperature, (2) maintain a high relative humidity, (3) ventilate to maintain 0.1% CO<sub>2</sub> content, (4) obtain uniform air distribution, and (5) provide air washing or air filtration.

Load calculations include (1) transmission losses, (2) internal load-fruit cooling and respiration, cooling fruit boxes, electric load, and people, and (3) outside air load—72 cfm per carlot.

Specific heat—Btu per (lb) (F deg):

Lemons 0.94, Grapefruit 0.87, Boxes 0.40

## HEAT OF EVOLUTION IN BTU PER (TON) (24 HR)

| TEMP. | LEMONS | GRAPEFRUIT |
|-------|--------|------------|
| 32    | 580    | 460        |
| 40    | 810    | 1070       |
| 60    | 2070   | 2770       |
| 80    | 6200   | 4180       |

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

## CITRUS FRUIT (Continued)

Approximately 10 percent of the cooling load is considered as latent heat load.

In a conventional system the air required is one cfm per storage box or 650 cfm per carload, resulting in a small temperature rise in the supply air making possible the required high humidities.

In a combination system the air required is one cfm per sq ft of floor area or 300 cfm per carlot with the addition of auxiliary humidifying nozzles to maintain the required high humidities.

Installation of metal ducts is required. Ductwork made of insulation board is sometimes preferred.

| PROCESS                    | TEMP. F  | R.H. %   |
|----------------------------|----------|----------|
| <b>DISTILLING</b>          |          |          |
| Storage:                   |          |          |
| Grain.....                 | 60       | 35 to 40 |
| Liquid Yeast.....          | 32 to 34 |          |
| General Manufacturing..... | 60 to 75 | 45 to 60 |
| Aging.....                 | 65 to 72 | 50 to 60 |

Mashing done at 150 to 155 F, then cooled to 64 to 68 F.

Yeast culture fermented at 170 F, then cooled to 70 to 72 F.

Yeast propagated at 150 to 154 F.

Mash heated to 165 F and then cooled to 80 F, then pitched with yeast and fermented at maximum temperature of 85 F.

Cooling for various distilling processes normally accomplished by use of river or well water depending on temperatures and availability.

Low humidity and dust control important where grains are ground.

Viscous filters preferred as mold spores and bacteria are trapped in the viscous film, preventing propagation.

| PROCESS                                          | TEMP. F  | R.H. %   |
|--------------------------------------------------|----------|----------|
| <b>ELECTRICAL PRODUCTS</b>                       |          |          |
| Electronics and X-Ray:                           |          |          |
| Coil & transformer winding.....                  | 72       | 15       |
| Tube assembly.....                               | 68       | 40       |
| Electrical Instruments:                          |          |          |
| Manufacture and Laboratory.....                  | 70       | 50 to 55 |
| Thermostat assembly & calibration.....           | 76       | 50 to 55 |
| Humidistat assembly & calibration.....           | 76       | 50 to 55 |
| Small Mechanisms:                                |          |          |
| Close tolerance assembly.....                    | 72       | 40 to 45 |
| Meter assembly and test.....                     | 74 to 76 | 60 to 63 |
| Switchgear:                                      |          |          |
| Fuse and cutout assembly.....                    | 73       | 50       |
| Capacitor winding.....                           | 73       | 50       |
| Paper storage.....                               | 73       | 50       |
| Conductor wrapping with yarn.....                | 75       | 65 to 70 |
| Lightning arrester assembly.....                 | 68       | 20 to 40 |
| Thermal circuit breakers assembly and test.....  | 76       | 30 to 60 |
| Water wheel generators:                          |          |          |
| Thrust runner lapping.....                       | 70       | 30 to 50 |
| Rectifiers:                                      |          |          |
| Processing selenium and copper oxide plates..... | 74       | 30 to 40 |
| Dust control is essential in these processes     |          |          |

| PROCESS                                  | TEMP. F    | R.H. %   |
|------------------------------------------|------------|----------|
| <b>FLOOR COVERING</b>                    |            |          |
| Linoleum:                                |            |          |
| Mechanical oxidizing of linseed oil..... | 90 to 100  | 20 to 28 |
| Printing.....                            | 80         | 30 to 50 |
| Stoving process.....                     | 160 to 250 | 60 gr*   |

\* grains per pound abs. hum.

Some operations are stabilized against possibility of mold growth.

Precise control of temperature and humidity is required for mechanical oxidizing of linseed oil. The rate of flow and the temperature of cooling water in the jacket surrounding the tank must be controlled.

Air filtration is recommended for the stoving process.

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

| PROCESS            | TEMP. °F |  |
|--------------------|----------|--|
| <b>FOUNDRIES</b>   |          |  |
| Core making.....   | 60 to 70 |  |
| Mold making:       |          |  |
| Bench work.....    | 60 to 70 |  |
| Floor work.....    | 55 to 65 |  |
| Pouring.....       | 40       |  |
| Shakeout.....      | 40 to 50 |  |
| Cleaning Room..... | 55 to 65 |  |

\* Winter design temp.

The charging room is usually unheated.

In core making fume exhaust hoods are required for oven and for cooling areas adjacent to ovens.

In mold making provide hoods at transfer points with wet collector dust removal system. Use 600 to 800 cfm per hood.

Pouring rooms require two-speed powered roof ventilators. Design for minimum of two cfm per sq ft floor area at low speed. Shielding is required to control radiation from hot surfaces. Proper introduction of air will minimize preheat requirements.

In shakeout room provide hoods with wet collector dust removal system. Exhaust 400 to 500 cfm per sq ft grate area. Roof ventilators are generally not effective.

In cleaning room provide hoods for grinders and cleaning equipment with dry cyclones or bag type collectors.

Winter ventilation (preheated) is required to the extent of replacing exhausted air. Summer ventilation is usually supplemented by use of pedestal fans.

Spot coolers are sometimes used in larger installations.

| PROCESS              | TEMP. °F | R.H. %   |
|----------------------|----------|----------|
| <b>FUR</b>           |          |          |
| Drying.....          | 110      | ....     |
| Shock treatment..... | 18 to 20 |          |
| Storage.....         | 40 to 50 | 55 to 65 |

Shock treatment, for eradication of any insect infestations, requires the lowering of the temperature to 18-20 °F for 3 to 4 days, then raising it to 60-70 °F for 2 days, then lowering it once again to 18-20 degrees for 2 days and raising it to the storage temperature.

Furs remain pliable, oxidation is reduced and color and luster are preserved when stored at 40 to 50 °F.

Mold growth is prevalent with humidities above 80 percent, while hair splitting is common where humidity is lower than 55 percent.

| PROCESS               | TEMP. °F | R.H. % |
|-----------------------|----------|--------|
| <b>LEATHER</b>        |          |        |
| Drying:               |          |        |
| Vegetable tanned..... | 70       | 75     |
| Chrome tanned.....    | 120      | 45     |
| Storage.....          | 50-60    | 40-60  |

After leather is moistened in preparation for rolling and stretching, it is placed in an atmosphere held at room temperature with a relative humidity of 95 percent.

Leather is usually stored in warehouses without temperature and humidity control. However, it is necessary to keep humidity below 85 percent to avoid mildew.

Air filtration is recommended for toggle machines.

| PROCESS                 | TEMP. °F | R.H. % |
|-------------------------|----------|--------|
| <b>LENSES (OPTICAL)</b> |          |        |
| Fusing.....             | 75       | 45     |
| Grinding.....           | 80       | 80     |

The air must be free of dust and temperature held constant.

To acquire desired cleanliness of air a combination of impingement and electrostatic filters are used. Dust collectors are required for grinding operations.

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

| ROOMS                        | TEMP. °F | R.H. % |
|------------------------------|----------|--------|
| <b>LIBRARIES AND MUSEUMS</b> |          |        |
| Museum.....                  | 70-80    | 40-50  |
| Book storage.....            | 70-80    | 40-50  |

Spray type dehumidifiers used to eliminate SO<sub>2</sub>. Water treatment is essential to maintain between 8.5 and 9.0 pH.

Reheat is usually needed for refrigeration cycle due to the low sensible heat load.

In extremely cold weather a lower relative humidity is required to prevent condensation on walls.

Positive high and low limit relative humidity controls are used. Do not locate water or steam piping where leakage can cause damage.

#### Check Figures for Cooling Estimates:

|                                              | Low  | MEDIUM | High |
|----------------------------------------------|------|--------|------|
| Square feet floor area per person.....       | 40   | 60     | 80   |
| Watts per sq ft of floor area.....           | 1    | 1      | 2    |
| Room sensible heat, Btu per (hr)(sq ft)..... | 20   | 35     | 45   |
| Grand total heat, Btu per (hr)(sq ft).....   | 30   | 51     | 75   |
| Sensible heat factor.....                    | 0.73 | 0.83   | 0.90 |
| Cooling load per person, tons.....           | 0.12 | 0.23   | 0.40 |
| cfm per sq ft of floor area.....             | 0.92 | 1.60   | 2.10 |

#### MALTING (BREWING)

Steeped 24 to 72 hr in 45 to 65 °F water.

Germinated six days at 55 to 75 °F.

Kilned at temperatures of 120 to 175 °F.

#### MALTING (DISTILLING)

Germinated twenty days at 63 °F.

Germination produces total heat of 16,000 Btu/bushel at varying rate depending upon grain and process.

| PROCESS          | TEMP. °F | R.H. % |
|------------------|----------|--------|
| <b>MATCHES</b>   |          |        |
| Manufacture..... | 72 to 74 | 50     |
| Drying.....      | 70 to 75 | 40     |
| Storage.....     | 60 to 63 | 50     |

Water evaporated is 18 to 20 lb per million matches simultaneously with the setting of the glue.

The match machine will turn out about 750,000 matches per hour.

| PROCESS                  | TEMP. °F   | R.H. %      |
|--------------------------|------------|-------------|
| <b>MUSHROOMS</b>         |            |             |
| Sweating-out period..... | 120 to 140 |             |
| Spawn added.....         | 60 to 75   | nearly sat. |
| Growing period.....      | 48 to 60   | moderate    |
| Storage.....             | 32 to 35   | 80 to 85    |

As spawn starts to grow, it is necessary to abruptly cool the mushroom house by 15 deg in a 12 hr period (approx.). Usually, this is the controlling factor in selection of refrigeration equipment, unless there is portable equipment available for such a purpose.

Ductwork is usually of wood, due to the deterioration of ferrous metals during sweating-out period.

Air filtration is essential in spawn rooms. Viscous filters are preferred, as mold spores are trapped in the viscous film. Odorless oil should be used.

Heat of emission is 4 Btu per (hr)(sq ft of growing surface).



TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

| PROCESS                                                                                                                                                                                                 | TEMP. F  | R.H. %   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|
| <b>PAINT APPLICATION</b>                                                                                                                                                                                |          |          |
| Lacquers:                                                                                                                                                                                               |          |          |
| Air drying.....                                                                                                                                                                                         | 70-90    | 60       |
| Baking.....                                                                                                                                                                                             | 180-300  |          |
| Oil Paints:                                                                                                                                                                                             |          |          |
| Air drying.....                                                                                                                                                                                         | 60-90    | 60       |
| Paint Spraying.....                                                                                                                                                                                     | 75       |          |
| <p>Spray booths to have 100 fpm face velocity. Make-up air must be preheated. Ovens must have air removed to keep fumes below explosive concentration. Equipment must be explosion-proof throughout</p> |          |          |
| ROOM OR PROCESS                                                                                                                                                                                         | TEMP. F  | R.H. %   |
| <b>PHARMACEUTICAL</b>                                                                                                                                                                                   |          |          |
| Powder storage (prior to mfg.).....                                                                                                                                                                     | 70 to 80 | 30 to 35 |
| Manufactured powder storage and packing areas.....                                                                                                                                                      | 75 to 80 | 15 to 35 |
| Milling room.....                                                                                                                                                                                       | 80       | 35       |
| Tablet compressing.....                                                                                                                                                                                 | 70 to 80 | 30       |
| Tablet coating room.....                                                                                                                                                                                | 80       | 35       |
| Effervescent tablets and powders.....                                                                                                                                                                   | 90       | 15       |
| Hypodermic tablets.....                                                                                                                                                                                 | 75 to 80 | 30       |
| Colloids.....                                                                                                                                                                                           | 70       | 30 to 50 |
| Cough syrups.....                                                                                                                                                                                       | 80       | 40       |
| Glandular products.....                                                                                                                                                                                 | 78 to 80 | 5 to 10  |
| Ampule manufacturing.....                                                                                                                                                                               | 80       | 35       |
| Gelatin capsules.....                                                                                                                                                                                   | 78       | 40 to 50 |
| Capsule storage.....                                                                                                                                                                                    | 75       | 35 to 40 |
| Micro-analysis.....                                                                                                                                                                                     | 80       | 50       |
| Biological manufacturing.....                                                                                                                                                                           | 70 to 80 | 20 to 30 |
| Liver extracts.....                                                                                                                                                                                     | 74 to 78 | 50       |
| Serums.....                                                                                                                                                                                             | 75 to 80 | 40       |
| Animal rooms.....                                                                                                                                                                                       | 75 to 78 | 47 to 48 |

Gelatin capsules require varying relative humidities, depending upon size of capsule. Moisture content should not exceed 0.25 gr per cu ft. Various kinds of gelatin require different temperatures.

Penicillin incubation process requires holding temperature within  $\frac{1}{2}$  deg F, with temperatures and humidity rigidly controlled during all manufacturing phases.

Ampule filling requires a 20 percent relative humidity when especially fine powders are used.

Uncoated tablet manufacturing requires accurate control of temperature and relative humidity, since low relative humidity causes formation of a hard outer layer, and high relative humidity retards drying at the proper rate.

Liver extracts require a low relative humidity after they are dried. Temperatures higher than 80 F will cause the extracts to deteriorate.

Tablet coating requires the control of the temperatures of all ingredients and the temperature of air introduced to coating pans.

Sterile conditions are essential in many pharmaceutical processes. Provide suitable air exhaust to remove surplus material from tablet compressing machine.

Air filtration is generally required, with positive air filtration in some areas.

#### ANIMAL ROOMS IN PHARMACEUTICAL LABORATORIES

In the following tabulation each of the items mentioned is equivalent in metabolism to one man:

| QUANTITY | ANIMAL      | WEIGHT EACH |
|----------|-------------|-------------|
| 872      | White Mice  | 21 g        |
| 110      | Rats        | 200 g       |
| 73       | Rats        | 400 g       |
| 70       | Guinea Pigs | 410 g       |
| 21       | Rabbits     | 2.6 kg      |
| 16       | Cats        | 3.0 kg      |
| 16       | Monkeys     | 3.0 kg      |
| 5        | Dogs        | 14.0 kg     |

Dogs are generally the worst offenders as far as odor generation is concerned.

Decontamination of exhaust air is recommended in populated areas.

For good air quality conditions the following space per animal and total air circulation (all outdoor or decontaminated in recirculation) should be provided:

| Animal      | cu ft | cfm  |
|-------------|-------|------|
| Mice        | 3     | 0.5  |
| Rats        | 4     | 0.75 |
| Guinea Pigs | 6     | 1.0  |
| Rabbits     | 10    | 1.9  |
| Hamsters    | 8     | 1.5  |
| Cats        | 35    | 10.0 |
| Dogs        | 150   | 28.0 |

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

| PROCESS              | TEMP. F | R.H. % |
|----------------------|---------|--------|
| <b>PHOTO STUDIO</b>  |         |        |
| Dressing Room.....   | 74      | 30-40  |
| Drying Room.....     | 75-80   | 50     |
| Printing Room.....   | 70      | 70     |
| Setting Room.....    | 72      | 65     |
| Developing Room..... | 70-75   | 60     |
| Storage Room.....    | 60      | 45     |

Heat liberated during printing, enlarging and drying processes is removed through an independent exhaust system, which also serves the lamp houses and dryer hoods.

Dust control is essential, and absolute filtration is required in some areas.

| PROCESS                          | TEMP. F | R.H. % |
|----------------------------------|---------|--------|
| <b>PHOTO MATERIAL</b>            |         |        |
| Drying.....                      | 20-125  | 40-80  |
| Cutting & Packing.....           | 65-75   | 40-60  |
| Film Base & Paper Storage.....   | 70-75   | 40-65  |
| Coated Paper & Film Storage..... | 70-75   | 40-65  |
| Safety Base Film Storage.....    | 60-80   | 45-50  |
| Nitrate Film Storage.....        | 40-50   | 40-50  |

Spray water must have algae inhibitor. Positive dust control must be maintained and absolute filtration is essential.

In nitrate film area take proper precautions against fires.

Recirculated air used for film drying is passed through activated carbon filters.

Relative humidity for film storage should never exceed 60 percent with a minimum of 25 percent.

| PROCESS                                | TEMP. F  | R.H. %   |
|----------------------------------------|----------|----------|
| <b>PLASTICS</b>                        |          |          |
| Manufacturing areas:                   |          |          |
| Thermo setting moulding compounds..... | 80       | 25 to 30 |
| Cellophane wrapping.....               | 75 to 80 | 45 to 65 |

Absolute filtration is required in some areas.

Collection and removal of dust and fumes is essential.

| PROCESS                   | TEMP. F | R.H. %   |
|---------------------------|---------|----------|
| <b>PLYWOOD</b>            |         |          |
| Hot Pressing (resin)..... | 90      | 60       |
| Cold Pressing.....        | 90      | 15 to 25 |

| PROCESS                | TEMP. F | R.H. % |
|------------------------|---------|--------|
| <b>POULTRY RAISING</b> |         |        |
| Incubator.....         | 70-75   | 30-60  |
| Brooder:               |         |        |
| 1st week.....          | 70-75   | 60     |
| 2nd week.....          | 50-60   | 60     |
| Battery room:          |         |        |
| Starting.....          | 70      | 70-75  |
| Growing.....           | 50-60   | 50-60  |
| Egg storage.....       | 45-60   | 70-80  |

Maximum ventilation is required for laying quarters during the summer months, while an attempt is made to maintain a temperature 10 deg above or below outdoor temperature during the winter, to minimize condensation on the exterior walls. This applies to houses not having forced ventilation systems.

| PROCESS                                    | TEMP. F | R.H. % |
|--------------------------------------------|---------|--------|
| <b>PRECISION MACHINING</b>                 |         |        |
| Spectrographic analysis.....               | 75-80   | 45-50  |
| Gear matching & special assembly room..... | 75-80   | 35-40  |
| Gasket storage.....                        | 100     | 50     |
| Cement & glue storage.....                 | 65      | 40     |
| Precision parts machining.....             | 75      | 45-50  |

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

| PROCESS                                 | TEMP. F | R.H. % |
|-----------------------------------------|---------|--------|
| <b>PRECISION MACHINING (Continued)</b>  |         |        |
| Accurate gaging & inspection            | 75      | 45-50  |
| Precision gage manufacture & adjustment | 68-75   | 45-50  |
| Precision gear drive assembly           | 72      | 42-50  |
| Watch main spring calibration           | 76      | 45     |
| Gage room                               | 78      | 50     |
| Precision parts—honing                  | 75-80   | 35-45  |

For product improvement and increased personnel efficiency some manufacturing areas are being provided with summer air conditioning. Where air conditioning is not provided, an ample supply of outdoor air and air motion are relied upon to provide acceptable working conditions.

Low relative humidity is usually maintained to prevent corrosion.

Temperature control within a narrow range is more important than temperature maintained.

Dust control is required wherever polishing operations occur.

Air distribution is important to maintain constant conditions throughout the area.

| PROCESS                                          | TEMP. F | R.H. %                 |
|--------------------------------------------------|---------|------------------------|
| <b>PRINTING</b>                                  |         |                        |
| Pressroom:                                       |         |                        |
| Multicolor offset lithography                    | 75-80   | 46-48                  |
| Other sheet fed printing                         | 75-80   | 45-50                  |
| Newspaper & other web printing                   | 75-80   | 50-55                  |
| Stock room:                                      |         |                        |
| Multicolor offset lithography                    | 73-80   | * 5-8% above pressroom |
| Other paper storage                              | 70-80   | b                      |
| Binding, cutting, drying, folding and gluing     | 70-80   | 45-50                  |
| Roll storage                                     | 73-80   | 50                     |
| * 5 to 8% above pressroom<br>b same as pressroom |         |                        |

Lithography requires constant humidity control of entire pressroom with paper conditioned 5 to 8 percent higher relative humidity at start. All printing requires conditioned paper otherwise it will not lie flat, with 40 to 45 percent R.H. low limit to eliminate static electricity; and 60 percent R.H. high limit to prevent swelling of the rolls and slow ink drying. Temperature is not critical, but extremes should be avoided due to softening of the rolls at high temperature and improper ink distribution at low temperatures.

Hoods must be provided for gas dryers, with solvent recovery recommended for all except job shops. Exhaust system with dust collectors incorporated is required for type and plate cleaning areas. Check use of gasoline and other solvents. Normal air cleaning is adequate. Air distribution must prevent drafts on paper in storage or process. Gas flame dryers impose unusual loads.

Air from press and storage rooms should not be recirculated through office areas.

| PROCESS                        | TEMP. F  | R.H. %   |
|--------------------------------|----------|----------|
| <b>REFRIGERATION EQUIPMENT</b> |          |          |
| Valve Manufacturing            | 75       | 40       |
| Compressor Assembly            | 70 to 76 | 30 to 45 |
| Refrigerator Assembly          | 75       | 30 to 50 |
| Testing                        | 65 to 82 | 47       |

| PROCESS                      | TEMP. F | R.H. % |
|------------------------------|---------|--------|
| <b>RUBBER DIPPED GOODS</b>   |         |        |
| Manufacture                  | 80      |        |
| Cementing                    | 80      | 25-30  |
| Dipping surgical articles    | 75-80   | 25-30  |
| Storage prior to manufacture | 60-75   | 40-50  |
| Laboratory (ASTM Standard)   | 73.4    | 50     |

Solvents used in manufacturing processes are usually explosive and toxic, requiring positive ventilation. Volume manufacturers usually install a solvent recovery system.

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Continued)

| PROCESS                           | TEMP. F | R.H. % |
|-----------------------------------|---------|--------|
| <b>TEXTILES</b>                   |         |        |
| Cotton: Opening                   | 70-75   | 55-60  |
| Picking                           | 75      | 55-60  |
| Carding, Winter                   | 75-80   | 55     |
| Carding, Summer                   | 83      | 90     |
| Carding, Summer                   | 85      | 80     |
| Carding, Summer                   | 87      | 70     |
| Drawing                           | 80      | 60     |
| Roving                            | 80      | 60     |
| Ring Spinning                     |         |        |
| Conventional                      | 80-85   | 70     |
| Long Draft                        | 80-85   | 55     |
| Frame Spinning                    | 80-85   | 55-60  |
| Spooling & Winding                | 78-80   | 65     |
| Weaving                           | 78-80   | 70-85  |
| Cloth Room                        | 75      | 65-70  |
| Combing                           | 75      | 50-65  |
| Linen: Carding                    | 75-80   | 60     |
| Spinning                          | 75-80   | 60     |
| Weaving                           | 80      | 80     |
| Woolens: Pickers                  | 80-85   | 60     |
| Carding                           | 80-85   | 65-70  |
| Spinning                          | 80-85   | 50-60  |
| Dressing                          | 75-80   | 60     |
| Weaving                           |         |        |
| Light goods                       | 80-85   | 60     |
| Overcoating (32 oz.)              | 80-85   | 60-65  |
| Drawing                           | 75      | 50-60  |
| Worsted: Carding                  | 80-85   | 65     |
| Combing                           | 80-85   | 65-70  |
| Gilling                           | 80-85   | 65-70  |
| Top Storage                       | 70-85   | 75-80  |
| Drawing                           | 80-85   | 65     |
| Cap Spinning                      | 80-85   | 50-55  |
| Spooling & Winding                | 75      | 65-70  |
| Weaving                           | 80      | 55-70  |
| Finishing                         | 75      | 60     |
| Silk: Preparatory                 | 80      | 60-65  |
| Weaving                           | 80      | 60-70  |
| Dressing                          | 80      | 60-65  |
| Spinning                          | 80      | 65-70  |
| Throwing                          | 80      | 60     |
| Rayon: Spinning                   | 80-90   | 50-60  |
| Throwing                          | 80      | 55-60  |
| Weaving                           |         |        |
| Regenerated                       | 80      | 50-65  |
| Acetate                           | 80      | 55-60  |
| Spun rayon                        | 80      | 80     |
| Picking                           | 75-80   | 50-60  |
| Carding, roving, drawing          | 80-90   | 50-60  |
| Knitting                          |         |        |
| Viscose or cuprammonium           | 80-85   | 65     |
| Acetate                           | 80-85   | 60     |
| Laboratory (ASTM)                 | 70      | 65     |
| Rayon synthetic fiber processing: |         |        |
| Viscose                           |         |        |
| Preparatory                       | 80      | 60     |
| Weaving                           | 80      | 60     |
| Celanese                          |         |        |
| Preparatory                       | 80      | 70     |
| Weaving                           | 80      | 70-75  |
| Nylon                             |         |        |
| Preparatory                       | 80      | 50-60  |
| Weaving                           | 80      | 50-60  |

Cotton: Relative humidity maintained in ring spinning depends on staple, twist and whether leather aprons are used for conveying long draft stock. Aprons readily absorb moisture causing cotton to stick when relative humidity is above 55 percent.

With conventional 3 or 4 roll spinning, relative humidity may be as high as 70 percent dependent upon draft, twist and staple.

Relative humidity carried in cotton weaving depends upon construction of the cloth. When automatic machines are to be tended and the warps are heavily sized, it may be as high as 90 percent.

Woolen: In woolen spinning, the relative humidity maintained for mules is generally 55 percent, with conditions over frame spinning at 55 to 60 percent. Both types of spinning depend on the class of stock spun, also the regain in the roving.

TABLE 1. TEMPERATURES AND HUMIDITIES APPLICABLE TO INDUSTRIAL AIR CONDITIONING—(Concluded)

## TEXTILES (Continued)

**Worsted:** Top storage temperature depends on whether cellar long period conditioning at low temperature or quick conditioning at high temperature is used. Weaving relative humidity depends upon staple, quality and construction.

Filtration of air is essential.

**Rayon manufacture:** The steeping room, where sheets of raw material are dipped in caustic soda then broken into a fine matted crumb, is held at 70 F and 55 percent relative humidity. Relative humidity is held down to prevent condensation on cold pipes and jackets.

In chum room, where sodium cellulose is converted into cellulose xanthate, temperatures of 75 to 80 F are maintained while humidity control is not important. Room temperatures are held below 85 F during the summer months.

The crumb is dumped into aging tanks located in a room held at 73 F with no humidity control.

For spinning operations it is desirable to limit the temperature to 90 F with a minimum relative humidity of 70 percent for the summer, while 70 percent and 75 F are desirable for the winter months.

The storage room, where the material is held for later processing design conditions, are 85 F and 100 percent relative humidity.

The material is washed, desulfurized, bleached and then washed again. It is then placed in a drier where controlled conditions of 100 deg and 65 percent relative humidity are required to bring the rayon back to the proper regain.

In the coning room, where winding machines place the rayon yarn on cones, temperature is held at a maximum of 80 F. Relative humidity is held at 55 percent.

| PROCESS                                  | TEMP. F  | R.H. %   |
|------------------------------------------|----------|----------|
| TOBACCO                                  |          |          |
| Cigar and cigarette making               | 70 to 75 | 55 to 65 |
| Softening                                | 90       | 55 to 85 |
| Stemming and stripping                   | 75 to 85 | 70 to 75 |
| Packing and shipping                     | 74 to 78 | 65       |
| Filler tobacco casing and conditioning   | 75       | 75       |
| Filler tobacco storage and preparation   | 78       | 70       |
| Wrapper tobacco storage and conditioning | 75       | 75       |

In preparation for stripping, the tobacco undergoes a softening operation, whereby it is automatically heated, moistened and then cooled.

Control of moisture regain, and of chemical and biological reactions is required in tobacco processing.

Exact temperature and humidity conditions maintained are usually trade secrets as they affect the finished product.

(Continued from page 1015).

- Control of dew-point for protection of highly polished surfaces.
- Control of humidity for static electricity elimination.
- Control of conditions for material test laboratories.

## Moisture Content and Regain

In the manufacture or processing of hygroscopic materials such as textiles, paper, wood, leather, tobacco and foodstuffs, the temperature and relative humidity of the air have a marked influence upon the rate of production and upon the weight, strength, appearance, and general quality of the product. The moisture content of materials having a vegetable or animal origin, and to a lesser extent minerals in certain forms, comes to equilibrium with the moisture of the surrounding air. This moisture content is known as *regain*. Standards of *regain* are fixed in the trade, and are the fundamental basis for the control of certain physical qualities of the material during manufacture.

Manufacturing economy requires that the moisture content be maintained at a level favorable to rapid and satisfactory manipulation, and to a minimum loss of material through breakage. A uniform condition is desirable in order that high speed machinery may be adjusted permanently for the desired production with a minimum loss from delays, wastage of raw material, and defective product. *Moisture content* refers to free moisture (as in a sponge) and to hygroscopic moisture (which varies with atmospheric conditions). It is usually expressed as a percentage of the

total weight of material. *Regain* is more specific and refers only to hygroscopic moisture. It is expressed as a percentage of the *bone-dry* weight of material. For example, if a sample of cloth weighing 100.0 g is dried to a bone-dry weight of 93.0 g, the loss in weight, or 7.0 g, represents the weight of moisture originally contained. This expressed as a percentage of the total weight (100.0 g) gives the moisture content of 7 percent. The regain, which is expressed as a percentage of the bone-dry weight, is  $(7.0/93.0) \times 100 = 7.5$  percent.

The use of the term *regain* does not imply that the material as a whole has been completely dried out and has re-absorbed moisture.

A basis for calculating the regain of textiles is obtained by drying, under standard conditions, a sample from the lot, and the dry weight thus obtained is used in the calculations to determine the regain.

Table 2 shows the regain or hygroscopic moisture content of several organic and inorganic materials when in equilibrium at a dry-bulb temperature of 75 F and various relative humidities. The effect of temperature as compared to the relative humidity is comparatively unimportant, although sudden changes in temperature cause a slight change in regain even when the relative humidity remains stationary. Changes in temperature do, however, affect the rate of absorption or drying, although this property generally varies with the nature of the material, its thickness and density.

When hygroscopic materials absorb moisture from the surrounding air, they deliver to the air sensible heat equivalent to the latent heat released by the moisture to the material. This amount of heat should be included in the load estimate.

## Conditioning and Drying

In general, the materials may be exposed to desirable humidities for treatment coincidentally with the manufacture or processing of the materials, or they may be treated separately in special enclosures. This latter treatment may be classified as conditioning or drying. The usual purpose of conditioning or drying is to establish a desired condition of moisture content and to regulate the physical properties of the material. When the final moisture content is lower than the initial one, the term *drying* is applied (See Chapter 47). If the final moisture content is to be higher, the process is termed *conditioning*. In the case of some textile products and tobacco, for example, drying and conditioning may be combined in one process for the dual purpose of removing undesirable moisture, and accurately regulating the final moisture content. Frequently, conditioning or drying is made a continuous process in which the material is conveyed through an elongated compartment by suitable means, and subjected to various controlled atmospheric conditions.

## Control of Rate of Chemical Reactions

A typical example of control of the rate of chemical reactions occurs in the manufacture of rayon. The pulp sheets are conditioned, cut to size, and passed through a mercerizing process. It is essential that, during this process, close control of both temperature and relative humidity should be maintained. The temperature controls the rate of reaction directly, while the relative humidity maintains a constant rate of evaporation from the surface of the solution, and maintains a solution of known strength throughout the mercerizing period.

Another well-known example in this class is the *drying* of varnish which

TABLE 2. REGAIN OF HYGROSCOPIC MATERIALS  
Moisture Content Expressed in Percent of Dry Weight of the Substance at Various  
Relative Humidities—Temperature, 75 F

| CLASSIFICATION            | MATERIAL                       | DESCRIPTION                    | RELATIVE HUMIDITY—PERCENT |      |      |      |      |      |      |      |      | AUTHORITY      |
|---------------------------|--------------------------------|--------------------------------|---------------------------|------|------|------|------|------|------|------|------|----------------|
|                           |                                |                                | 10                        | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   |                |
| Natural Textile Fibers    | Cotton                         | Sea island—roving              | 2.5                       | 3.7  | 4.6  | 5.5  | 6.6  | 7.9  | 9.5  | 11.5 | 14.1 | Harte-horne    |
|                           | Cotton                         | American—cloth                 | 2.6                       | 3.7  | 4.4  | 5.2  | 5.9  | 6.8  | 8.1  | 10.0 | 14.3 | Schloesing     |
|                           | Cotton                         | Absorbent                      | 4.8                       | 9.0  | 12.5 | 15.7 | 18.5 | 20.8 | 22.8 | 24.3 | 25.8 | Fuwa           |
|                           | Wool                           | Australian merino—skein        | 4.7                       | 7.0  | 8.9  | 10.8 | 12.8 | 14.9 | 17.2 | 19.9 | 23.4 | Hart-shorne    |
|                           | Silk                           | Raw cheyennes—skein            | 3.2                       | 5.5  | 6.9  | 8.0  | 8.9  | 10.2 | 11.9 | 14.3 | 18.8 | Schloesing     |
|                           | Linen                          | Table cloth                    | 1.9                       | 2.9  | 3.6  | 4.3  | 5.1  | 6.1  | 7.0  | 8.4  | 10.2 | Atkinson       |
|                           | Linen                          | Dry spun—yarn                  | 3.6                       | 5.4  | 6.5  | 7.3  | 8.1  | 8.9  | 9.8  | 11.2 | 13.8 | Sommer         |
|                           | Jute                           | Average of several grades      | 3.1                       | 5.2  | 6.9  | 8.5  | 10.2 | 12.2 | 14.4 | 17.1 | 20.2 | Storch         |
| Rayons                    | Hemp                           | Manila and sisal—rope          | 2.7                       | 4.7  | 6.0  | 7.2  | 8.5  | 9.9  | 11.6 | 13.6 | 15.7 | Fuwa           |
|                           | Viscose Nitro-cellulose        | Average skein                  | 4.0                       | 5.7  | 6.8  | 7.9  | 9.2  | 10.8 | 12.4 | 14.2 | 16.0 | Robertson      |
|                           | Cuprammonium Cellulose Acetate |                                | 0.8                       | 1.1  | 1.4  | 1.9  | 2.4  | 3.0  | 3.6  | 4.3  | 5.3  | Robertson      |
| Paper                     | M. F. Newsprint                | Wood pulp—24% ash              | 2.1                       | 3.2  | 4.0  | 4.7  | 5.3  | 6.1  | 7.2  | 8.7  | 10.6 | NBS            |
|                           | H. M. F. Writing               | Wood pulp—3% ash               | 3.0                       | 4.2  | 5.2  | 6.2  | 7.2  | 8.3  | 9.9  | 11.9 | 14.2 | NBS            |
|                           | White Bond                     | Rag—1% ash                     | 2.4                       | 3.7  | 4.7  | 5.5  | 6.5  | 7.5  | 8.8  | 10.8 | 13.2 | NBS            |
|                           | Com. Ledger                    | 75% rag—1% ash                 | 3.2                       | 4.2  | 5.0  | 5.6  | 6.2  | 6.9  | 8.1  | 10.3 | 13.9 | NBS            |
|                           | Kraft Wrapping                 | Coniferous                     | 3.2                       | 4.6  | 5.7  | 6.6  | 7.6  | 8.9  | 10.5 | 12.6 | 14.9 | NBS            |
| Misc. Organic Materials   | Leather                        | Sole oak—tanned                | 5.0                       | 8.5  | 11.2 | 13.6 | 16.0 | 18.3 | 20.6 | 24.0 | 29.2 | Phelps         |
|                           | Catgut                         | Racquet strings                | 4.6                       | 7.2  | 8.6  | 10.2 | 12.0 | 14.3 | 17.3 | 19.8 | 21.7 | Fuwa           |
|                           | Glue                           | Hide                           | 3.4                       | 4.8  | 5.8  | 6.6  | 7.6  | 9.0  | 10.7 | 11.8 | 12.5 | Fuwa           |
|                           | Rubber                         | Solid tires                    | 0.11                      | 0.21 | 0.32 | 0.44 | 0.54 | 0.66 | 0.76 | 0.88 | 0.99 | Fuwa           |
|                           | Wood                           | Timber (average)               | 3.0                       | 4.4  | 5.9  | 7.6  | 9.3  | 11.3 | 14.0 | 17.5 | 22.0 | Forest P. Lab. |
|                           | Soap                           | White                          | 1.9                       | 3.8  | 5.7  | 7.6  | 10.0 | 12.9 | 16.1 | 19.8 | 23.8 | Fuwa           |
|                           | Tobacco                        | Cigarette                      | 5.4                       | 8.6  | 11.0 | 13.3 | 16.0 | 19.5 | 25.0 | 33.5 | 50.0 | Ford           |
| Food-stuffs               | White Bread                    |                                | 0.5                       | 1.7  | 3.1  | 4.5  | 6.2  | 8.5  | 11.1 | 14.5 | 19.0 | Atkinson       |
|                           | Crackers                       |                                | 2.1                       | 2.8  | 3.3  | 3.9  | 5.0  | 6.5  | 8.3  | 10.9 | 14.9 | Atkinson       |
|                           | Macaroni                       |                                | 5.1                       | 7.4  | 8.8  | 10.2 | 11.7 | 13.7 | 16.2 | 19.0 | 22.1 | Atkinson       |
|                           | Flour                          |                                | 2.6                       | 4.1  | 5.3  | 6.5  | 8.0  | 9.9  | 12.4 | 15.4 | 19.1 | Bailey         |
|                           | Starch                         |                                | 2.2                       | 3.8  | 5.2  | 6.4  | 7.4  | 8.3  | 9.2  | 10.6 | 12.7 | Atkinson       |
|                           | Gelatin                        |                                | 0.7                       | 1.6  | 2.8  | 3.8  | 4.9  | 6.1  | 7.6  | 9.3  | 11.4 | Atkinson       |
| Misc. Inorganic Materials | Asbestos Fiber                 | Finely divided                 | 0.16                      | 0.24 | 0.26 | 0.32 | 0.41 | 0.51 | 0.62 | 0.73 | 0.84 | Fuwa           |
|                           | Silica Gel                     |                                | 5.7                       | 9.8  | 12.7 | 15.2 | 17.2 | 18.8 | 20.2 | 21.5 | 22.6 | Fuwa           |
|                           | Domestic Coke                  |                                | 0.20                      | 0.40 | 0.61 | 0.81 | 1.03 | 1.24 | 1.46 | 1.67 | 1.89 | Selvig         |
|                           | Activated Charcoal             | Steam activated                | 7.1                       | 14.3 | 22.8 | 26.2 | 28.3 | 29.2 | 30.0 | 31.1 | 32.7 | Fuwa           |
|                           | Sulfuric Acid                  | H <sub>2</sub> SO <sub>4</sub> | 33.0                      | 41.0 | 47.5 | 52.5 | 57.0 | 61.5 | 67.0 | 73.5 | 82.5 | Mason          |

is an oxidizing process dependent upon temperature. High relative humidities have a retarding effect on the rate of oxidization at the surface, and allow the internal gases to escape freely as the chemical oxidizers cure the varnish from within. This produces a surface free from bubbles and a homogeneous film throughout. Desirable temperatures for drying varnish vary with the type. A relative humidity of 65 percent is beneficial for obtaining the best processing results.

#### Control of Rate of Biochemical Reactions

In the field of biochemical control, industrial air conditioning has been applied to many different and well-known products. All problems involving fermentation are classed under this heading. As biochemistry is a subdivision of chemistry, subject to the same laws, the rate of reaction may be controlled by temperature. An example of this is the dough room of the modern bakery. Yeast develops best at a temperature of 80 F. A relative humidity of 70 percent is maintained to hold the surface of the dough open to allow the carbon dioxide gases formed by the fermentation to pass through and produce a loaf of bread, when baked, of even, fine texture without large voids.

The curing of fruits, such as bananas and lemons, also comes under this classification. Bananas require a cycle of temperatures and relative humidities for ripening. The starches in the pulp of the fruit must be changed and the skin cured and colored, after which the fruit is cooled to maintain as low a rate of metabolism as possible. Ideal storage conditions range between 56 and 60 F, with about 85 percent relative humidity, and ventilation at the rate of three or four air changes per hour.

The curing of lemons is an entirely different problem. Bananas are cured for a quick market, while lemons are held for a future market. The process, therefore, varies in the temperature used. Temperatures from 54 to 59 F have been found to be best suited for this process. A high relative humidity of 84 to 88 percent is necessary to hold shrinkage to a minimum and, at the same time, develop the rind so it will be sufficiently tough to permit handling.

Tobacco from the field to the finished cigar, cigarette, plug or pipe tobacco, offers another interesting example of what may be done by industrial air conditioning in the control of color, texture and flavor. In the processing of tobacco, control of moisture regain, and of chemical and biochemical reactions, is involved, and only through close atmospheric control can the best quality of leaf be developed.

#### Control of Rate of Crystallization

The rate of cooling of a saturated solution determines the size of the crystals formed. Both dry- and wet-bulb temperatures are of importance, as the one controls the rate of cooling, while the other, through evaporation, changes the density of the solution.

In the coating pans for pills, gum, and nuts, a heavy sugar solution is added to the tumbling mass. As the water evaporates, each separate piece is covered with crystals of sugar. A smooth, opaque coating is only accomplished by blowing into the kettle the proper amount of air at the right dry- and wet-bulb temperatures. If the cooling and drying are too slow, the coating will be rough and semi-translucent, and the appearance unsightly; if too fast, the coating will chip through to the interior. Only by balancing temperature, relative humidity, and volume of air to the sugar solution, can the proper rate be obtained and a perfect coating assured.

### Control of Temperature for Close Machining Tolerances

Where tolerances must be held within 2 or 3 ten-thousands of an inch, as in the manufacture of precision instruments, tools, and high quality lenses, temperature variations may cause expansion and contraction of material to an extent that will seriously affect the quality of the work. This type of work usually requires close temperature control to assure accuracy and uniformity of the product.

Usually the temperature level with respect to the product is not as important as controlling the temperature within close limits. For this reason, conditions are usually selected within the comfort range.

### Control of Dew-Point for Protection of Polished Surfaces

In the manufacture of certain metal articles, the presence of finger prints, tarnish, or *etching* can not be tolerated in the finished article. If these articles are manufactured under conditions of effective temperatures that will cause the hands to perspire, an unsatisfactory product will result. The salt and acid contained in body perspiration, when deposited on the highly polished article, can show corrosion and rust within a few hours if examined under a microscope.

It is therefore important to maintain temperatures and relative humidities (dew-point) low enough to prevent sweating of the hands. In addition, the manufacture of polished surfaces usually requires a better-than-average job of air filtering to avoid abrasion of the surfaces.

### Control of Humidity for Reduction of Static Electricity

The presence of static electricity is often detrimental to the satisfactory and economical processing of many light materials, such as textile fibers, paper, etc. It is also extremely dangerous where explosive atmospheres or materials are present. Fortunately, this hazard is minimized by increasing the relative humidity to at least 55 percent, if the material being processed is not damaged thereby.

It must be borne in mind that for successful elimination, the air that actually comes in contact with the material in the machine must be at a relative humidity of 55 percent or more. As some machines consume a great deal of power, which is converted directly into heat, the temperature in the machine may be considerably higher than the temperature adjacent to the machine where the relative humidity is normally measured. In such cases, the relative humidity in the machine will be appreciably lower than that elsewhere in the room, and it may therefore be necessary to maintain a room relative humidity of 65 percent, or even more, to maintain the desired humidity.

### Control of Conditions for Material Test Laboratories

Laboratories having controlled conditions of temperature and humidity, are becoming more common, not only for the purposes of scientific research, but also for routine testing and for quality production control. A control of temperature and humidity within fairly close plus or minus limits is usually required. Laboratories designed for scientific research may require control of conditions over a wide range, whereas the routine testing laboratory or quality control laboratory will usually be designed to maintain the A.S.T.M. Standard Conditions of 50 percent relative humidity and 23 C (73.4 F) temperature.

## CALCULATIONS

The methods for determining the heating and cooling loads for the various industrial processes are similar to those outlined in Chapters 12 and 13. Some factors affecting heating or cooling requirements are given in Table 1. Because of the large number of motors and heat producing units usually found in an industrial application, it is particularly important that operating allowances, for the latent and sensible heat loads, be definitely ascertained and used in the calculations to determine the total design load.

## GENERAL REQUIREMENTS FOR HEALTH, SAFETY AND EFFICIENCY

### Control of Atmospheric Contaminants

Safeguarding the health and maintaining the safety and efficiency of workers, require control of dusts, fumes, smokes, mists, fogs, vapors, and gases, and control of the effective temperature, which includes temperature, humidity and motion of air about the worker.

General ventilation may be relied upon in some cases to control air contaminants. Chapter 11 gives information on natural ventilation. If mechanical ventilation is to be used, Chapter 33, Fans; Chapter 31, Air Distribution; Chapter 32, Air Duct Design; Chapter 34, Air Cleaning; and Chapter 35, Spray Apparatus, furnish information on a broad range of industrial design conditions.

Specialists in the field of industrial hygiene should be consulted in case of doubt concerning the presence of airborne industrial hazards to health. Chapter 8, Air Contaminants; Chapter 6, Physiological Principles; and Chapter 7, Air Conditioning in the Prevention and Treatment of Disease, will be of help in determining the atmospheric conditions which should be maintained around the worker. Local codes, ordinances, or state labor laws must likewise be observed, particularly for ventilation requirements for hazardous trades. Comfortable conditions are desirable because they are likely to increase the efficiency of workers. For purposes of analysis, both sensible and latent heat should be included as contaminants of industrial atmospheres. A recent small scale survey has indicated that more than half of the air conditioning and ventilation installations in a typical industrial plant were concerned with removal of either sensible or latent heat as a source of air contamination.

### Contaminant Control Systems

In general, systems for control of atmospheric contamination in industrial plants will be of three types:

1. *Local exhaust systems* will be indicated where the contamination originates at concentrated areas and is characterized by low or imperceptible air motion, or where the contaminant is a dust, mist or fume requiring a capture velocity exceeding 25 fpm. Design of this type system is discussed in Chapter 46, and will not be further treated in this chapter.
2. A system employing the *dilution* method will usually be indicated where the contamination originates at scattered points dispersed generally throughout the area.
3. Combination of *local exhaust* and *dilution* methods is often economical, since well designed exhaust hoods or openings, removing from the space that portion of the contamination load which is susceptible to such treatment, will often reduce greatly the air volumes required for dilution purposes. The choice of the type of system should be made on the basis of economic comparisons.

### Design of Dilution Systems

The first step in the design of a system employing the dilution method is to determine as exactly as possible the nature and extent of the contaminating load. This will often be difficult, and may require construction of pilot production models. Often, however, the required data will be available from production records, showing the weight or volume rate of loss of the contaminating agent to the atmosphere, or it may be estimated from parallel operations in other plants, or by applying experienced engineering judgment. However obtained, the determination of the nature and magnitude of the contaminating load is an indispensable step in the proper design of the corrective system. Designs based on number of air changes per hour, or other rule-of-thumb methods, are hopelessly inadequate, and lead either to unsuccessful operation or to excessive and unnecessarily high cost of installation.

1. *Gases and Vapors.* Once having established the nature and magnitude of the contamination load, it is rarely necessary to completely remove contaminating agents from the atmosphere. For cases involving diffusible vapor or gas contaminants, maximum allowable concentrations (MAC) of commonly encountered gases and vapors have been established, and these data are tabulated in Chapter 8. From these data, and the previously established rate of addition of the contaminant to the space, the volume of air required to dilute the addition to a tolerable level can be calculated by the equation:

$$Q = \frac{V \times 10^6}{(\text{MAC}) - (\text{SAC})} \quad (1)$$

where

$Q$  = quantity of air circulated, cubic feet per minute.

$V$  = rate of generation of contaminant, cubic feet per minute.

$\text{MAC}$  = maximum allowable concentration, ppm by volume.

$\text{SAC}$  = concentration in supply air, ppm by volume.

The rate of generation of the contaminating vapor will often be available as a *weight or volume* of liquid evaporated into the space per unit time. These may be converted to the units of Equation 1 by applying the principle that a pound-mol of a gas or vapor will occupy approximately 359 cu ft at standard pressure and temperature. Thus,

$$\text{cfm (vapor)} = \frac{W}{M_w} \times 359 \times \frac{t + 460}{492} \quad (2)$$

where

$W$  = rate of generation of contaminant, pounds of liquid solvent per minute.

$M_w$  = molecular weight.

$t$  = air temperature, Fahrenheit.

A special case occurs where local concentrations of solvent vapors *at the breathing zone*, resulting from concentrated sources of contamination, are intolerably higher than the average design concentration when using dilution methods. Data are available for calculations, but involve many assumptions regarding boundary conditions, such as convection area and random air movement in the vicinity.

2. *Dusts and Fumes.* Maximum allowable concentration of various dusts, fumes and mists are also tabulated in Chapter 8. However, the dilution method as a means of treating particulate contaminating agents should be used with care, since the allowable air movement in spaces will ordinarily be lower than the capture velocity required for such particles. Exhausting at the source (see Chapter 46) will generally be the recommended treatment for these particulate contaminants.

3. *Sensible Heat.* Excessive sensible heat contamination is subject to treatment, similar to that for vapors, by the dilution method, the difference being that the rate of generation of the contaminant must be expressed in units of energy rather than volume or weight, and that the effect will be expressed as excessive temperature. In this case, the circulated air required will be:

$$Q = \frac{H}{(t_1 - t_o) \times d \times c} \quad (3)$$

where

$Q$  = quantity of air circulated, cubic feet per minute.

$H$  = rate of generation of heat, Btu per minute.

$t_1$  = allowable temperature in the space, Fahrenheit.

$t_o$  = temperature of supply air, Fahrenheit.

$d$  = density of air in pounds per cubic foot.

$c$  = specific heat of air.

In some cases, such as ventilation systems not employing refrigeration, unusually large and uneconomical air quantities may be required when the desired or tolerable temperature  $t_1$  approaches too closely the temperature  $t_o$  of the dilution air. This condition may sometimes be corrected by a combination of treatment by dilution and central exhaust, large sources of heat load being eliminated by exhaust through hoods at the source.

### Heat Storage in Structure

A special condition is sometimes encountered in large masonry structures when, due to the heat storage capacity and time lag of the structure, a prolonged period of hot weather may cause storage of such large quantities of heat in the structure that they continue to be a source of heat load after the outside weather has moderated.

In general, the solution to ventilation problems by the simple *dilution method* is limited to cases where a practical and economical equilibrium may be established between the maximum rate of generation of the contaminant distribution and cost of the air required for its removal.

### LOCAL RELIEF IN HOT AND HOT HUMID INDUSTRIAL ENVIRONMENTS

In many areas in industrial buildings, it is not economically feasible to provide acceptable working conditions by the conventional means of ventilation and air conditioning. In such cases, local control of the environment (spot cooling) may be provided by means of shielding, air cooled booths, and spot cooling by means of air motion to provide a relatively cool area for the worker. These methods of local control may be used in conjunction with the natural or mechanical ventilation systems of the building to obtain the desired conditions for the worker, process or equipment.

Spot cooling may be defined for the purposes of industrial environment control as heat relief of a local area within a larger space, independently of the general surroundings; a so-called oasis to provide conditions of relative comfort.

### Environmental Considerations

In the preliminary design for hot environments the following should be considered:

1. Estimate the conditions of dry-bulb temperature, humidity, air motion, radiant

heat, effective temperature, and body heat balance. For buildings with low ceiling heights, the possibility that heated air may accumulate under the ceiling or that the ceiling may absorb heat and become a radiant heating panel should be explored. (See Chaps. 5 and 24.) Such radiant heat loads may represent other heat loads considered but not dissipated to the outside. In addition to the pertinent chapters in *THE GUIDE*, the designer should refer to the articles by Small<sup>1</sup>, and Haines and Hatch<sup>2</sup> on the subject of heat relief in industry, in evaluating the above factors.

2. Consider the practicability of reducing the heat loads imposed on the area and worker by:

- a. Designing a building structure of adequate height, reducing the glass area exposed to sun radiation, and utilizing heat-reflecting glass to shield the high intensity radiant sources.
  - b. Changing the process in such manner as to provide lower operating temperatures, thereby lowering the heat release to the area.
  - c. Providing air cooled booths, possibly in conjunction with remote operating controls and visual aid devices, so that the hot areas may be avoided except for short exposures.
  - d. Insulating all surfaces above 125 F in temperature where these surfaces are extensive enough to add appreciably to the ambient air temperature or mean radiant temperature.
  - e. Using canopy hoods for hot equipment or providing local hoods at flues and doors of furnaces and similar hot equipment to reduce the heat dissipated to the work area.
  - f. Shielding hot equipment (often used in conjunction with hoods) so as to reduce sources of radiant heat.
3. Give careful consideration to the type of clothing used by the workers.<sup>3</sup> Lightweight, open-weave fabrics in white, will frequently reduce the heat received by the worker to a small extent and will materially increase the workers' ability to lose heat by convection and evaporation. Also, reflective clothing can be provided, as noted hereinafter under the heading Radiation Shielding.
4. Heat removed from exchangers, motors, generators and similar equipment can be used to temper necessary make-up air or to heat the building in the winter. This heat can be discharged outdoors in warm weather.

### Physiological Considerations

In hot environments, the major physiological considerations are the degree of activity of the occupants (this affects their metabolic rate or rate of heat production), the length of the period of activity and occupancy, and the ambient environmental factors (dry-bulb temperature, mean radiant temperature, humidity and air motion) which control the dissipation and reception of heat by the occupants. The subjects of work activity, and the correlated effective temperature limitations are covered in detail in Chapter 6. While effective temperature is a good index for hot areas (when mean radiant temperature effects are included), it must be realized that the allowable effective temperature which can be considered for a particular area must be dependent upon the degree of activity or work rate, and, consequently, on the body heat balance. It is essential that body heat balance (metabolic rate plus heat received by the body, versus the heat dissipated by the body) be maintained except for relatively short exposures to hot environments. The subject is treated to some extent in Chap. 6, but Haines and Hatch<sup>2</sup> have recently provided detailed data for estimating the maximum heat removal that can be expected for various environmental conditions. These data and calculations will also provide a means of estimating the maximum practical work rate for the area under consideration, and will indicate the best means for providing relief for the worker.

Too little information is available on the effect of air motion (draft) on human comfort. An understanding of the subject is of great importance in designing areas for local cooling. The comfort reaction to a draft is a function of (a) the physiological factors of work activity, position, age, sex, health and acclimatization; and (b) the environmental conditions of

temperature, air movement (over the body), and humidity. In hot atmospheres with high mean radiant temperatures and with high degrees of activity, a draft may be pleasant. In cooler conditions with less active work, a draft may be unpleasant. The body extremities are sensitive to draft and the head, neck, and shoulders have been found particularly sensitive if subjected to continued or excessive air movement in conjunction with low humidity, sweating, and the impingement of low temperature air.

The position of the worker is important. A person sitting, at rest, will produce less heat than a person standing, but because of the increased convection and evaporation surface exposed, the latter can lose more heat. Likewise, a person whose job requires him to stay at a fixed point, cannot be comfortable under the same conditions of air movement as a person who is moving about and exposed intermittently to the same air movement. Yaglou<sup>4</sup> among others, has pointed out that minimum body stress occurs with uniform cooling or heating over the body area. On the basis that the maximum work rate which can normally be maintained for an 8 hr day is 88 Btu per (sq ft)(hr) or 1700 Btu per hr for a surface area of 19.5 sq ft, the following stress factors may be used as guides in determining the design of local relief areas in hot industries.

1. The effective temperature should be maintained below 85 F. (See Ref. 2 also.)
2. The relative humidity should not exceed 80 percent for normal temperatures nor should the wet bulb temperature exceed 83 F. (See Chap. 6, Fig. 9.)
3. The skin temperature should not exceed 95 F.
4. The pulse rate should not exceed 125 beats per minute (from an initial rate of 70 to 80).
5. The rectal temperature should not exceed 100 F (from an initial level of 98 to 99 F).

These are neither rigid nor exact limitations but do provide guides for design purposes. Generally, the designer will do well to stay reasonably below these limits. If the limits of paragraphs 3, 4, and 5 are not exceeded within the first two hours of work they probably will not be exceeded during the work day provided there is no change in the rate of work or the environmental conditions.

### Radiation Shielding

Shielding is an all-important method for reducing radiant heat exposures and the one technique that has been largely neglected in industry.

A shield consists of a sheet of suitable material placed between a hot object, such as a furnace, and its cooler surroundings. The closer it is placed to the hot object, the greater the effective coverage. Hot surfaces emit infra-red waves which reach all objects within visible range. Essential to all shielding is the presence of an air space between the hot object and the shield to avoid conduction to the shield or a thermal short circuit.

Radiation shields in the following forms are very effective:

1. Sheets of reflective metal or insulating board, either semi-permanently attached to the hot equipment (such as furnace buck stays) or arranged as semi-portable floor stands.
2. Aluminum foil faced cloth curtains which can be raised or lowered on spring rolls.
3. Transparent shields, including heat reflecting tempered plate glass, reflective metal chain curtains and close mesh wire screens. These have lower efficiency than opaque shields described in preceding paragraphs 1 and 2.
4. Reflective garments, such as aprons, or in the form of a sandwich in cases of



continuous front and back exposures. For continuous wear the apron or sandwich width should be limited to 14 to 18 in. to assure adequate continuous side openings for air circulation and body ventilation. In addition gauntlets and face shields are particularly applicable to operations such as the pouring and casting of hot metal. Supply houses dealing in safety clothing for industry offer suitably lightweight flame proofed foil-faced cotton drill or denim of excellent reflectivity.

For repairs inside hot coke ovens and industrial furnaces, a complete suit is available using forced ventilation from a small blower or a compressed air source. These suits may be made of asbestos cloth, faced with a reflective metal in atomized form.

If the shield is a good reflector, it will remain relatively cool in the presence of severe radiant heat. This reflectivity is a surface characteristic. Hence a thin sheet is as effective as a thick one. Tinplate, stainless

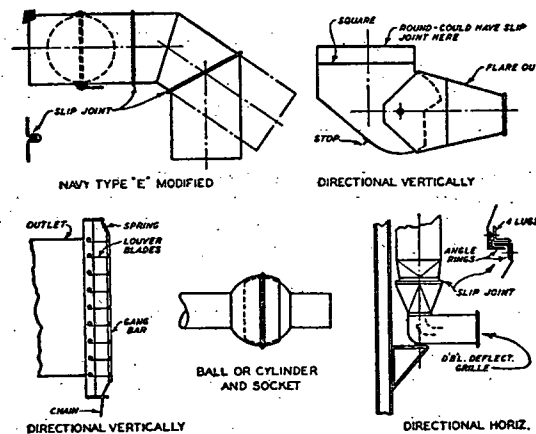


FIG. 1. DIRECTIONAL OUTLETS FOR SPOT COOLING

steel and ordinary flat or corrugated aluminum sheets are efficient and long-lived. Foil-faced plaster board, though less durable, obtains good reflectivity on one side.

### Spot Cooling By Air Motion

The previous paragraphs have described the steps which should be taken to reduce the heat load on the worker or the work area. When these factors have been considered and the heat load has been minimized to a practical degree, the designer may then resort to spot cooling by air motion to cool the worker himself. Such cooling may be provided by supplying air to the local areas or into suitable working enclosures or booths, or to ventilated coverall suits. The air supplied should be at such conditions of temperature, relative humidity and air motion as to provide a cooling effect on the worker.

These systems may also be used to provide make-up air for industrial exhaust systems, or to provide spot heating in the winter time.

Such installations may be provided to improve the conditions around the

worker continuously, or else to provide a relief area where the worker will be in a cool zone intermittently. The designer should keep this in mind in selecting the proper method of air cooling.

Spot cooling may be provided by means of recirculated (man-coolers), direct outside, dehydrated, evaporatively cooled or mechanically cooled air, the solution depending upon the environmental conditions existing in the working area, and the economic factors. Generally, recirculated air will be effective only for areas of moderate heat release. Other systems will be required for areas having high heat release.

A great variety of outlets may be used for spot cooling. Several different types are shown by Fig. 1. In addition, several manufacturers make remotely adjustable ceiling diffusers such that the air patterns may be altered from horizontal (parallel to the ceiling) to vertical, down. A number of manufacturers also make double deflection grilles that are good for this service. Such outlets can be provided in conjunction with an elbow type outlet and slip joint (see lower right diagram in Fig. 1) so as to provide directional discharge at any desired angle. The latter is very important to the worker because he may frequently want the air discharging into the space but may not want it to blow on him.

Perforated panels may also be used for the supply air. Such panels have low induction characteristics and, used in conjunction with a booth could provide a low velocity blanket of air which should be effective for local heat relief, if supplied with cooled air. A booth would shield the worker from radiant heat and would permit effective cooling by means of the air supplied through the panel.

The outlet air velocities used for spot cooling systems may vary from 50 to 2000 fpm. The higher velocities are frequently used but should be used with caution as noted hereafter. The data in Chap. 31 Air Distribution, should be studied in determining the required outlet velocities corresponding to the desired velocity at the worker or the operating station.

The following items are particularly important in designing spot cooling installations:

1. Where the personnel are engaged in work requiring little activity and where the exposure is continuous, the air velocity at the personnel should be low, approaching the normal room velocities. The maximum velocity for such cases is sometimes given as 200 fpm. With greater worker activity, and where the worker is in the air current intermittently, higher velocities may be used. See Chap. 6, Effective Temperature Chart, Fig. 9.
2. Generally the temperature of the air impinging on the worker should exceed 80 F.
3. When the temperature of the air impinging on the worker exceeds the skin temperature the critical point is approached where too high an air velocity will add to the body heat load and too low a velocity will fail to remove the sweat, and thus fail to provide the maximum evaporative cooling for the existing conditions. (See Ref. 2.)
4. The outlets should be placed as close as practicable to the worker in order to take advantage of the lower discharge air temperature and the relatively larger core of air at the discharge air temperature. Installations in which the air is discharged from outlets 4 to 8 ft. from the worker are effective with small volumes of air, 200 to 1000 cfm. per outlet. At hot metal furnace working stations, 2000 to 3000 cfm. will be adequate. At greater distances more air is required due to the increased entrainment of room air. However, the effect of the lower velocity air would be more tolerable.
5. In selecting the outlets it should be kept in mind that large outlets have greater cooling effect because of the larger core of cool air. Slot outlets by comparison have high induction ratios, thus higher impinging temperature (at the worker). Per-

forated panels have low induction ratios and thus will provide lower impingement temperatures.<sup>5</sup> See Chap. 31.

6. Generally the outlets should have remote directional or volume control or, preferably, both. The worker should be able in most cases to operate the outlet damper, vanes or louvers (or to turn the outlet) from the floor by some convenient means.

The damper control should provide at least 80 percent reduction in velocity. The workers may desire the full air velocity in hot weather, but may wish to reduce the velocity or to direct the air above the head zone in cold weather.

7. Generally the spot cooling air should be directed to the front and to the torso of the worker. If possible the air should not be directed at the head, shoulders or the back of the worker.

8. When providing spot cooling with evaporatively cooled air, be sure that conditions of high humidity will not exist and cause conditions detrimental to the comfort of the personnel or cause rusting or other difficulty with the equipment or process.

Generally the evaporatively cooled air should be limited to 20 to 50 percent of the total outside air circulated through the building.

### Odors

There is little information available either on the rate of generation of common odors, or on the maximum concentration which would be tolerated by a majority of persons. Thus a quantitative specification covering systems for locker rooms and toilet rooms, or other applications where odors constitute the contaminant, is not now possible. Pending research in this important field, it is suggested that the data in Table 1, Chapter 6, showing the outside air supply required per person, at various socioeconomic levels, be used.

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## CHAPTER 46

### INDUSTRIAL EXHAUST SYSTEMS

Elements of Exhaust Systems, Hoods or Enclosures, Capture Velocities, Air Volume, Duct System Design, Calculations, Construction of System, Materials, Details, Air Flow Producing Equipment, Air Cleaning Equipment, Make-Up Air, Maintenance of Performance, Materials for Corrosion Resistance

**I**n industrial plants, some type of exhaust system designed to collect and remove dusts, fumes, mists, vapors, and gases is installed to protect health and safety of industrial personnel, promote worker efficiency, salvage usable material, or improve plant housekeeping. This chapter will not include consideration of systems similar in design, but used to convey heavy loadings (100 or more grains per cu ft) of materials. Definitions of various air contaminants, their particle sizes, maximum allowable concentrations, and upper and lower explosion limits are included in Chapter 8, Air Contaminants.

Exhaust systems are extensively used for control of contaminants from:

1. Mechanical cutting and abrading operations including abrasive blasting and rock cutting.
2. Fuel burning and exhaust gas producing operations.
3. Molten materials handling operations.
4. Welding, burning, and soldering operations.
5. Fiber handling operations.
6. Volatile and gaseous material handling operations.
7. Chemical processes.

Local exhaust systems should be considered whenever possible rather than general ventilation methods which allow contaminants to be dispersed within the workroom. More positive control, great reduction in exhaust volume handled, and reduced cost of air cleaning equipment will result.

#### ELEMENTS OF EXHAUST SYSTEMS

An exhaust system will consist of (1) hoods or enclosures at all sources of air contamination, (2) branch and main ducts through which an air stream transports the contaminant to air cleaning device or to the outside atmosphere, (3) air moving equipment to produce required air flow into hoods or enclosures, and (4) air cleaning equipment when required. See Chapter 34, Part II, for discussion of types, applications, and principles of operation.

#### HOODS OR ENCLOSURES<sup>1 to 10</sup>

Basically, hood design requires sufficient knowledge of a process or operation so the most effective hood or enclosure can be installed to provide minimum exhaust volumes for effective contaminant control. The more complete the enclosure, the more economical and effective will be the installation. Many designers develop their hoods by mentally enclosing the operation completely and then providing access and working openings as indicated. From this complete enclosure concept are developed the familiar hood shapes like booths, side or downdraft hoods (with or without side shields). All

openings are kept to a minimum size and are placed away from the natural path of the contaminant travel wherever possible. Inspection and maintenance openings are provided with doors whenever practicable.

### Capture Velocities and Air Volume Exhausted

Only after the hood design has been determined can exhaust volume requirements be calculated. With enclosures, volumes are calculated from the known open area of the hood and the selection of the capture or indraft velocity sufficient to prevent outward escapement. Where enclosure of the process is impracticable, the air flow pattern in front of the hood must be such that selected capture velocities will be maintained in the area of generation, conveying the contaminant to the hood opening.

Usual capture velocities for typical operations are listed in Table 1 and

TABLE 1. MINIMUM AIR VELOCITIES REQUIRED AT POINT OF ORIGIN TO CAPTURE CONTAMINANT EFFECTIVELY

| CONDITION OF GENERATION OF CONTAMINANT | MINIMUM CAPTURE VELOCITY, FPM | PROCESS                                                                                                                                                      |
|----------------------------------------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Released without noticeable movement   | 50-100                        | Evaporation of vapors, exhaust from pickling, washing, degreasing, plating, welding, etc.                                                                    |
| Released with low velocity             | 100-200                       | Paint spraying in booth; inspection, sorting, weighing, packaging, low speed (less than 200 fpm) conveyor transfer points, blending, mixing, barrel filling. |
| Active generation                      | 200-500                       | Foundry shakeout, high speed (over 200 fpm) conveyor transfer points, crushers, screens.                                                                     |
| Released with great force              | 500-2000                      | Grinding, tumbling mills, abrasive cleaning.                                                                                                                 |

refer in the case of remote hoods to the air movement required at the zone of air contaminant generation. Required capture velocities for any operation will vary with the magnitude of the air volume handled, with uncontrolled air movement in the area, and oftentimes with the location of the process or operation and size of the workroom. Larger remote hoods exhausting large air volumes will provide effective control at lower maintained capture velocities than in the case of small remote hoods handling lower exhaust volumes. A hood at one end of a small narrow room with air supply at opposite end will provide control with lower capture velocities than that required from the same hood in a large room where no perceptible air flow will be obtained except in the immediate area of the hood.

The method for determining, approximately, the quantity of air that must be exhausted from an unobstructed hood, without flanges, to produce these capture velocities at the point of origin, is given in Equation 1:

$$Q = V(10X^2 + A) \quad (1)$$

where

$Q$  = quantity of air exhausted, cubic feet per minute.

$V$  = air velocity in feet per minute at  $X$  distance in feet from the hood and on the centerline of the hood.

$X$  = distance in feet, along the hood centerline, from the face of the hood to the point where the air velocity is  $V$  feet per minute.

$A$  = area in square feet of the hood opening.

Fig. 1 shows lines of equal velocities (velocity contours) for a rectangular hood opening with a side ratio of one-half. The velocities are expressed as percentages of the velocity at the opening. Studies have established the principle of *similarity of contours* which states that the positions of the velocity contours for any hood (when the contours are expressed in terms of the average velocity at the hood opening) are purely functions of the shape of the hood. Extensive studies<sup>2, 11, 12</sup> have revealed variations in values of such velocity contours for long narrow slots and for hoods with one or more planes shielded against air flow.

For smaller hoods, flanges which are usually 3 to 6 in. wide surrounding the hood opening usually will improve the air flow in front of the hood

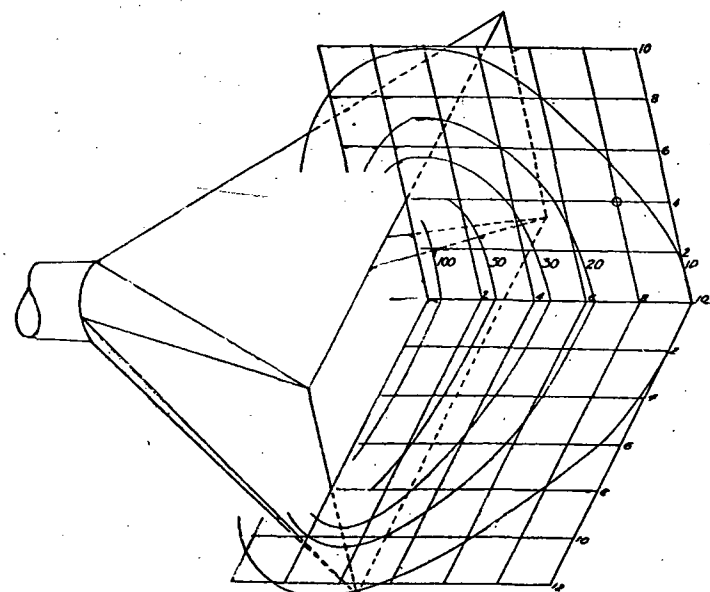


FIG. 1. VELOCITY CONTOURS FOR RECTANGULAR OPENING WITH A SIDE RATIO OF ONE-HALF. CONTOURS ARE EXPRESSED AS PERCENTAGES OF THE VELOCITY AT THE OPENING

and will reduce the air volume required to provide desired capture velocity by as much as 25 percent.

### Special Exhaust Requirements

It is important to note that certain operations may require exhaust volumes in excess of the quantities based on design data from Table 1 and Equation 1. Typical reasons for increased ventilation rates include:

1. Induced air flow caused from falling granular material in large quantities through considerable height, or from internal rotating parts like some types of crushers, knives, macerators.
2. Induced air flow caused by the thermal or stack effect from sources of extreme heat.

TABLE 2. A GUIDE TO VENTILATION RATES FOR TYPICAL INDUSTRIAL EQUIPMENT.  
State or Local Regulations Should be Consulted and Followed Where Higher Ventilation Rates are Specified

| OPERATION                                                  | VENTILATION                                             |                                                                                                                                                                                                                | USUAL TRANSPORT VELOCITY (FPM) | REMARKS AND REFERENCES                                                                                                                                    |
|------------------------------------------------------------|---------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                            | Type of Hood                                            | Air Flow                                                                                                                                                                                                       |                                |                                                                                                                                                           |
| Abrasive blast rooms (sand, grit or shot)                  | Tight enclosure with air inlets (usually in roof)       | 60-100 fpm downdraft (long rooms of tunnel proportions 100 fpm cross-draft)                                                                                                                                    | 3500                           | Ref. 8 Many codes specify minimum downdraft of 80 fpm                                                                                                     |
| Abrasive blast cabinets                                    | Tight enclosure with access openings                    | 20 air changes per minute but not less than 500 fpm through all openings                                                                                                                                       | 3500                           | Ref. 14                                                                                                                                                   |
| Asbestos Carding Spool winding                             | Enclosure Local Hoods                                   | 800 cfm per machine 50 cfm per spool                                                                                                                                                                           | 3000<br>3000                   | Ref. 2, 15, 16. See references for details and other operations                                                                                           |
| Bagging Open Bag Top                                       | Booth or enclosure (provide spillage hopper)            | Paper bags—100 cfm per sq ft open area<br>Cloth bags—200 cfm per sq ft open area                                                                                                                               | 3500<br>3500                   | Ref. 17                                                                                                                                                   |
| Barrels—Drums (filling or removing material by scoop)      | Local Hood<br>Booth                                     | 100 cfm/sq ft of container cross section<br>100 fpm at face                                                                                                                                                    | 3500<br>3500                   | Ref. 13, 18. Hood with 1-in slot extending 120 to 180 deg container. Does not confine spillage. Confine spillage—also recommended for container upsetting |
| Belt conveyors                                             | Hood at transfer point                                  | Belt speeds less than 200 fpm—350 cfm per foot of belt width, but not less than 150 fpm through open area. Belt speeds over 200 fpm—300 cfm per foot of belt width but not less than 200 fpm through open area | 3500                           | Ref. 17, 19                                                                                                                                               |
| Bins (closed top)                                          | Connect to bin top away from feed point                 | 150-200 fpm through open area at feed points                                                                                                                                                                   | 3500                           | Ref. 18, 19                                                                                                                                               |
| Bucket elevators                                           | Tight casing required                                   | 10 cfm per sq ft of elevator casing cross-section                                                                                                                                                              | 3500                           | Ref. 18                                                                                                                                                   |
| Brick cutting and sizing (abrasive cut-off wheel used dry) | Local Hood<br>Booth with saw at face of booth           | 500 cfm<br>100 fpm at face                                                                                                                                                                                     | 3500<br>3500                   | Ref. 7, 18. For portable operations. Control not as effective as booth                                                                                    |
| Ceramics Dry pan Dry press                                 | Enclosure Local at die Local at die At supply bin Booth | 200 fpm through all openings<br>500 cfm<br>500 cfm<br>500 cfm<br>100 fpm (face)                                                                                                                                | 3500<br>3500<br>3500<br>3500   | Ref. 18, 20, 21<br>Automatic feed<br>Manual feed                                                                                                          |
| Aerographing Fetting, brushing, sagger filling and unload  | Downdraft or side hood                                  | 100-150 cfm per sq ft of plan area of dust producing operation                                                                                                                                                 | 3500                           |                                                                                                                                                           |

TABLE 2. A GUIDE TO VENTILATION RATES FOR TYPICAL INDUSTRIAL EQUIPMENT (Continued)  
State or Local Regulations Should be Consulted and Followed Where Higher Ventilation Rates are Specified

| OPERATION                                                                                               | VENTILATION                                 |                                                                                                                                                   | USUAL TRANSPORT VELOCITY (FPM)      | REMARKS AND REFERENCES                                                                                                                                                                                                                                                  |
|---------------------------------------------------------------------------------------------------------|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                         | Type of Hood                                | Air Flow                                                                                                                                          |                                     |                                                                                                                                                                                                                                                                         |
| Cooling Tunnels (foundry molds)                                                                         | Enclosure                                   | 75-100 cfm per running foot of enclosure                                                                                                          |                                     | Ref. 19                                                                                                                                                                                                                                                                 |
| Crushers and grinders                                                                                   | Enclosure                                   | 200 fpm through openings                                                                                                                          | 3500                                | Ref. 17, 22                                                                                                                                                                                                                                                             |
| Furnaces Stationary melting pots for non-ferrous Tinning or roasting melting for Electric Arc for Steel | Enclosure Canopy Hood attached to roof ring | 100-200 fpm at hood opening<br>3000-4000 cfm<br>2500 cfm per ton charged                                                                          | 1500-2000<br>1500-2000<br>2500-3500 | Ref. 11, 13, 21, 23, 24<br>Use higher ventilation rate for toxic fumes<br>Ventilation rate can be materially reduced with more complete enclosures<br>General ventilation of melting room may be substituted but involves greatly increased ventilation rate<br>Ref. 23 |
| Forge (hand)                                                                                            | Canopy                                      | 200 fpm at face                                                                                                                                   | 1500                                | Ref. 13                                                                                                                                                                                                                                                                 |
| Garage (tail pipe at servicing location)                                                                | Local hood slipped over tail pipe           | 100 cfm thru 3-in. flexible duct for autos<br>200 cfm thru 4-in. flexible duct for trucks<br>300 cfm thru 4½-in. flexible duct for Diesel engines | 2000                                |                                                                                                                                                                                                                                                                         |
| Granite cutting and finishing Pneumatic hand tools Surfacing machine                                    | Local hood<br>Local hood                    | 500 cfm<br>500 cfm for tools up to 2½ in. diameter<br>1000 cfm for 2½ to 3½ in. diameter                                                          | 5500-6000<br>5500-6000              | Ref. 25, 26<br>Typical hood 3 x 8 in. opening with 3 in. flange<br>Hood surrounds tool                                                                                                                                                                                  |
| Grinders Polishers, buffers, etc. Portable                                                              | Standard wheel hood Downdraft bench         | See Table 3<br>Bench type, 2-400 cfm per sq ft of exhaust grille but not less than 150 cfm per sq ft of plan working area.                        | 3500                                | Ref. 21, 27<br>Ref. 13, 18, 21, 28                                                                                                                                                                                                                                      |
| Swing frame                                                                                             | Booth Booth                                 | 100 fpm at face<br>100-200 fpm indraft through opening in booth face                                                                              | 3500<br>3000                        | Recommended for larger parts (Usual cfm per grinder 2000-4000)                                                                                                                                                                                                          |
| Kitchen range                                                                                           | Canopy                                      | 100 fpm at hood face                                                                                                                              | 1500-1800                           | Provide drip gutter on all interior vertical walls to catch condensed grease. (Ref. 41)                                                                                                                                                                                 |
| Laboratory hood (provide with door)                                                                     | Booth type                                  | 50-100 fpm                                                                                                                                        |                                     | Ref. 23, 29. Air supply location very critical                                                                                                                                                                                                                          |
| Metallizing                                                                                             | Local hood<br>Booth                         | 200 fpm at hood face<br>125-200 fpm at booth face                                                                                                 | 3500<br>3000                        | Ref. 13. Not recommended for toxic materials<br>Use higher ventilation rates for toxic materials                                                                                                                                                                        |

TABLE 2. A GUIDE TO VENTILATION RATES FOR TYPICAL INDUSTRIAL EQUIPMENT (Continued)  
*State or Local Regulations Should be Consulted and Followed Where Higher Ventilation Rates are Specified*

| OPERATION                                                                  | VENTILATION                   |                                                                                                          | USUAL TRANSPORT VELOCITY (FPM) | REMARKS AND REFERENCES                                                                                     |
|----------------------------------------------------------------------------|-------------------------------|----------------------------------------------------------------------------------------------------------|--------------------------------|------------------------------------------------------------------------------------------------------------|
|                                                                            | Type of Hood                  | Air Flow                                                                                                 |                                |                                                                                                            |
| Mixers                                                                     | Enclosure                     | 100-200 fpm thru feed and inspection openings                                                            | 3000-3500                      | Ref. 18, 21                                                                                                |
| Motion picture projector (carbon arc)                                      | Enclosure                     | 12-100 cfm (for fume and gas removal) directly exhausted from projector housing                          |                                | Ref. 30. 1000-1500 cfm or 20-30 air changes per hour for heat removal                                      |
| Pharmaceuticals                                                            | Fully enclosed Hood           | 100 to 200 fpm through opening                                                                           | 2500-3500                      | Exhaust required only when filling or emptying                                                             |
| Coating pans                                                               | Enclosure                     | 120 cfm exh 24-in. diam. pan<br>60 cfm supply direct to pan. Differential 60 cfm                         | 3000                           | flexible exhaust hood connection exhausted into room. Feed opening covered all possible                    |
| Centrifuges                                                                | Local hood                    | 250-300 fpm through opening                                                                              | 1500-2000                      | Centrifuge to be provided with cover for 50-75 percent of opening                                          |
| Hammer mills<br>Grinders<br>Shakers<br>Mixers<br>Process kettles and tanks | Hood Enclosure                | 200 fpm but not less than 50 cfm                                                                         | 2500-3500<br>1500-2000         | Hood with slot at each end of mixer<br>Ref. 31. Use higher ventilation rate when contents are being heated |
| Pouring hoods<br>Foundry                                                   | Side hood                     | 200 to 300 cfm per linear ft of hood with slot velocities of 1500 fpm. Exhaust take-off every 8 to 10 ft | 3500                           | Ref. 19                                                                                                    |
| Rock drilling<br>Dry drilling (rock)                                       | Special trap (see references) | 80 cfm—vertical (downward) work<br>200 cfm—horizontal work                                               | 3500                           | Ref. 25, 26. May vary with size and speed of drill. Wet drilling offers alternate control methods          |
| Rubber calendar rolls                                                      | Canopy—side panels            | 75-100 fpm indraft                                                                                       | 3500                           | Ref. 23, 29                                                                                                |
| Quartz fusing                                                              | Booth on bench                | 150-200 fpm at face                                                                                      |                                | Ref. 32, 33                                                                                                |
| Resins<br>Vitrifying<br>Flux deck                                          | Enclosure                     | 150-200 fpm indraft through hood openings but not less than 25-50 cfm per sq ft of screen area           | 3500                           | Ref. 13, 18                                                                                                |
| Shakeouts<br>Foundry                                                       | Enclosure                     | 200 fpm through all openings in enclosure, but not less than 200 cfm per sq ft of grate area             | 3500                           | Ref. 19, 21                                                                                                |

TABLE 2. A GUIDE TO VENTILATION RATES FOR TYPICAL INDUSTRIAL EQUIPMENT (Concluded)  
*State or Local Regulations Should be Consulted and Followed Where Higher Ventilation Rates are Specified*

| OPERATION                                                                                                                              | VENTILATION                                                        |                                                                                                                                                                                                                    | USUAL TRANSPORT VELOCITY (FPM)      | REMARKS AND REFERENCES                                                                                                                               |
|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                        | Type of Hood                                                       | Air Flow                                                                                                                                                                                                           |                                     |                                                                                                                                                      |
| Spray coating                                                                                                                          | Booth—operator inside<br>Booth—operator outside<br>Booth—downdraft | 100-200 fpm at booth cross section<br>150-200 fpm at booth cross section<br>100-200 fpm downdraft                                                                                                                  | 1500-2000<br>1500-2000<br>1500-2000 | Ref. 13<br>Use higher ventilation rate for small booths 4 sq ft or less                                                                              |
| Tanks, open surface                                                                                                                    | See Table 4                                                        |                                                                                                                                                                                                                    |                                     | Ref. 34, 42                                                                                                                                          |
| Tumbling mills<br>Hollow trunnion type                                                                                                 | Exhaust connection by manufacturer                                 | Use branch diameter same size as exhaust duct. For round mill, branch diam should be 1/2 diam of mill. For square mills branch diam should be 1 in. plus 1/4 side dimension of mill.                               | 3500-5000                           | Ref. 14                                                                                                                                              |
| Tumbling mills, drums, cages, barrels                                                                                                  | Enclosure                                                          | 400 fpm thru openings but not less than 75 cfm per sq ft plan area                                                                                                                                                 | 3500                                | Where equipment is enclosed and dust tight during rotation, enclosure may not be needed if feed and discharge operations can be otherwise controlled |
| Welding                                                                                                                                | Local hood with flange<br>Downdraft bench<br>Booth                 | 6 in. from arc—150 cfm<br>8-9 in. from arc—275 cfm<br>8-10 in. from arc—425 cfm<br>10-12 in. from arc—600 cfm<br>150-250 cfm per sq ft grille area<br>100 fpm at booth face                                        | 2000-4000<br>2000<br>2000           | Ref. 35                                                                                                                                              |
| Woodworking                                                                                                                            | See Table 5                                                        |                                                                                                                                                                                                                    |                                     | Ref. 21, 36                                                                                                                                          |
| Miscellaneous<br>Packaging machines, granulators<br>Enclosed dust producing units<br>Encaging, weighing, container filling, inspection | Complete enclosure<br>Booth<br>Downdraft                           | 100-400 fpm indraft through inspection or working openings, but not less than 25 cfm per sq ft of enclosed plan area<br>50-150 cfm per sq ft of open face area<br>75-150 cfm per sq ft of dust producing plan area | 3000<br>3000<br>3500                | Ref. 18                                                                                                                                              |

3. Exhaust volumes insufficient to dilute mixtures of combustible vapor and air to less than 20 percent of the lower explosive limit of the combustible.

4. Room air currents caused by cross drafts, spot cooling, motion of machinery or operators.

5. Local or State regulations may specify larger exhaust volumes for specific operations.

Exhaust volume requirements for many specific operations have been listed in Tables 2, 3, 4, and 5.

TABLE 3. EXHAUST REQUIREMENTS<sup>17</sup> FOR GRINDING, POLISHING, BUFFING, SCRATCH BRUSHING ABRASIVE CUT-OFF WHEELS, GRINDING AND POLISHING BELTS

(Air Volume: 4500 fpm in all branches.) (2 in. water suction at average hood)

| GRINDING OR CUT-OFF WHEELS |                  |                   |      | BUFFING, POLISHING, AND SCRATCH BRUSHING |                  |                   |      |
|----------------------------|------------------|-------------------|------|------------------------------------------|------------------|-------------------|------|
| Wheel Diam., In.           | Max. Width*, In. | Branch Diam., In. | CFM  | Wheel Diam., In.                         | Max. Width*, In. | Branch Diam., In. | CFM  |
| - 9                        | 1½               | 3                 | 225  | - 9                                      | 2                | 3½                | 300  |
| 10-16                      | 2                | 4                 | 390  | 10-16                                    | 3                | 4½                | 500  |
| 17-19                      | 3                | 4½                | 500  | 17-19                                    | 4                | 5                 | 610  |
| 20-24                      | 4                | 5                 | 610  | 20-24                                    | 5                | 5½                | 740  |
| 25-30                      | 5                | 6                 | 880  | 25-30                                    | 6                | 6½                | 1040 |
| 31-36                      | 6                | 7                 | 1200 |                                          |                  |                   |      |

| HORIZONTAL SINGLE SPINDLE DISC GRINDERS |                   |     | HORIZONTAL DOUBLE SPINDLE DISC GRINDERS |                   |      | VERTICAL SINGLE SPINDLE DISC GRINDERS |                   |      |
|-----------------------------------------|-------------------|-----|-----------------------------------------|-------------------|------|---------------------------------------|-------------------|------|
| Wheel Diam., In.                        | Branch Diam., In. | CFM | Wheel Diam., In.                        | Branch Diam., In. | CFM  | Wheel Diam., In.                      | Branch Diam., In. | CFM  |
| -12                                     | 3                 | 225 | -19                                     | 1-5               | 610  | -20                                   | 1-4½              | 500  |
| 13-19                                   | 4                 | 390 | 20-25                                   | 1-6               | 880  | 21-30                                 | 2-4               | 730  |
| 20-30                                   | 5                 | 610 | 26-30                                   | 1-7               | 1200 | 31-53                                 | 2-6               | 1760 |
| 31-36                                   | 6                 | 880 | 31-53                                   | 2-6               | 1760 | 54-72                                 | 2-8               | 3120 |
|                                         |                   |     | 54-72                                   | 4-8               | 6240 |                                       |                   |      |

#### GRINDING OR POLISHING BELTS:

To 3 in. wide—3 in. branch, add ½ in. to branch diameter for each 2 in. or fraction increase in belt width over 3 in.

\* Increase branch diameter 0.3 in., but not less than ¼ in., for each 1 in. increase in width over dimension noted.

#### Duct System Design

The duct system will consist of branch ducts connected to a main duct which will convey the air from the hoods to the exhaust fan and the air cleaning equipment, if used. Round ducts should be used wherever possible. Their gage size and construction differ from air supply practice due to the rougher usage encountered, and in the case of dusts, to the abrasive effect. (See later section on Exhaust System Design and Construction Features.) Usual conveying velocities are shown in Table 6. Where solid contaminants are handled, recommended velocities must be maintained throughout the system to prevent material from settling in the ducts and obstructing the air flow. For conveying of solid particles, velocities shown in Table 6 include a reasonable factor of safety, and design velocities may therefore be adjusted to use commercial pipe sizes which are available generally in ½-in. diameter steps through 6-in. diameter and 1-in. steps through 16-in. diameter or larger with 2-in. diameter steps for large diameters. For contaminants that are not solids, conveying velocities are based on a balance

TABLE 4. VENTILATION RATES FOR OPEN SURFACE TANKS<sup>24,25</sup>

| PROCESS                                     | MINIMUM VENTILATION RATE CFM PER SQ FT HOOD OPENING |                |                  |                 | MINIMUM VENTILATION RATE CFM PER SQ FT TANK AREA LATERAL EXHAUST (NOTE 1) W/L = Tank Width / Tank Length RATIO |     |               |     |              |     |
|---------------------------------------------|-----------------------------------------------------|----------------|------------------|-----------------|----------------------------------------------------------------------------------------------------------------|-----|---------------|-----|--------------|-----|
|                                             | Enclosing Hood                                      |                | Canopy Hood      |                 | W/L 0-0.24                                                                                                     |     | W/L 0.25-0.49 |     | W/L 0.50-1.0 |     |
|                                             | One Open Side                                       | Two Open Sides | Three Open Sides | Four Open Sides | A B                                                                                                            |     | A B           |     | A B          |     |
|                                             |                                                     |                |                  |                 | A                                                                                                              | B   | A             | B   | A            | B   |
| Plating                                     |                                                     |                |                  |                 |                                                                                                                |     |               |     |              |     |
| Chromium (Chromic Acid Mist)                | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Arsenic (Arsine)                            | 65                                                  | 90             | 100              | 150             | 90                                                                                                             | 130 | 110           | 150 | 130          | 170 |
| Hydrogen Cyanide                            | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Cadmium                                     | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| acidizing                                   | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Metal Cleaning (Pickling)                   |                                                     |                |                  |                 |                                                                                                                |     |               |     |              |     |
| Cold Acid                                   | 65                                                  | 90             | 100              | 150             | 90                                                                                                             | 130 | 110           | 150 | 130          | 170 |
| Hot Acid                                    | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Nitric and Sulphuric Acid                   | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Nitric and Hydrofluoric Acid                | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Metal Cleaning (Degreasing)                 |                                                     |                |                  |                 |                                                                                                                |     |               |     |              |     |
| See Note 2 and Ref. 43 and 44               |                                                     |                |                  |                 |                                                                                                                |     |               |     |              |     |
| Metal Cleaning (Caustic or Electrolytic)    |                                                     |                |                  |                 |                                                                                                                |     |               |     |              |     |
| Not Boiling                                 | 65                                                  | 90             | 100              | 150             | 90                                                                                                             | 130 | 110           | 150 | 130          | 170 |
| Boiling                                     | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Bright Dip (Nitric Acid)                    | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Stripping                                   |                                                     |                |                  |                 |                                                                                                                |     |               |     |              |     |
| Concentrated Nitric Acid                    | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Conc. Nitric and Sulphuric Acid             | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Salt Baths (Molten Salt)                    | 50                                                  | 75             | 75               | 125             | 60                                                                                                             | 90  | 75            | 100 | 90           | 110 |
| Salt Solution (Parkerize, Bond-erize, etc.) |                                                     |                |                  |                 |                                                                                                                |     |               |     |              |     |
| Not Boiling                                 | 90                                                  | 90             | 100              | 150             | 90                                                                                                             | 130 | 110           | 150 | 130          | 170 |
| Boiling                                     | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |
| Hot Water (if vent. desired)                |                                                     |                |                  |                 |                                                                                                                |     |               |     |              |     |
| Not Boiling                                 | 50                                                  | 75             | 75               | 125             | 60                                                                                                             | 90  | 75            | 100 | 90           | 110 |
| Boiling                                     | 75                                                  | 100            | 125              | 175             | 125                                                                                                            | 175 | 150           | 200 | 175          | 225 |

Note 1—Column A refers to tank with hood along one side or two parallel sides when one hood is against a wall or a baffle running length of tank and as high as tank is wide; also to tanks with exhaust manifold along center line with  $\frac{W}{L}$  becoming tank width in W/L Ratio.

Column B refers to free standing tank with hood along one side or two parallel sides.

Note 2—Complete control of the vapors and mist from degreasing operations requires the same ventilation rates as recommended for pickling. However, the solvents employed in degreasing operations are relatively volatile, and the solvent loss caused by evaporation increases rapidly as the exhaust rate at the tank increases. For this reason perfect control is usually sacrificed in favor of lower solvent evaporation rates. Where solvent loss does not present an important cost or operating problem, the exhaust rates given for pickling should be adhered to, but where solvent loss must be kept at a minimum, an exhaust rate of 50 cfm per sq ft of tank area is commonly employed. Where this rate is used, control will be adequate only if the tank is located in an area free of drafts and if the degreasing operations are carried out in accordance with a rigid schedule.<sup>44</sup>

between the higher resistance and lower first cost of smaller diameter ducts against higher first cost and lower resistance of larger diameter ducts.

Main ducts connecting two or more branches are sized by the same procedure. The main should be designed for the total exhaust volume to be handled through all branch ducts.

Where exhaust systems handling solids are to provide for a substantial increase of future capacity, required conveying velocities can be maintained by:

1. Providing open end stub branches in main through which air will be admitted into system until future connection is made. The volume admitted into the main



TABLE 5. EXHAUST REQUIREMENTS FOR WOODWORKING OPERATIONS<sup>16</sup>  
(Air Velocity: 4000 fpm in all branches unless noted otherwise)

|                                                                                                                                                                                                                                                                                                                                 |                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|
| <b>Self Feed Table Rip Saw</b>                                                                                                                                                                                                                                                                                                  |                                     |
| Use 1-5 in. branch at bottom pulley; 1-4 in. branch at saw head.                                                                                                                                                                                                                                                                |                                     |
| <b>Large Self Feed Rip Saws Other Than Table Saws</b>                                                                                                                                                                                                                                                                           |                                     |
| Use 1-6 in. branch at bottom; 1-5 in. branch at top.                                                                                                                                                                                                                                                                            |                                     |
| <b>Swing Saws</b>                                                                                                                                                                                                                                                                                                               |                                     |
| Up to 20 in. use 1-4 in. branch; over 20 in. use 1-4½ in. branch.                                                                                                                                                                                                                                                               |                                     |
| <b>Circular Saws</b>                                                                                                                                                                                                                                                                                                            |                                     |
| Up to 12 in. diam.                                                                                                                                                                                                                                                                                                              | 1-4 in. branch                      |
| Over 12 in. diam.                                                                                                                                                                                                                                                                                                               | 1-5 in. branch                      |
| Dado head saws.                                                                                                                                                                                                                                                                                                                 | 1-5 in. branch                      |
| <b>Gang Circular Saws</b>                                                                                                                                                                                                                                                                                                       |                                     |
| Ventilation rate depends on effectiveness of hood and maximum number and diameter of saws.                                                                                                                                                                                                                                      |                                     |
| <b>Disc Sanders</b>                                                                                                                                                                                                                                                                                                             |                                     |
| Up to 12 in. diam.                                                                                                                                                                                                                                                                                                              | 1-4 in. branch                      |
| 12 in. to 18 in. diam.                                                                                                                                                                                                                                                                                                          | 1-4½ in. branch                     |
| 18 in. to 26 in. diam.                                                                                                                                                                                                                                                                                                          | 1-5 in. branch                      |
| 26 in. to 32 in. diam.                                                                                                                                                                                                                                                                                                          | 2-4 in. branch                      |
| 32 in. to 38 in. diam.                                                                                                                                                                                                                                                                                                          | 1-4 in. branch and 1-5 in. branch   |
| 38 in. to 48 in. diam.                                                                                                                                                                                                                                                                                                          | 1-5 in. branch and 2-4 in. branch   |
| <b>Multiple Drum Sanders (over the table)</b>                                                                                                                                                                                                                                                                                   |                                     |
| Up to 31 in. wide.                                                                                                                                                                                                                                                                                                              | 5 in. branch (see note)             |
| 31 in. to 49 in. wide.                                                                                                                                                                                                                                                                                                          | 6 in. branch (see note)             |
| 49 in. to 67 in. wide.                                                                                                                                                                                                                                                                                                          | 7 in. branch (see note)             |
| Over 67 in. wide.                                                                                                                                                                                                                                                                                                               | 8 in. branch (see note)             |
| Note: One branch of size indicated required for each drum. Fewer branch pipes may be used as long as total branch pipe cross sectional area is not reduced. Some manufacturers use 1 extra branch of equal size on feed side. 1-4 in. branch may be required for exhausting bed rubber cushions or mechanically operated brush. |                                     |
| <b>Single Drum and Spindle Type Sanders</b>                                                                                                                                                                                                                                                                                     |                                     |
| Up to 50 sq in. sanding surface.                                                                                                                                                                                                                                                                                                | 1-3 in. branch                      |
| 50 to 200 sq in. sanding surface.                                                                                                                                                                                                                                                                                               | 1-4 in. branch                      |
| 200 to 400 sq in. sanding surface.                                                                                                                                                                                                                                                                                              | 1-5 in. branch                      |
| 400 to 700 sq in. sanding surface.                                                                                                                                                                                                                                                                                              | 1-6 in. branch                      |
| 700 to 1400 sq in. sanding surface.                                                                                                                                                                                                                                                                                             | 1-7 in. branch                      |
| 1400 to 2400 sq in. sanding surface.                                                                                                                                                                                                                                                                                            | 1-8 in. branch                      |
| <b>Horizontal Belt Sander or Edge Sander (see note)</b>                                                                                                                                                                                                                                                                         |                                     |
|                                                                                                                                                                                                                                                                                                                                 | Drive Pulley      Idler Pulley      |
| Up to 6 in. wide.                                                                                                                                                                                                                                                                                                               | 1-4½ in. branch      1-4 in. branch |
| 6 in. to 9 in. wide.                                                                                                                                                                                                                                                                                                            | 1-5 in. branch      1-4 in. branch  |
| 9 in. to 14 in. wide.                                                                                                                                                                                                                                                                                                           | 1-6 in. branch      1-4 in. branch  |
| Over 14 in. wide.                                                                                                                                                                                                                                                                                                               | 1-7 in. branch      1-5 in. branch  |
| Note: Where more than one belt is used, the pipe sizes specified shall be required for each belt. Where a common hood is used for more than one belt, a single pipe of an area not less than the sum of the areas of the pipes specified may be used.                                                                           |                                     |
| Where belt is reversible, pipe at idler pulley shall be the size specified for the drive pulley.                                                                                                                                                                                                                                |                                     |
| <b>Vertical Belt Sanders (rear belt and both pulleys enclosed)</b>                                                                                                                                                                                                                                                              |                                     |
| Up to 6 in. wide.                                                                                                                                                                                                                                                                                                               | 4½ in. branch on bottom             |
| 6 in. to 9 in. wide.                                                                                                                                                                                                                                                                                                            | 5 in. branch on bottom              |
| 9 in. to 14 in. wide.                                                                                                                                                                                                                                                                                                           | 6 in. branch on bottom              |
| Over 14 in. wide.                                                                                                                                                                                                                                                                                                               | 7 in. branch on bottom              |
| <b>Band Saws and Resaws</b>                                                                                                                                                                                                                                                                                                     |                                     |
|                                                                                                                                                                                                                                                                                                                                 | Bottom      Top                     |
| Up to 2 in. wide.                                                                                                                                                                                                                                                                                                               | 1-4 in. branch      1-4 in. branch  |
| 2 in. to 3 in. wide.                                                                                                                                                                                                                                                                                                            | 1-5 in. branch      1-4 in. branch  |
| 3 in. to 4 in. wide.                                                                                                                                                                                                                                                                                                            | 1-6 in. branch      1-5 in. branch  |
| 4 in. to 5 in. wide.                                                                                                                                                                                                                                                                                                            | 1-7 in. branch      1-5 in. branch  |
| Over 5 in. wide.                                                                                                                                                                                                                                                                                                                | 1-8 in. branch      1-5 in. branch  |
| <b>Jointers</b>                                                                                                                                                                                                                                                                                                                 |                                     |
| Up to 6 in. knives.                                                                                                                                                                                                                                                                                                             | 1-4 in. branch                      |
| 6 in. to 12 in. knives.                                                                                                                                                                                                                                                                                                         | 1-5 in. branch                      |
| 12 in. to 20 in. knives.                                                                                                                                                                                                                                                                                                        | 1-6 in. branch                      |
| Over 20 in. knives.                                                                                                                                                                                                                                                                                                             | 1-7 in. branch                      |

TABLE 5. EXHAUST REQUIREMENTS FOR WOODWORKING OPERATIONS (Concluded)  
(Air Velocity: 4000 fpm in all branches unless noted otherwise)

|                                                                                                                                                                                                                                                                                                     |                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| <b>Single Planers or Surfacers</b>                                                                                                                                                                                                                                                                  |                                                         |
| Up to 20 in. max. working width.                                                                                                                                                                                                                                                                    | 1-6 in. branch                                          |
| 20 in. to 26 in. max. working width.                                                                                                                                                                                                                                                                | 1-7 in. branch                                          |
| 26 in. to 32 in. max. working width.                                                                                                                                                                                                                                                                | 1-8 in. branch                                          |
| 32 in. to 38 in. max. working width.                                                                                                                                                                                                                                                                | 1-9 in. branch                                          |
| Over 38 in. max. working width.                                                                                                                                                                                                                                                                     | 1-10 in. branch                                         |
| <b>Double Planers or Surfacers</b>                                                                                                                                                                                                                                                                  |                                                         |
|                                                                                                                                                                                                                                                                                                     | Upper head      Lower                                   |
| Up to 20 in. max. working width.                                                                                                                                                                                                                                                                    | 1-6 in. branch      1-5 in. branch                      |
| 20 in. to 26 in. max. working width.                                                                                                                                                                                                                                                                | 1-7 in. branch      1-6 in. branch                      |
| 26 in. to 32 in. max. working width.                                                                                                                                                                                                                                                                | 1-8 in. branch      1-7 in. branch                      |
| 32 in. to 38 in. max. working width.                                                                                                                                                                                                                                                                | 1-9 in. branch      1-8 in. branch                      |
| Over 38 in. max. working width.                                                                                                                                                                                                                                                                     | 1-10 in. branch      1-8 in. branch                     |
| <b>Moulders, Matchers, Sizers (see Note)</b>                                                                                                                                                                                                                                                        |                                                         |
|                                                                                                                                                                                                                                                                                                     | Matcher head      Top      Bottom                       |
| Up to 4 in.                                                                                                                                                                                                                                                                                         | 2-4 in. branch      1-5 in. branch      1-6 in. branch  |
| 4 to 6 in.                                                                                                                                                                                                                                                                                          | 2-5½ in. branch      1-6 in. branch      1-6 in. branch |
| 6 to 8 in.                                                                                                                                                                                                                                                                                          | 2-6 in. branch      1-7 in. branch      1-6 in. branch  |
| 8 to 18 in.                                                                                                                                                                                                                                                                                         | 2-6 in. branch      1-8 in. branch      1-8 in. branch  |
| Note: Where profiler is used, provide additional pipe not less than that specified for top head.                                                                                                                                                                                                    |                                                         |
| <b>Wood Shapers</b>                                                                                                                                                                                                                                                                                 |                                                         |
| 1-4½ to 10 in. branch for each spindle according to size and character of work.                                                                                                                                                                                                                     |                                                         |
| <b>Tenoner</b>                                                                                                                                                                                                                                                                                      |                                                         |
| For cutoff saws: Up to 12 in. diam.                                                                                                                                                                                                                                                                 | 1-4 in. branch                                          |
| Over 12 in. diam.                                                                                                                                                                                                                                                                                   | 1-5 in. branch                                          |
| Use 1-5 in. branch minimum for each top and bottom tenon, cope and dado head.                                                                                                                                                                                                                       |                                                         |
| <b>Automatic Lathes</b>                                                                                                                                                                                                                                                                             |                                                         |
| Use 1-3 in. to 1-10 in. branch according to work length.                                                                                                                                                                                                                                            |                                                         |
| <b>Hogs</b>                                                                                                                                                                                                                                                                                         |                                                         |
| Air volume based on 50 cu ft per lb of refuse conveyed. Use 4500 fpm minimum conveying velocity.                                                                                                                                                                                                    |                                                         |
| <b>Floor Sweeps</b>                                                                                                                                                                                                                                                                                 |                                                         |
| Use 6 in. branch for fine dust to 8 in. branch for coarse material.                                                                                                                                                                                                                                 |                                                         |
| Mouth at floor, 10 X 4 in. to 12 X 5 in.                                                                                                                                                                                                                                                            |                                                         |
| Note: Area of floor sweep pipe need not be included in computing main pipe area.                                                                                                                                                                                                                    |                                                         |
| <b>Miscellaneous Equipment</b>                                                                                                                                                                                                                                                                      |                                                         |
| Pulley pockets and chain mortises-3 in. branch; dovetail and lock corner machines, dowel machines, duplex molding sanders, forming lathes, panel raisers (each head), ploughs, rail shears, routers, sash stickers (each head) 4 in. branch; pulley stiles-5 in. branch; glue jointer-6 in. branch. |                                                         |

can be adjusted to required air flow rate, cfm, by use of a blast gate or orifice plate in such stub branch.

2. Arranging system layout so future points can be picked up by a separate main which will run directly to the fan or air cleaning equipment inlet.

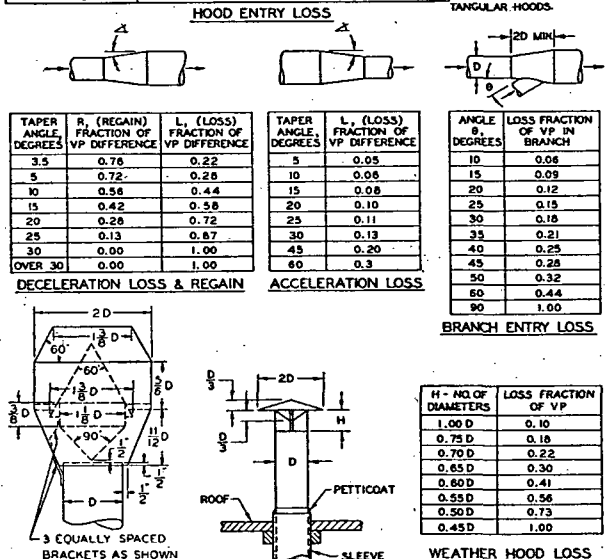
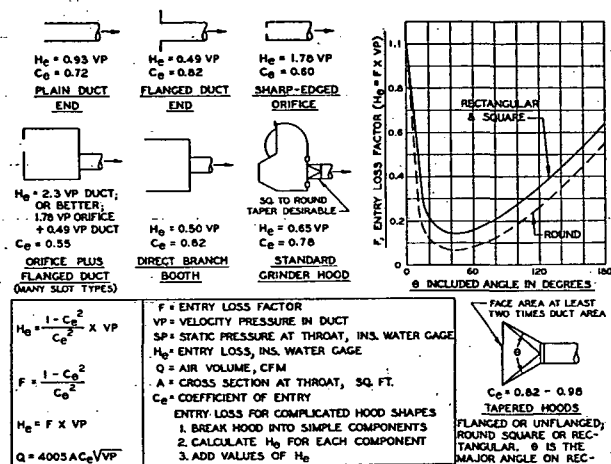
### CALCULATION OF SYSTEM PRESSURE LOSS

The pressure loss of the system includes entrance loss<sup>17</sup> as air is accelerated through the hood to a branch duct connection, resistance loss of ducts,<sup>18</sup> elbows, and junctions, and acceleration or deceleration losses from velocity changes within the system. Chapter 32 includes data on duct resistance and on resistance of elbows, and provides sample calculations. In exhaust systems, either the equal friction method (illustrated in Chapter 32) or the use of blast gates in the branches to equalize pressure loss of all runs is employed.<sup>8, 11, 12, 18</sup>

Data on losses for hood entrance and branch entry, transitions and weather hoods are given in Fig. 2. The static pressure in branch ducts close to the hood connection is frequently referred to as *hood suction*. It is the sum of the velocity pressure in the branch and the hood entrance loss.

TABLE 6. APPROXIMATE CONVEYING VELOCITIES

| MATERIAL CONVEYED                             | DESIGN VELOCITY<br>FPM |
|-----------------------------------------------|------------------------|
| Vapors, gases, fumes, very fine dust          | 2,000                  |
| Fine dry dusts                                | 3,000                  |
| Average industrial dusts                      | 3,500                  |
| Coarse particles                              | 3,500-4,500            |
| Large particles, heavy loads, moist materials | 4,500 and over         |

FIG. 2. EXHAUST SYSTEM DESIGN DATA<sup>13</sup>

Tapered hood data from Reference 37  
 Weather hood data from Reference 38

EXHAUST SYSTEM CONSTRUCTION SPECIFICATIONS AND DESIGN DETAILS<sup>13</sup>

Correct design and competent installation of sheet steel ducts and hoods are necessary for the proper functioning of any exhaust system. The following specifications are mainly those recommended in the manual Industrial Ventilation.<sup>13</sup>

## General Requirements

All exhaust systems shall be constructed with the materials recommended here-with and shall be installed in a permanent and workmanlike manner. The interior of all ducts shall be smooth and free from obstructions; with joints either welded, flanged, or soldered air-tight.

## Materials

a. Ducts shall be constructed of black iron welded or of galvanized sheet steel riveted and soldered unless the presence of corrosive gases, vapors and mists makes use of such material impracticable. Galvanized construction is not recommended for temperatures exceeding 400 F. Welding of black iron of 18 gage and lighter is not recommended for field fabrication.

b. For average exhaust systems on non-corrosive applications the metal thickness in the following table shall be supplied.

| DIAMETER OF STRAIGHT DUCTS (INCHES) | U. S. STANDARD GAUGE FOR STEEL DUCT |          |           |
|-------------------------------------|-------------------------------------|----------|-----------|
|                                     | Class I                             | Class II | Class III |
| Up to 8                             | 24                                  | 22       | 20        |
| Over 8 to 18                        | 22                                  | 20       | 18        |
| Over 18 to 30                       | 20                                  | 18       | 16        |
| Over 30                             | 18                                  | 16       | 14        |

Class 1. Includes ducts non-abrasive applications such as for paint spray, wood-working, pharmaceutical, and food products.

Class II. Includes ducts for non-abrasive material in high concentration (low pressure pneumatic conveying); moderately abrasive material; and highly abrasive materials in light concentrations. Typical examples are chemicals and wood dust; exhaust of foundry shakeouts and sand handling systems, grain dusts; coal crushing and screening; exhaust of grit blast cabinets; and grinding, buffing and polishing.

Class III. Includes ducts for conveying all highly abrasive materials in moderate to heavy concentrations and moderately abrasive materials in heavy concentrations as in: low pressure conveying of tobacco; and exhaust systems from abrasive cleaning operations, rock and ore screening and crushing, dryers and kilns, and flyash from boiler stacks.

Where aluminum duct is indicated, the following equivalent B & S gage thickness of sheets should be used:

|                           |    |    |    |    |    |
|---------------------------|----|----|----|----|----|
| Steel—U. S. Standard Gage | 26 | 24 | 22 | 20 | 18 |
| Aluminum—B & S Gage       | 24 | 22 | 20 | 18 | 16 |

c. Elbows and angles shall be a minimum of two gages heavier than straight lengths of equal diameter.

d. Hoods shall be a minimum of two gages heavier than straight section of connecting branches.

e. Where flexible piping is necessary, a non collapsible type of flexible piping shall be used and its length shall be kept at a minimum.

## Construction

a. Longitudinal joints of ducts shall be lapped, and riveted or spot-welded on 3-in. centers, maximum.

b. Girth joints of ducts unless flanged or butt welded shall be made with lap in direction of air flow with not less than 1-in. lap.

c. Elbows and angles should have an inside or throat radius of two pipe diameters whenever possible, but the radius shall never be less than one pipe diameter. Large radii are recommended for heavy concentrations of highly abrasive dusts. Construct elbows 6 in. or less in diameter of at least five sections, over 6 in. diameter of seven sections. Angles shall be pieced proportionately.

d. Hoods must be free of sharp edges or burrs and shall be reinforced to provide necessary stiffness.

e. Provide dead end caps within 6 in. from last branch of all mains and sub-mains.

f. Provide cleanouts every 10 ft and near each elbow, angle, or duct junction in horizontal sections.

g. Support ducts sufficiently to prevent placing of any load on connecting equipment and to carry weight of system if plugged with material. Use maximum supporting interval 12 ft for 8 in. or smaller ducts and 20 ft for larger ducts.

h. Provide 6 in. minimum clearance between ducts and ceiling, wall, or floor.

i. Rectangular ducts can be used only when clearances prevent the use of round construction. Rectangular ducts must be as nearly square as possible. Weight of metal, lap and other construction details are to be the equal of round duct construction whose diameter equals the longest side.

j. All branches shall enter the main at the large end of the transition at an angle not to exceed 45 deg (30 deg is recommended). Connect branches only to top or sides of main, with no two branches entering diametrically opposite.

#### System Details

a. Connect duct to fan inlet with split sleeve drawband one pipe diameter long but not less than 5 in.

b. Transitions in mains and sub-mains are to be tapered; taper 5-in. long for each 1-in. change in diameter is recommended.

c. Place blast gates for adjustment of system near connection of branch to main. Provide means for locking gates after adjustments have been made.

d. Fire dampers, explosion vents, etc., should be installed in accordance with NFPA Codes or local fire ordinances.

#### Deviation From Specifications

Where State or local laws conflict with the specifications given, the more stringent regulation shall be followed. Any other deviation must be approved before installation.

#### AIR FLOW PRODUCING EQUIPMENT

The principal types of air moving equipment are centrifugal fans, axial flow fans, and venturi ejectors. Chapter 33 includes information on fan types, arrangements, and application. Gravity stacks have application for some systems handling higher air temperatures or steam where no air cleaning equipment is installed.

Centrifugal fans are most frequently used for the bulk of exhaust system applications due to the system pressures involved. Where air cleaning equipment is included, fans are usually located on the clean air side. The paddle wheel or modified paddle wheel designs are heavily constructed and have few blades to make them more suitable if wear, corrosion, or accumulations are a factor. The higher efficiency backward curved blade designs find application where relatively clean, non-corrosive air is handled. Forward curved blade designs have limited application due to the number, shape, and metal thickness of the short curved blades.

Belt driven fans are recommended by many designers because a change in fan speed is often needed where future changes of the system may be involved, where added pressure losses from air cleaning equipment improvements are anticipated, or where the fan may be used at some later date for another application.

The axial flow fan is used for systems having low pressure losses. Pro-

PELLER or disc designs develop pressures under 1 in., the vane axial designs develop higher pressures but seldom are used where pressures exceed 3 in.

The venturi ejector<sup>39</sup> is an inefficient method of air movement, but has the advantage of causing air flow without the exhaust air passing through the air flow producing equipment. It minimizes the explosion or corrosion potentialities in certain types of system.

Fans, motors, and drives should be located so that safe and easy access for periodic inspection, servicing, and maintenance is possible.

#### AIR CLEANING EQUIPMENT

As discussed in detail in Chapter 34, air cleaning equipment should be considered in all systems to prevent property damage, neighborhood pollution, re-entry to the working space; to salvage usable material, reduce fire and explosion hazards or to make possible some recirculation of air to the working spaces. The present growing emphasis on air pollution control makes it desirable to remove all contaminants to the greatest practical degree based on reasonable cost and maintenance.

#### MAKE-UP AIR REQUIREMENTS

A correctly designed exhaust system may be ineffective during periods when windows and doors are closed. This condition should be anticipated and prevented by making provision for an adequate air supply. Poor performance of exhaust hoods is caused by: absence of air supply systems; cold drafts due to high indraft velocities through cracks and openings in building construction especially at windows and doors; reverse air flow through low pressure systems of roof ventilators or general ventilation systems; downflow through heater vent stacks preventing exhaust of flue gases to the outside. Systems for conditioning make-up air do not necessarily increase heating requirements for the space, as cold air due to infiltration from the outside must be heated somehow to maintain comfortable temperatures in the area. The cost will depend on the ratio of exhaust air to that required for ventilation of the space occupied.

#### MAINTENANCE OF PERFORMANCE

Periodic inspection and checking of exhaust systems are necessary if control is to be maintained at the effective level of the original installation. Continued effectiveness depends on maintained design air volume flowing through the exhaust hoods. A checking procedure, therefore, must include some data to indicate at least relative air flow through the hoods. The static pressure or hood suction measurement will prove useful for such checking if data are available on air volumes and pressures at the time the system was installed. Testing and recording of such data for each new installation are of the utmost importance.

While hood suction readings have rightfully been discarded as a means of measuring air flow, they do offer a quick and accurate method of measuring relative air flow. If the hood suction is known while an exhaust system is functioning properly, its continued effectiveness can be assured so long as the hood suction is not reduced from its original value.

Unless the hood design is altered or there are accumulations in the hood or branch pipe between hood and point of hood suction reading, the air volume

TABLE 7. RESISTANCE TO CORROSION OF MATERIALS USED FOR HOODS AND DUCTS<sup>a</sup>

| CLASSIFICATION    | APPROXIMATE SERVICE LIFE | SEE FOOTNOTE 1  |            |                 |       |             |          |             |                |              |          |             |        |
|-------------------|--------------------------|-----------------|------------|-----------------|-------|-------------|----------|-------------|----------------|--------------|----------|-------------|--------|
|                   |                          | Galvanized Iron | Black Iron | Stainless Steel | Monel | Lead Lining | Aluminum | Hard Rubber | Natural Rubber | Pressed Wood | Neoprene | Turns Plate | Buna S |
| E—Excellent       | Over 5 years             | EP              | EP         | S               | S     | ES          |          | E           | E4             | SP           | S        | S           | E      |
| S—Satisfactory    | 2 to 5 years             | EP              | P          | E               | S     | F           |          |             | S              |              | E        | E           |        |
| F—Fair            | 1 to 2 years             | P               | P          | E               | S     | E           |          |             | S              |              | E        |             |        |
| P—Poor            | 6 months                 | P               | P          | E               | E     | E           |          |             |                |              |          |             |        |
| Combinations (EP) | Indefinite rating        |                 |            | S5              |       | E8          |          |             | E7             |              |          |             |        |
| 1                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 2                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 3                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 4                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 5                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 6                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 7                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 8                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 9                 |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 10                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 11                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 12                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 13                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 14                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 15                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 16                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 17                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 18                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 19                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 20                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 21                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 22                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 23                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 24                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 25                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 26                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 27                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 28                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 29                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 30                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 31                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
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| 37                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 38                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 39                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
| 40                |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |
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| 100               |                          |                 |            |                 |       |             |          |             |                |              |          |             |        |

Notes: 1. Ratings are based upon collated field service reports. Indefinite ratings are given where reports are inconsistent due to varying operating conditions (such as dilution, exposure to weather, etc.). Blank spaces denote insufficient information, not poor service. 2. Mild soaps, detergents, water soluble oils, 140–180 F. 3. Cresote oil, kerosene, ethylene dichloride. 4. To 20 percent; E: 50–70 percent, 150 F; S: 5. To 50 percent; plating; E: 20 percent anodizing, agitated 80 F; S: 6. To 50 percent plating; S: over 50 percent pickling, 20 percent anodizing; E: 7. 5–22 percent, 135–215 F pickling; S: plating, pickling, anodizing; E: 8. Except acid. 9. Acid.

TABLE 8. RESISTANCE TO CORROSION OF MATERIALS USED FOR EXHAUST FANS<sup>a</sup>

| PROCESS                                   | SEE FOOTNOTE 1 |          |                  |           |       |      |               |                   |                |             |                              |                    |             |          |             |         |              |          |             |
|-------------------------------------------|----------------|----------|------------------|-----------|-------|------|---------------|-------------------|----------------|-------------|------------------------------|--------------------|-------------|----------|-------------|---------|--------------|----------|-------------|
|                                           | STEEL          | ALUMINUM | GALVANIZED STEEL | CAST IRON | BRASS | LEAD | ASPHALT PAINT | VINYL RESIN PAINT | RED LEAD PAINT | HOT ASPHALT | PHENOLIC RESIN BAKED COATING | HARD RUBBER LINING | SOFT RUBBER | NEOPRENE | EPOXY RESIN | KOROLAC | PRESSED WOOD | ALSI 316 | ACID BRONZE |
| Acid Dipping, Pickling and Stripping..... | EP             | S        | S                | E         |       | E    | EP            |                   | E              |             | S                            | E                  | ES          | E        | E           | E       |              | E        |             |
| Alkaline Cleaning.....                    | EP             | S        | E                | E         |       |      | EP            |                   |                |             | S                            | ES                 |             | E        | E           | E       |              |          |             |
| Anodizing.....                            | SF             | S        | S                |           |       |      | E             |                   |                |             | E                            | E                  |             | E        | E           | E       |              |          |             |
| Coating—Enamel and Lacquer.....           | E              | E        |                  |           |       |      |               |                   |                |             | E                            | E                  |             | E        | E           | E       |              |          |             |
| Decarbonizing.....                        | ES             |          |                  |           |       |      |               |                   |                |             | S                            |                    |             |          |             |         |              |          |             |
| Degreasing and Metal Cleaning.....        | ES             |          | ES               |           |       |      |               |                   |                |             |                              |                    |             |          |             |         |              |          |             |
| Hardening and Quenching.....              | ES             |          | ES               |           |       |      |               |                   |                |             |                              |                    |             |          |             |         |              |          |             |
| Plating.....                              | EP             | S        |                  | E         |       |      | ES            | S                 |                |             | ES                           | E                  | E           | E        | E           |         |              |          |             |
| Washing and Rinsing.....                  | EP             | E        |                  | E         |       |      | SP            |                   |                | S           |                              |                    |             |          |             |         |              |          |             |

CLASSIFICATION

APPROXIMATE SERVICE LIFE

Note: Ratings are based upon collated field service reports. Forward curved fans are not recommended for open-tank ventilation service. Cleanout doors and bottom drains are recommended on all fans on open-tank operations. The deposits which build up on fan wheels and casings should be removed by regular cleaning. Repaint where any coating has been broken and removed.

Combinations: Variable performance

exhausted from a hood cannot change without a change in hood suction reading.

The Pitot tube can be used for routine check purposes instead of the static pressure method.

Difficulty from plugging may be encountered where heavy dust loads or moist air is encountered. In any case, the hood suction method of checking can more readily be delegated to an assistant having no technical training, whereas the Pitot tube method requires care in reading velocity pressures in an exact position with the tube paralleling the flow of air. U-gages have been standard plant equipment long enough to eliminate any feeling of uncertainty in their use.

Since pressure readings vary as the square of the velocity or volume of flow, a slight change in flow is magnified by a comparison of gage readings. Normally, a reduction of volume or velocity of 10 to 15 percent will not be sufficient to reduce the effectiveness of the exhaust system. This range is equivalent to a reduction in static pressure readings of 19 to 30 percent.

A marked reduction in hood suction can often be traced to one or more of the following items:

1. Reduced performance by the exhaust fan caused by reduced speed due to belt slippage, wear on rotor or casing, or an accumulation of material in the rotor or casing, obstructing the air flow.
2. Incorrect direction of exhaust rotation.
3. Reduced performance caused by defects in the exhaust piping, such as accumulations of material in branch or main ducts due to insufficient conveying velocities, condensation of oil or water vapors on duct walls, adhesive characteristics of material exhausted.
4. Leakage losses caused by loose clean-out doors, broken joints, holes worn in duct (most frequently in elbows), or poor connection to the exhaust inlet.
5. Losses in suction due to additional exhaust points added to the system or a change of setting of blast gates in branch lines.
6. Increased pressure loss through the dust collector due to lack of maintenance, improper operation, wear, etc.

### MATERIALS REQUIRED FOR CORROSION RESISTANCE

In many cases, exhaust systems including hoods, ducts, air flow producing equipment, and air cleaning equipment will require protective coatings if carbon steel is used, or other materials of construction will be required. Need for such materials will be determined by (a) the corrosion rates on interior or exterior duct surfaces, (b) protection against product contamination, and (c) explosion hazards.

Of the above groups, construction for corrosion protection is the most difficult due to the complex factors that influence rate of corrosion. It is seldom possible to predict the concentration, composition, and dry- and dew-point temperatures that will exist in actual operations. A guide for selecting corrosive resistant materials based on a survey of actual experiences has been reproduced in Tables 7 and 8.<sup>40</sup>

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## CHAPTER 47

## INDUSTRIAL DRYING SYSTEMS

Drying Terminology, Mechanism of Drying, Internal and External Conditions, Periods of Drying, Approximate Equations for Estimating Drying Time, Equilibrium Moisture Content, Applications of Hygrometry to Drying, Dryer Calculations, Drying Methods and Equipment; Radiant, Conduction and Convection Drying; Solution of Drying Problem

THE term *drying*, in a broad sense, encompasses the removal of water, and occasionally other liquids, from gases, liquids, or solids. However, the common usage of the word confines the meaning principally to the removal of water or solvent from solids by thermal means. *Dehumidification* is the term that is commonly assigned to the drying of gases. This is usually accomplished by condensation or adsorption by various drying agents, and is treated in Chapter 38. *Distillation*, and more particularly *fractional distillation*, is associated with the drying of liquids.

It is usually more economical to employ, whenever possible, mechanical means of separating as much water as is practicable from the solid materials before undertaking drying or dehydration steps. These mechanical methods such as filtration, screening, pressing, centrifuging, or settling usually require much less power, and frequently less capital outlay, thereby making the operation cheaper in terms of cost per pound of water removed.

DRYING TERMINOLOGY<sup>1</sup>

The generally accepted definitions of terms used in drying technology follow:

*Bound moisture* refers to liquid (held by a solid) which exerts a vapor pressure less than that of the pure liquid at the same temperature. Liquid may become *bound* by retention in small capillaries, by solution in cell or fiber walls, by homogeneous solution throughout the solid, and by chemical or physical adsorption on solid surfaces. Bound moisture can be removed from a solid only under specific conditions of humidity in the external surroundings.

*Capillary flow* refers to the flow of liquid through the interstices and over the surface of a solid. It is caused by liquid-solid molecular attraction.

*Commercial-dry basis* expresses the moisture content of a product as pounds of water per pound of solid as it leaves the dryer, i.e., per pound of commercially dry solid.

*The constant-rate period* is that drying period during which the rate of water removal per unit of drying surface is constant.

*The critical moisture content* is that obtaining when the constant-rate period ends and the falling-rate period begins.

*Dry basis* indicates the moisture content of a wet solid as pounds of water per pound of bone-dry solid. The advantage of using this basis is that the absolute amount of moisture loss is obtained simply by subtracting the moisture contents before and after drying. (See definition of *Wet Basis*.)

*Dryer efficiency* is that fraction of the total heat, supplied by fuel, used to evaporate water. *Overall efficiency* is sometimes used to distinguish overall system efficiency from the efficiency of the drying space or evaporative efficiency.

*Equilibrium moisture content* is that to which a given material can be dried under specific conditions of air temperature and humidity.

*Evaporative efficiency* compares the amount of evaporation actually obtained in a dryer with that which would obtain by saturation of the air.

*The falling-rate period* is that drying period during which the instantaneous drying rate continually decreases.

**Fiber saturation point** is the moisture content of cellular materials (wood, etc.) at which the cell walls are completely saturated while the cavities are liquid-free. It may be defined as the equilibrium moisture content as the humidity of the surrounding atmosphere approaches saturation.

**Free moisture content** is that liquid content which is removable at a given temperature and humidity. Free moisture may include both bound and unbound moisture.

**The funicular state** is that condition in drying a porous body when capillary suction causes air to be sucked into the pores.

**Humidity** denotes the amount of water vapor actually present in a gas, and is generally expressed as weight of vapor per unit weight of any gas.

A **hygroscopic material** is one that may contain bound moisture.

**Initial moisture distribution** refers to the moisture distribution throughout a solid when drying begins.

**Internal diffusion.** Diffusion is a single-phase phenomenon; internal diffusion must therefore occur as solid through solid, liquid through liquid, or gas through gas. Internal diffusion occurs when the moving phase obeys the fundamental laws of diffusion.

**The moisture content** of a solid is usually expressed as moisture quantity per unit weight of volume of the dry or wet solid. A weight (dry or wet) basis is preferred.

**Moisture gradient** refers to the internal distribution of water in a solid at a given moment in the drying process, the nature of which depends on the characteristics of the solid involved.

A **non-hygroscopic material** is one that can contain no bound moisture.

**Pendular state** is that state of a liquid in a porous solid when a continuous film of liquid no longer exists around and between discrete particles and, therefore, flow by capillarity cannot occur. This state succeeds the funicular state.

**Unaccomplished moisture change** refers to the ratio of the free moisture present at any time to that initially present.

**Unbound moisture** in a hygroscopic material is that moisture in excess of the equilibrium moisture content corresponding to saturation humidity. All water in a non-hygroscopic material is unbound water.

**Wet basis** expresses the moisture in a material as a percentage of the weight of the wet solid. This basis is less satisfactory than the dry-weight basis on which the percentage change of moisture is constant for all moisture contents. Fig. 1 shows the relationship between the dry- and wet-weight bases, and indicates that when the wet-weight basis is used to express moisture content, a 2 or 3 percent change at high moisture content (above 70 percent) actually represents a 15 to 20 percent change in evaporative load. An evaporative increase of this amount might well increase the load above the capacity of a dryer.

### MECHANISM OF DRYING<sup>1</sup>

When a solid dries, two fundamental processes are involved: (1) the transfer of heat to evaporate the liquid, and (2) the transfer of mass as vapor and internal liquid. These two processes occur simultaneously, and the factors governing the rate of each process determine the rate of drying.

In any commercial drying problem, a principal objective is to supply the required heat in the most efficient manner. Consequently, heat transfer may occur by convection, conduction, or radiation, or by any combination of these mechanisms. The various types of industrial dryers may be shown to differ fundamentally with respect to the method used for transferring heat to the solid. In general, heat must flow first to the outer surface of the solid and then into the interior. An important exception is drying with high frequency electrical currents where heat is generated within the solid, producing a higher temperature at the interior than at the surface, and consequently, causing heat to flow from inside the solid to the outer surfaces.

Mass transfer in drying occurs as liquid or vapor flow, or both, within

the solid, and as vapor flow from the external wet surfaces. The nature of liquid concentration gradients in solids during drying depends on the mechanism of internal liquid flow, and this mechanism, in turn, depends to a large extent upon the physical and chemical characteristics of the solid being dried.

### Internal vs. External Conditions

A study of how a solid dries may be based on the *internal* mechanism of liquid flow, or on the effect of the *external conditions* of temperature, humidity, air flow, state of subdivision, etc., on the drying rate of the solid. The former procedure involves a fundamental study of the liquid flow conditions within a solid during drying. The latter procedure, although less fundamental, is more generally used because the effects are

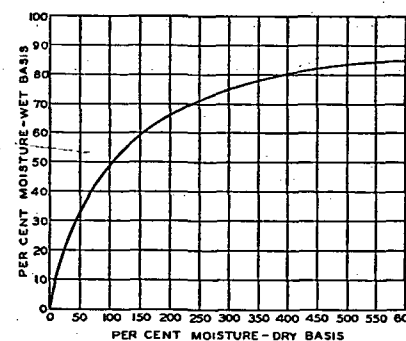


FIG. 1. RELATION BETWEEN WET-WEIGHT AND DRY-WEIGHT BASES

easier to establish and the results have greater immediate application in dryer design and operation.

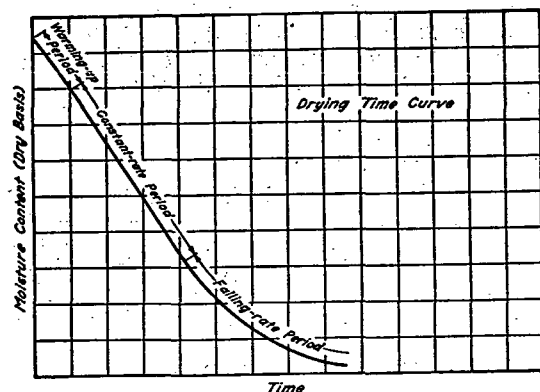
**Internal Mechanism of Liquid Flow.** Internal liquid flow may occur by several mechanisms, depending on the structure of the solid. Several mechanisms of flow are as follows:

1. Diffusion in continuous, homogeneous solids.
2. Capillary flow in granular and porous solids.
3. Flow caused by shrinkage and pressure gradients.
4. Flow caused by a vaporization-condensation sequence.
5. Flow caused by gravity.
6. Flow caused by an electrical potential, electro-osmosis.
7. Flow caused by temperature gradients, thermal diffusion.

Although more than one of these mechanisms of flow may be effective at one time, only one predominates as a rule at a given time in a solid during drying. However, a different mechanism may predominate at a different time in the cycle. The mechanism of moisture flow is usually established experimentally from a study of moisture gradients.

**External Variables.** The principal external variables involved in any drying problem are: temperature, humidity, air flow, state of subdivision of the solid, agitation of the solid, method of supporting the solid, and the contact between hot surfaces and wet solid. All these variables do not necessarily occur simultaneously in one problem.

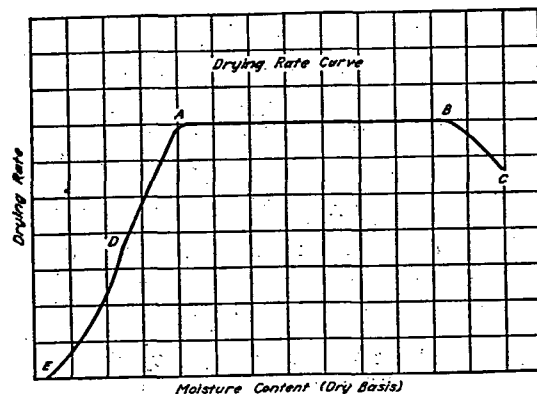


FIG. 2. MOISTURE CONTENT  $W$  vs. DRYING TIME  $\theta$ 

### Periods of Drying<sup>1</sup>

A typical drying time curve for a wet solid is shown in Fig. 2. This curve is a plot of the moisture content at any time in a solid undergoing drying. It is the usual method of presenting experimental drying data. Although Fig. 2 shows that the moisture content is subject to a continuous variation with time, a more precise illustration of the nature of this variation can be obtained by differentiating the curve and plotting the drying rate (pounds of water per hour per pound of dry material) against the moisture content (pounds of water per pound of dry material) as shown in Fig. 3, or plotting the rate of drying against time as shown in Fig. 4. These *rate curves* show that the drying process is not a smooth, continuous one in which a single mechanism controls throughout. The rate curve in Fig. 4 has the advantage of showing how long each drying period predominates.

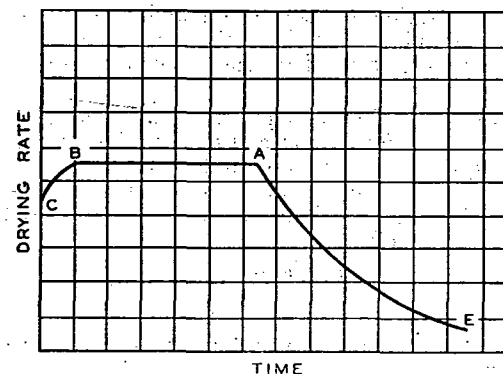
Section AB on each curve represents a *constant-rate period*. In Fig. 2, it is shown by a straight line of constant slope  $dW/d\theta$ , which becomes a horizontal line on the rate curves in Figs. 3 and 4.

FIG. 3. RATE OF DRYING  $\frac{dW}{d\theta}$  vs. MOISTURE CONTENT  $W$ 

The curved portion of Fig. 2 is termed the falling-rate period, and, as shown in Figs. 3 and 4, it is typified by a continuously changing rate. Point A, where the constant rate ends and the drying rate begins to decrease, is termed the *critical moisture content*.

The portion of the curves designated by CB represents a warming-up period, and it may, or may not, be a significant item depending on the total time involved.

**Constant-Rate Period.** Drying during the constant-rate period is equivalent to evaporation from a free-water surface on the surface of the solid. The rate of drying in this period is determined by the rate of diffusion of water vapor through an air film at the wet surface of the solid. A constant rate of evaporation on the surface of the solid maintains the surface at a constant temperature, which, in the absence of other heat effects, is very nearly the wet-bulb temperature of the air. If heat flows to the surface of evaporation by radiation and conduction, or both, in addition

FIG. 4. RATE OF DRYING,  $\frac{dW}{d\theta}$  vs. TIME  $\theta$ 

to convection, the surface temperature will be constant at some value between the air temperature and the wet-bulb temperature. This higher temperature in turn produces a higher constant rate of evaporation.

In those dryers in which heat is transferred to a wet solid by conduction through hot surfaces, and heat transfer by convection is not a factor, the wet surfaces approach the boiling point temperature rather than a wet-bulb temperature.

When all the heat for evaporation in the constant-rate period is supplied by a hot gas, a dynamic equilibrium is established between the rate of heat transfer to the material and the rate of vapor removal from the surface. This equilibrium between heat and mass transfer rates can be expressed as follows:

$$\frac{dw}{d\theta} = \frac{h_t A \Delta t}{\lambda} = k_g A \Delta p \quad (1)$$

where

$\frac{dw}{d\theta}$  = drying rate, pounds of water per hour.

- $h_t$  = total heat transfer coefficient, Btu per (hour) (square foot) (Fahrenheit degree).  
 $A$  = area of heat transfer and evaporation, square feet.  
 $\lambda$  = latent heat of evaporation at  $t_s$ , Btu per pound.  
 $k_s$  = mass transfer coefficient, pounds per (hour) (square foot) (atmosphere).  
 $\Delta t = (t_s - t_a) =$  temperature difference between air and surface of evaporation, Fahrenheit degrees.  
 $t_a$  = air temperature, Fahrenheit.  
 $t_s$  = temperature of surface of evaporation, Fahrenheit.  
 $\Delta p = (p_s - p_a) =$  vapor pressure difference, atmospheres.  
 $p_s$  = vapor pressure of water at  $t_s$ , atmospheres.  
 $p_a$  = partial pressure of water vapor in air, atmospheres.

When  $h_t = h_c$ , the coefficient of heat transfer by convection only, then  $t_s$  under equilibrium conditions becomes  $t_w$ , the wet-bulb temperature of the air, and  $p_a$  is the vapor pressure at this temperature. If heat is also supplied by radiation, then  $h_t$  is the sum ( $h_c + h_r$ ) where  $h_r$  is the radiation coefficient and  $h_c$  is the convection coefficient, and  $t_s$  becomes higher than the wet-bulb temperature. A similar result occurs when heat reaches the surface of evaporation by convection and conduction. When the surface is at the wet-bulb temperature, the value of  $\Delta p$  in millimeters of mercury, is almost exactly one-half the wet-bulb depression ( $t_a - t_w$ ), in Centigrade degrees.

**Effect of Air Velocity.** The principal effect of air velocity is on  $h_c$  and  $k_s$ , since the rate of transfer of heat and mass in the constant-rate period depends mainly on the rate of diffusion of heat and vapor through the air film at the surface of the solid, and air velocity is the chief factor affecting the thickness of this film. The influence of air velocity may be expressed by the following relationship:<sup>3</sup>

$$h_c = 0.0128 G^{0.8} \quad (2)$$

where

- $h_c$  = convection heat transfer coefficient, Btu per (hour) (square foot) (Fahrenheit degree).  
 $G$  = mass velocity of dry air, pounds per (hour) (square foot).

For estimating the constant rate in drying from plane surfaces with air flow parallel to the surface of evaporation and with no radiation or conduction effects, the following heat transfer expression can be used:

$$\frac{dw}{d\theta} = \frac{0.0128 G^{0.8} A}{\lambda} (t_a - t_w) \quad (3)$$

where

- $t_w$  = wet-bulb temperature of the drying air, Fahrenheit degrees.

Heat transfer coefficients, rather than mass transfer coefficients, should be used to estimate drying rates, because heat transfer coefficients are generally more reliable, and, unless the temperature of the drying surface is measured, it must be calculated from heat transfer considerations before mass transfer coefficients can be applied for drying-rate predictions. The assumption that the surface of drying is at the wet-bulb temperature of the air, introduces a more serious error in the computation of mass transfer than of heat transfer.

**Determination of True Surface Temperature.** Frequently, radiation and conduction are of sufficient magnitude to cause the temperature of evaporation to exceed the wet-bulb temperature of the air. When this occurs, it is necessary to estimate the true surface temperature in order to calculate

the constant rate. This may be done by means of a heat balance equating the total heat transferred by convection, conduction, and radiation to the latent heat of evaporation.

**Constant-Rate Period in Through-Circulation Drying.** The equation for estimating the rate of evaporation when air flows across a free-water surface must be modified for the case of air-flow through a permeable bed of solids. The constant rate in through-circulation drying depends on the air rate, air temperature, air humidity, size of the particles making up the permeable bed, and physical characteristics of these particles.<sup>4</sup>

The following general expression for the constant rate in through-circulation drying for the system water and air, was developed<sup>5</sup> from experiments on the rate of evaporation of water from the surface of wet spheres and cylindrical particles with through-circulation of air:

$$\frac{dW}{d\theta} = \frac{0.42 a G^{0.59} (\Delta H)_m}{D_p^{0.41}} = \frac{0.37 c_s a G^{0.59} \Delta t_m}{\lambda a D_p^{0.41}} \quad (4)$$

where

- $\frac{dW}{d\theta}$  = constant rate, pounds of water per (hour) (pound of dry stock).  
 $a$  = drying area, square feet per cubic foot of bed volume.  
 $G$  = superficial mass velocity, pounds of dry air per (hour) (square foot).  
 $\Delta H_m$  = logarithmic mean of inlet and outlet humidity driving force across the air film adjacent to the particle through which the water vapor diffuses, pounds per pound (the surface humidity is taken as the humidity corresponding to the wet-bulb temperature of the drying air).  
 $\rho_s$  = bulk density of dry granular bed, pounds per cubic foot.  
 $D_p$  = average diameter of particle, feet.  
 $\Delta t_m$  = logarithmic mean difference between temperature entering and leaving the bed and the wet-bulb temperature, Fahrenheit degree.  
 $c_s$  = humid heat, Btu per (pound of dry air) (Fahrenheit degree).  
 $\lambda$  = latent heat of evaporation, Btu per pound.

Equation 4 applies when the Reynolds number  $D_p G / \mu$  is greater than 300, where  $\mu$  is the viscosity of the air stream. For values less than 300, a modification of Equation 4 has been presented.<sup>6</sup>

**Evaporation from Liquid Drops.** For the important problem of spray drying, evaporation rates of liquid drops must be estimated. Below a value of Reynolds number ( $D_p G / \mu$ ) of 10 for spherical particles, the heat transfer coefficient across the gas film surrounding the drop is given by

$$h = \frac{2k_f}{D_p} \quad (5)$$

where

- $h$  = film heat transfer coefficient, Btu per (hour) (square foot) (Fahrenheit degree).  
 $k_f$  = thermal conductivity of gas film, Btu per (hour) (square foot) (Fahrenheit degree per foot).

Equation 5 is applicable when the Reynolds number for liquid drops is less than 10. Drop diameters are almost always less than 500 microns, and usually in the range of 20 to 150 microns.

The rate of evaporation of drops may be expressed in terms of heat transfer or mass transfer. In terms of heat transfer, the evaporation rate is given by the equation:

$$\frac{dw}{d\theta} = \frac{2\pi k_f D_p}{\lambda} (t_a - t_s) \quad (6)$$

where

$\frac{dw}{d\theta}$  = evaporation rate, pounds per hour.

A similar expression based on mass transfer is

$$\frac{dw}{d\theta} = \frac{2\pi M d_v D_p}{RT} (p_a - p_s) \quad (7)$$

where

$M$  = molecular weight of the diffusing vapor.

$d_v$  = diffusivity of the vapor, square feet per hour.

$T$  = absolute temperature of the gas, Fahrenheit degrees.

$R$  = gas constant, (cubic feet) (atmosphere) per (Fahrenheit degree).

$p_a$  = vapor pressure at the particle surface corresponding to the liquid temperature, atmospheres.

$p_s$  = vapor pressure of liquid in the drying medium, atmospheres.

Both Equations 6 and 7 are based on the assumption that Equation 5 applies. If Equation 6 is integrated for a constant drop diameter (*i.e.*, if it is assumed that the solid being dried in the liquid drop creates a structure which becomes rigid at a fixed  $D_p$ ) and evaporation proceeds as from a pure liquid drop, an expression for the time of evaporation is obtained as follows:

$$\theta = \frac{W \lambda \rho_s D_p^2}{12 k_f (t_a - t_s)} \quad (8)$$

where

$\theta$  = time, hours.

$W$  = water content of the drop as it enters the drying chamber, pounds per pound.

$\rho_s$  = density of dry particle, pounds per cubic foot.

The temperature difference between drop and gas ( $t_a - t_s$ ) is essentially constant for a single drop evaporating in a large mass of gas. However, in spray dryers this is not true, and an overall average temperature difference must be used in Equation 8 in this case.

When the drop diameter varies as evaporation proceeds, the expression for the time of evaporation becomes

$$\theta = \frac{\rho_L \lambda [(D_{p1})^3 - (D_{p2})^3]}{8 k_f (t_a - t_s)} \quad (9)$$

where

$\rho_L$  = density of the evaporating liquid, pounds per cubic foot.

$D_{p1}$  = drop diameter at the start of evaporation, feet.

$D_{p2}$  = drop diameter of dry particle, feet.

Equation 9 assumes that the drop density is essentially that of the liquid.

*Drying at Air Temperatures above the Boiling Point of the Liquid.* When the temperature of the drying air is maintained above the boiling point of the liquid being evaporated, or when superheated vapors are used for drying, the usual equations for mass transfer, expressing rate of evaporation

as a function of the vapor pressure difference, lose significance, since large errors are introduced in the expression for vapor pressure driving force due to its apparently small value. Such cases can be treated conveniently on a basis of heat transfer, since a temperature difference must always exist in order that drying may proceed. At drying temperature above 260 F, recirculation has no retarding effect on the drying process.

*Constant-Rate Period When Heat Transfer Depends on Conduction and Radiation.* In indirect drying, where heat transfer and drying do not depend on the flow of heated gases, the drying rate depends either on heat conduction through retaining walls to wet material in contact with such surfaces, or on radiation, or both. This applies to drum dryers, agitated pan dryers, indirect continuous sheeting dryers, steam tube rotary dryers, vacuum rotary and vacuum tray dryers, and infra-red dryers.

A principal difference between indirect drying and direct drying is that, with the former, the material is usually at a higher temperature than the surrounding air, so that heat is actually transferred to the air instead of from the air.

Generally, the individual heat transfer coefficients for indirect dryers are difficult to determine or estimate, and therefore, an overall coefficient, as defined by Equation 10, is generally used:

$$q = UA (t_h - t_s) \quad (10)$$

where

$q$  = rate of heat transfer, Btu per hour.

$U$  = overall heat transfer coefficient based on the temperature difference between the heating medium and the product, Btu per (hour) (square foot) (Fahrenheit degree).

$t_h$  = temperature of the heating medium, Fahrenheit.

$t_s$  = temperature of the solid, Fahrenheit.

The overall coefficient is a function of dryer type. Thus, in agitated pan dryers,  $U$  depends on the degree of agitation, temperature of the surface, physical properties of the wet material, etc., and will sometimes vary throughout a drying cycle as the physical properties of the solid vary with a changing moisture content.

As long as  $U$  and the temperature difference in Equation 10 remain constant, a constant drying rate will be maintained. However, as drying proceeds the material temperature will begin to increase after some critical moisture content is reached, and, as in the case of direct dryers, a falling-rate period is encountered.  $U$  is frequently defined, for the entire drying period, on the basis of an overall mean temperature difference. Therefore,

$$q = UA (\Delta t)_m \quad (11)$$

*The Falling-Rate Period.* In the discussion of the periods of drying, it was shown that the drying process is discontinuous, consisting of a period of a constant rate of evaporation and a period in which the rate continuously decreases. (See Figs. 3 and 4). This latter period is usually designated as the falling-rate period. It begins when the constant-rate period ends at the critical moisture content. If the critical moisture content is less than the required final moisture content, the constant-rate period will constitute the whole of the drying process. On the other hand, if the initial moisture content is less than the critical moisture content, as

in the case of some slow-drying materials, such as soap and wood, then no constant rate will appear, and the whole of the drying process will be in the falling-rate period. This period, in the most general case, can be divided into two zones which may be termed (1) the zone of unsaturated surface drying, and (2) the zone where internal liquid flow controls.

The zone of unsaturated surface drying follows immediately after the critical point and results from a progressively decreasing wetted surface. With the surface no longer completely wetted, dry portions of the solid protrude into the air film, so that the rate of evaporation per unit of total surface is reduced. The effective wetted surface in this zone is frequently a linear function of the water content, so that the curve representing rate of drying *vs.* water content of the solid is straight in this region, as shown by line AD in Fig. 3. The mechanism of drying is essentially the same as during the constant-rate period.

The zone where internal liquid flow is in control, is usually the second zone of the falling-rate period. In this phase the rate of internal liquid movement controls the drying rate, and in drying to low moisture contents, this period may be the principal factor determining the drying time.

Studies of internal moisture flow have indicated the possibility of several controlling mechanisms, the more significant ones having been postulated previously as diffusion, capillarity and pressure gradients due to shrinkage. Of these mechanisms, internal moisture movement by diffusion has been treated extensively, while capillary flow and flow caused by shrinkage and pressure gradients, have received only preliminary consideration.

When diffusion does control in the falling-rate period, it obeys the same fundamental laws of diffusion as those applying to the diffusion of heat. On this basis, the integrated diffusion equation for the falling-rate period (for the case where the surface is dry or at its equilibrium moisture content and the solid has a uniform initial moisture distribution) expresses the average moisture content as a function of time as follows:

$$\frac{W - W_o}{W_o - W_o} = \frac{8}{\pi^2} \left[ e^{-\pi^2 d (\pi/2L)^2} + \frac{1}{9} e^{-9\pi^2 d (\pi/2L)^2} + \frac{1}{25} e^{-25\pi^2 d (\pi/2L)^2} + \dots \right] \quad (12)$$

where

$W, W_o, W_o$  = the moisture contents, on a dry basis, at any time  $\theta$ ; at  $\theta = 0$ , the start of the diffusional flow period; and in equilibrium with the external conditions, respectively, pounds of water per pound of dry solid.

$d$  = the liquid diffusivity, square feet per hour.

$L$  = one-half the thickness of the solid layer through which the liquid is diffusing, feet.

In Equation 12 it is assumed that evaporation is occurring from two opposite faces of the solid. When evaporation occurs from only one surface, substitute the total thickness of the solid layer for  $L$  in Equation 12.

Equation 12 is based on the assumption that  $d$  is constant. However, this is rarely true, and  $d$  has been shown to vary with moisture content, temperature and humidity.<sup>7</sup>

When the time becomes large, a limiting form of Equation 12 is obtained as follows:

$$\frac{W - W_o}{W_o - W_o} = \frac{8}{\pi^2} e^{-\pi^2 d (\pi/2L)^2} \quad (13)$$

From Equation 13 an expression for the rate of drying may be derived to give

$$\frac{dW}{d\theta} = -\frac{\pi^2 d}{4L^2} (W - W_o) \quad (14)$$

where  $dW/d\theta$  = drying rate, pounds per (hour) (pound dry material).

Equation 14 states that the rate of drying, when internal diffusion controls for long times, is directly proportional to the free moisture content ( $W - W_o$ ), the liquid diffusivity  $d$ , and that the time of drying varies as the square of the material thickness. However, Equation 14 holds only when  $(W - W_o)/(W_o - W_o) < 0.6$ . When this ratio exceeds 0.6, the curve of drying rate *vs.* moisture content is concave upward.

Equations 12, 13, and 14 hold only for a slab-shaped solid, the length of which is large compared with its thickness.

The falling rate frequently can be expressed with fair accuracy over the required range of moisture content by an equation similar to Equation 14:

$$\left( \frac{dW}{d\theta} \right)_t = -K(W - W_o) \quad (15)$$

where  $K$  is a function of the constant rate as follows:

$$K = \frac{(dW/d\theta)_c}{(W_o - W_o)} \quad (16)$$

where

$(dW/d\theta)_c$  = the constant drying rate, pounds per (hour) (pound dry material).  
 $W_o$  = the critical moisture content, pounds per pound dry material.

Substituting in Equation 16 the proper expression for  $(dW/d\theta)_c$  the value of  $K$  becomes

$$K = \frac{h_i(t_a - t_o)}{\rho_s L \lambda (W_o - W_o)} \quad (17)$$

and hence, the falling rate for this case is given by

$$\left( \frac{dW}{d\theta} \right)_t = -\frac{h_i(t_a - t_o)(W - W_o)}{\rho_s L \lambda (W_o - W_o)} \quad (18)$$

For materials obeying Equation 18, the drying time varies directly as the thickness. When the surface temperature in the constant-rate period is at the wet-bulb temperature,  $t_w$  can be substituted for  $t_o$  and 0.0128  $G^{0.8}$  can be substituted for  $h_i$  in Equations 17 and 18.

The drying time for each case of the falling-rate period may be obtained by integration of Equations 14 and 18, respectively, to give:

1. Diffusion law

$$\theta_t = \frac{4L^2}{\pi^2 d} \log_e \left( \frac{W_o - W_o}{W - W_o} \right) \quad (19)$$

2. Proportional-to-thickness law

$$\theta_t = \frac{\rho_s L \lambda (W_o - W_o)}{h_i(t_a - t_o)} \log_e \left( \frac{W_o - W_o}{W - W_o} \right) \quad (20)$$

Table 1 gives an approximate classification of materials which are most likely to obey Equations 19 and 20.

Equations 18 and 20 hold for cross-circulation drying. When through-circulation drying is involved, the appropriate constant-rate expression given by Equation 4 must be used to determine  $K$  in Equation 16. Thus, for through-circulation drying in the falling-rate period when Equation 15 holds, the rate is given by

$$\left(\frac{dW}{dt}\right)_t = -\frac{0.37c_s a G^{0.59}(\Delta t)_m}{\rho_s \lambda D_p^{0.41}(W_s - W_e)}(W - (W_e)) \quad (21)$$

where the symbols have been defined for Equations 4, 12, and 16.

**Critical Moisture Content.** In order to use the above equations for estimating the drying time in the falling-rate period, it is necessary to know values of the critical moisture content. Such values are usually difficult

TABLE 1. APPROXIMATE CLASSIFICATION OF MATERIALS MOST LIKELY TO OBEY EQUATIONS 19 AND 20

| MATERIALS OBEYING EQUATION 19                                                                                                        | MATERIALS OBEYING EQUATION 20                                                                                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Single-phase solid systems such as soap, gelatin, glue.                                                                           | 1. Coarse granular solids, such as sand, paint pigments, minerals, etc.                                                                                             |
| 2. Wood and similar solids below the fiber saturation point.                                                                         | 2. Materials in which moisture flow occurs at concentrations above the equilibrium moisture content at atmospheric saturation, or above the fiber saturation point. |
| 3. Last stages of drying starches, textiles, paper, clay, hydrophilic solids, and other materials when bound water is being removed. |                                                                                                                                                                     |

to obtain without making actual drying tests which, in themselves, would give the required drying time and thereby obviate the necessity of the calculations.

It appears that the constant-rate period ends when the moisture content at the surface reaches some specific value. If the rate of drying is great, the moisture gradients within the solid will be steep and the average moisture content considerably greater than that at the surface. It is for this reason that the critical moisture content (average through the material) increases with increase in rate of drying, and with an increase in thickness of the layer being dried.

#### Approximate Equations for Estimating Drying Time

An estimate of the overall drying time for a given drying problem usually involves an estimate of the time required for the constant-rate period, plus an estimate of the time for the falling-rate period. An approximate equation for the overall drying time applicable to the cross-circulation drying of materials of the type listed in Table 1 as obeying Equation 20, may be written as follows:

$$\begin{aligned} \theta_t &= \theta_c + \theta_f = \frac{(W_s - W_e)\lambda L \rho_s}{h_i(t_s - t_a)} + \frac{\rho_s L \lambda (W_s - W_e)}{h_i(t_s - t_a)} \log_e \frac{W_s - W_e}{W - W_e} \\ &= B \left[ \frac{W_s - W_e}{W_s - W_e} + \log_e \frac{W_s - W_e}{W - W_e} \right] \end{aligned} \quad (22)$$

where

$$B = \frac{\rho_s L \lambda (W_s - W_e)}{h_i(t_s - t_a)} = \frac{1}{K}$$

$\theta_t$  = total drying time, hours.

$\theta_c$  = drying time for constant-rate period, hours.

$\theta_f$  = drying time for falling-rate period, hours.

$W_s$  = initial moisture content, pounds per pound of dry solid.

$W_c$  = critical moisture content, pounds per pound of dry solid.

$W_e$  = equilibrium moisture content, pounds per pound of dry solid.

$W$  = moisture content at time  $\theta_t$ , pounds per pound of material.

$h_i$  = total overall heat transfer coefficient Btu per (hour) (square foot) (Fahrenheit degree).

$t_s$  = air temperature, Fahrenheit.

$t_a$  = temperature of surface of material, Fahrenheit.

$L$  = depth of material in tray, feet.

$\lambda$  = latent heat of evaporation at  $t_s$ , Btu per pound.

$\rho_s$  = density of dry solid, pounds per cubic foot.

Equation 22 will apply to those materials satisfying Equation 20 when drying to very low moisture content is not involved.

For through-circulation drying, an expression similar to Equation 22 is obtained. Thus, the total drying time for through-circulation drying is given by

$$\theta_t = B' \left[ \frac{W_s - W_e}{W_s - W_e} + \log_e \frac{W_s - W_e}{W - W_e} \right] \quad (23)$$

$$\text{where } B' = \frac{2.7 \rho_s \lambda D_p^{0.41} (W_s - W_e)}{c_s a G^{0.59} (\Delta t)_m}$$

The drying times estimated from Equations 22 and 23 apply only to cross-circulation drying and through-circulation drying, respectively. Drying times for other methods, such as rotary drying or drum drying, must be estimated by other methods.

#### Equilibrium Moisture Content

In the drying of solids it is important to distinguish between hygroscopic and non-hygroscopic materials. A hygroscopic material is one which retains a definite percentage of moisture under definite conditions of air humidity. This bound moisture is in a state of equilibrium with the water vapor in the surrounding air, and a decrease in the water vapor content will decrease the amount of equilibrium bound water. Water so retained by a solid in equilibrium with the humidity of the surrounding air, is designated as the *equilibrium moisture content*. Such moisture may be held as adsorbed surface films or condensed in fine capillary structures at reduced vapor pressure.

The equilibrium moisture content varies with the temperature and humidity of the surrounding air. Consequently, any correlation of equilibrium moisture content should take these two factors into account. However, at low temperatures, e.g., 60 to 120 F, a plot of equilibrium moisture content vs. percent relative humidity, expressed as 100 ( $p/p_s$ ), is essentially independent of temperature. Such a plot usually results in a curve of double curvature with a point of inflection (see Fig. 5).

The equilibrium moisture content at a given relative humidity is not

independent of temperature for all temperature ranges. As the temperature increases at a given relative humidity, the equilibrium moisture content tends to decrease. A limiting condition exists when temperatures above the boiling point of the adsorbed liquid are encountered. In such cases, relative humidity loses its significance with regard to equilibrium moisture content, and complete dryness of most hygroscopic materials is possible, even when a large amount of vapor exists in the atmosphere. This makes possible drying by means of superheated vapors.

In the special case of the dehydration of hydrated inorganic salts, such as copper sulfate, sodium sulfate, and barium chloride, temperature and humidity are very important in obtaining the desired degree of dehydration. Thus, in the drying of wet salt crystals to obtain a product with the maximum number of molecules of hydrate water, it is necessary to dry under closely controlled conditions of air temperature and humidity. Generally, the temperature is low and the humidity is high.

The equilibrium moisture content of a hygroscopic material may be determined in a number of ways. The requirement for any method is a

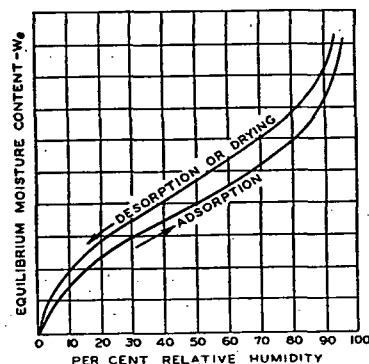


FIG. 5. TYPICAL EQUILIBRIUM MOISTURE CONTENT CURVES<sup>1</sup>

source of constant humidity and constant temperature air into which the sample may be placed. The determination may be made under either static or dynamic conditions, the latter being preferred if the data are to be used for drying calculations.

Probably the simplest static procedure is to place a series of samples in ordinary laboratory desiccators over sulfuric acid solutions of known concentration, which thereby produce atmospheres of known relative humidity. The sample in each desiccator is weighed periodically until a constant weight is obtained. The moisture content at this final weight represents the equilibrium moisture content for the particular relative humidity involved. The value of equilibrium moisture content so obtained will depend on whether it is reached by losing moisture, as in drying, or by gaining it, *i.e.*, whether the sample is at a moisture content higher or lower than the equilibrium value. The equilibrium moisture content reached by losing moisture, *i.e.*, by drying, is generally higher than that reached when moisture is adsorbed, as shown in Fig. 5.

The equilibrium moisture content of a solid has particular significance in drying because it represents a limiting final moisture content for specific

conditions of air humidity and temperature. Drying costs can be unnecessarily high if a material is dried to a moisture content less than that which it normally possesses in equilibrium with atmospheric air. For example, if a dryer dries a material to 1 percent final moisture, and on standing under normal atmospheric humidities it regains moisture to 5 percent, the material is considered to be overdried, so that probably the dryer would be capable of a considerably higher capacity and efficiency with a 5 percent final moisture content.

### Applications of Hygrometry to Drying

Drying of a solid by hot air or hot gases may be divided into two processes: (1) transfer of heat to evaporate the water, and (2) removal of the

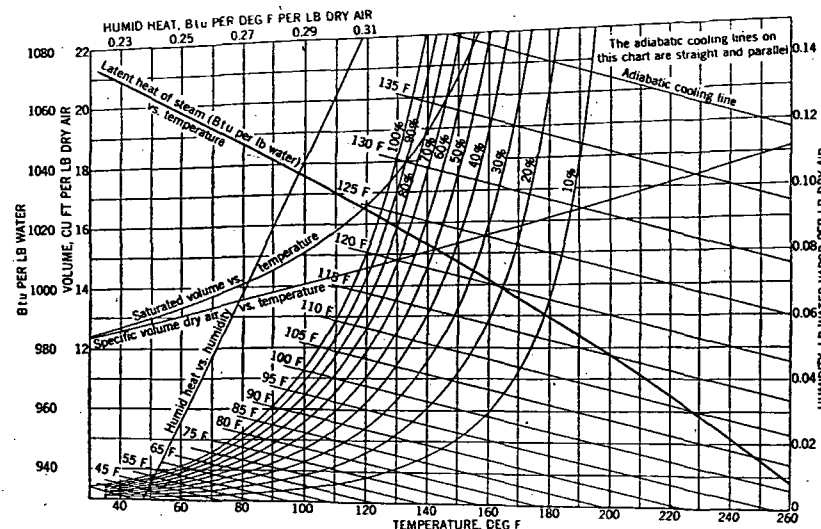


FIG. 6. PSYCHROMETRIC CHART

vapor by the air or gas stream. Likewise, two processes are involved in the *design* and *operation* of direct dryers: (1) the estimation of the drying rate or drying time, and the effect of the external variables on the drying rate; and (2) the calculation of the heat and air quantities required. The first estimates concerning drying time have been considered in the first part of this chapter. The second calculations are based on the use of the psychrometric chart, Fig. 6.

In drying, the humidity chart finds its greatest utility in analyzing the operation of existing dryers, in making design calculations, and in checking calculations of air quantities. It is equally useful in interpreting the humidity-temperature relations within the dryer. The adiabatic cooling lines on the humidity chart indicate the relation between the temperature and the humidity which are present in air passing through an adiabatic dryer, *i.e.*, one in which all of the sensible heat given up by the air in cooling is used to evaporate water from the wet stock. Referring to the section of the humidity chart shown in Fig. 7, where AB is one adiabatic saturation line, it follows that air entering an adiabatic dryer at temperature  $t_1$

and a humidity  $H_1$  will cool, following this cooling line toward point A. Air leaving with a humidity  $H_2$  will consequently have cooled to  $t_2$ , the wet-bulb temperature of the air throughout the dryer being  $t_w$ . When heat is lost to the surroundings, the operation is somewhat lower than  $t_2$ , so that the actual humidity-temperature relation is represented by the line Bb, having less slope than the adiabatic saturation line. The ratio  $(t_1 - t_2)/(t_1 - t_w)$  then gives a measure of the evaporative efficiency of the dryer. For the case of dryers containing steam coils maintained at a constant temperature, the humidity-temperature relation is obviously represented by the vertical line Bc, assuming the initial and final humidities to be  $H_1$  and  $H_2$  as before. The heat supplied within the dryer itself is usually less, but may be greater, than the total heat requirements of the dryer. If less, the cooling is indicated by some such line as Bd, and if greater, by a line such as Be having a positive slope.

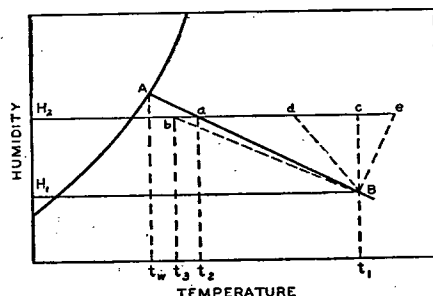


FIG. 7. HUMIDITY-TEMPERATURE RELATIONS IN DRYERS<sup>1</sup>

### DRYER CALCULATIONS

As shown in the foregoing part of this chapter calculations for drying during the constant-rate period are different from those applying to the falling-rate period, and in contrast are subject to relatively simple mathematical analysis.

The constant rate of drying by convection is directly proportional to the temperature difference between air and wet solid, and also proportional to the 0.8 power of the air velocity as shown by Equation 3. Usually the wet surface is assumed to attain the wet-bulb temperature of the air passing over it, and evaporation takes place at a constant rate under equilibrium conditions. This is a conservative assumption, however, and when conduction and radiation effects occur, the constant rate may be increased by 30 to 60 percent over that for pure convection.

Fig. 8 permits a ready estimate of the constant drying rate for various air temperatures and humidities. The chart is based on the difference between the dry-bulb and wet-bulb temperatures of the entering stream of air, and on an air velocity of 300 fpm. It may be assumed satisfactory for tray drying of any material in the constant-rate drying period. It does not apply to rotary or through-circulation drying.

A curve for correcting the air velocity in any given problem is incorporated in Fig. 8. This curve is based on the variation of drying rate with the 0.8 power of the velocity, as given by Equation 3.

The use of Fig. 8 in practical drying problems is as follows: Since the drying conditions of temperature and relative humidity are fixed, the corresponding absolute drying rate is read from Fig. 8. This value is then multiplied by the correction factor corresponding to the air velocity employed. The rate so obtained, however, does not include any effects of radiation or of conduction through unwetted surfaces. These effects tend to increase the rate of evaporation so that the chart is conservative.<sup>3</sup>

It has been demonstrated empirically for certain materials that the rate of drying during the falling-rate period is approximately proportional to the free water content of the material. Actual calculations of drying time

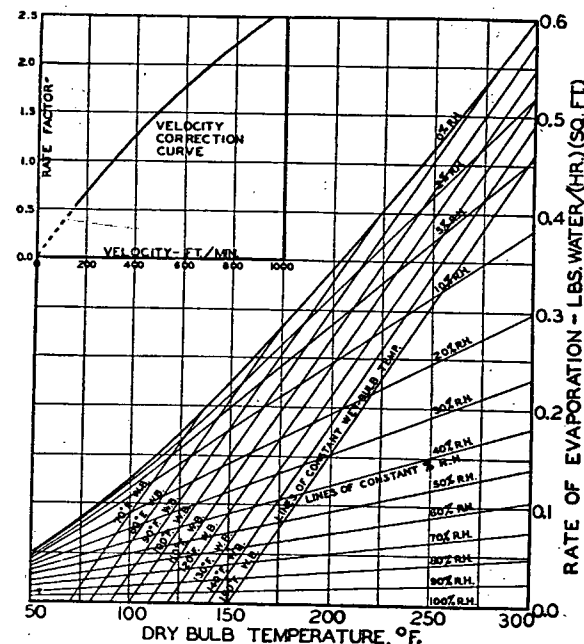


FIG. 8. RATE OF EVAPORATION CHART<sup>3</sup>

during the falling-rate period for this case require only a knowledge of the critical moisture content and the constant rate. For other cases of the falling-rate period, calculations are not feasible. Consequently, it is best to determine drying times for design purposes by means of pilot tests. However, when tests are not feasible, drying times may often be estimated approximately from Equations 22 and 23.

The following nomenclature will be used in the discussion of design calculations:

- $H$  = humidity ratio of air, pounds of water vapor per pound of dry air.
- $N_a$  = pounds of dry air supplied to the dryer per unit of time.
- $S$  = pounds of stock dried per unit of time in a continuous dryer.
- $S'$  = pounds of stock charged per batch to a discontinuous dryer.
- $\theta$  = time, hours.
- $Q$  = total heat supplied to the dryer, Btu.





Actual dryer operation is somewhat more complicated because even if radiation and conduction losses are neglected, the wet-bulb temperature of the air remains constant only as long as surface evaporation of water is taking place. When sub-surface evaporation is occurring, some heat from the air is used to heat the material and hence, there is a drop in wet-bulb temperature. Fig. 10 illustrates the drying process in a tunnel dryer in which the air is flowing parallel to the product.<sup>2</sup>

In design calculations using Equation 26, the following steps outline the procedure:

1. The unit drying rate, pounds of water per hour, is determined from the experimental drying time curve and the amount of product to be dried per hour. The drying time may also be approximated from previous experience.
2. The experimental data or experience also determine the drying condition, *i.e.*, point L Fig. 9. This fixes  $H_2$ . Where experimental data are lacking L may be approximated from Regain Tables (see Chapter 45 Industrial Air Conditioning) since the relationship between the vapor pressure in the product and in the air at equilibrium for the desired final moisture content must prevail in the dryer. The air temperature must be not greater than the maximum permissible product temperature.

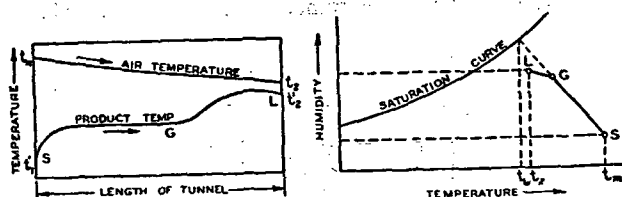


FIG. 10. TEMPERATURE AND MOISTURE CONDITIONS IN A TUNNEL DRYER  
Parallel Flow Air and Product

3. The rate of air circulation  $N_a$  must be determined and also the supply air condition S. In the design of some dryers, such as rotary or tunnel types, it is customary to determine S first and then to calculate the air rate  $N_a$ . In other types of dryers, such as tray dryers or through circulation dryers, where a fixed air velocity is maintained,  $N_a$  is calculated first and then point S is found. Because of the many variables involved, it is generally not possible to select S except on the basis of past experience or on the basis of experimental drying tests.
4. The prevailing outside air conditions establish point A and hence, the line AL. The percent of recirculated air can then be calculated.
5. The physical arrangement of the dryer must then be selected to handle the desired quantity of product, and at the same time circulate the calculated air quantity at the desired velocity.
6. Equation 26 can then be used to calculate the heat requirements.

### DRYING METHODS AND EQUIPMENT

Drying systems are sometimes classified according to the method of heat transfer that is employed, since the entire problem of drying resolves itself into individual problems of heat transfer and the thermodynamics of air and water vapor. The methods of heat transfer are radiation, conduction and convection. Many types of dryers have been built on these principles for different purposes.

Drying systems can also be classified, according to the method of product handling, as batch operation, semi-continuous and continuous.

#### Radiant Drying

Sun drying, the oldest form known to man, is still practiced where the material is amenable to such treatment, where the necessary time can be allowed, and where there is little danger of rain or atmospheric pollution.

In artificial systems, radiating surfaces, heated by steam, electricity or other means, afford a good method of heat distribution and control. Radiant heating sets up convection currents, and in low-temperature dryers only about one-third to one-half of the total heat for evaporation is actually supplied to the material by radiation. At high temperatures the radiation output increases rapidly, according to the *fourth-power law*. The total radiation may be computed by the equations and tables given in Chapter 5. In general, fins and irregular surfaces do not increase radiation, hence, the area to be used in calculations is the area of a smooth-surface envelope enclosing the radiating elements.

A certain amount of air circulation is required through a radiant dryer in order to carry off the vapor.

Radiant heat from infra-red lamps has been accepted by certain industries as practicable for their specific problems. An example of successful application is found in the drying of lacquers.

Lacquers and similar surface films can be very effectively dried by radiation. Special electric lamp units have been developed which give off a high percentage of infra-red and similar heat rays. For continuous manufacturing processes these units are mounted in tunnels through which conveyors pass. For local applications, as for example paint drying in automobile repair shops, they may be mounted on portable racks. Objects of relatively large surface area in proportion to their weight, and fabricated materials having a rather high heat absorption, may be satisfactorily heated by such a source.

For drying, baking, pre-heating and de-hydrating, where a low temperature infra-red heat source is desired, or where use of glass-enclosed radiant lamps is objectionable for safety reasons, electric heating units employing low temperature metal sheathed resistors, are available.

#### Conduction Drying

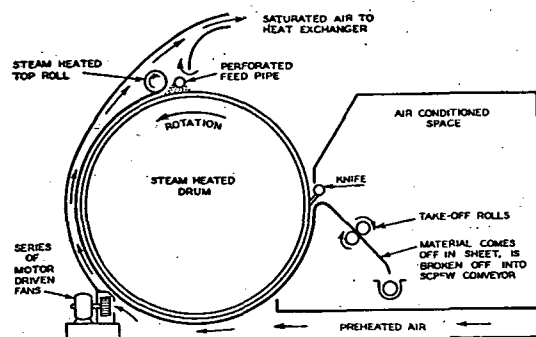
Drying rolls or drums, Fig. 11,<sup>8</sup> flat surfaces, open kettles and immersion heaters are examples of the direct-contact method. Intimate contact of the material with the heating surface is important, and in some cases agitation is desirable to increase the uniformity of heating or to prevent over-heating.

Greatest resistance to heat transfer occurs on the air side of the material being dried. The rate of heat transfer from the surface of the heated material to the air, and hence the rate of drying, may be increased by (a) forced convection or air circulation, and (b) vacuum operation to lower the boiling point of the liquid being evaporated.

A rather interesting method of conduction drying was put into practical use during the war for the drying of blood plasma, and has since been expanded to other fields such as the preservation of bacteria and other micro-organisms. This has come to be known as freeze drying or drying by sublimation. The material to be dried is first frozen and then placed in a high vacuum chamber connected to extremely low temperature condensers. The water is removed by vaporizing from the solid directly to the gas without ever becoming liquid.

#### Convection Drying (Direct Dryers)

A limited amount of convection drying takes place in almost any dryer such as those described in the preceding paragraphs. However, to be

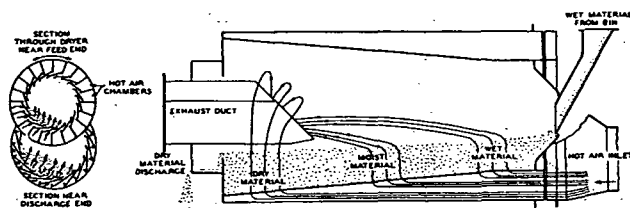
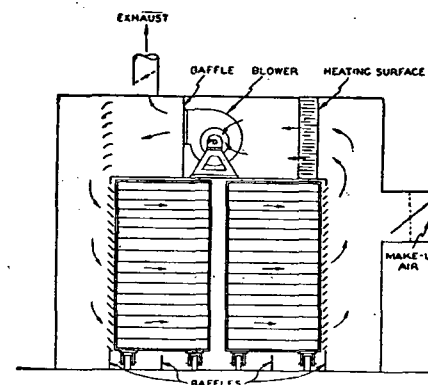
FIG. 11. DRUM DRYER<sup>8</sup>

classified as a convection dryer the principal source of heat is the heated air or other gases circulated in the dryer. There are a number of mechanical means of accomplishing this circulation of air or gases, each of which has some particular virtue. Brief descriptions of some important types of convection dryers follow:

**Rotary Dryers.** These dryers are cylindrical drums which cascade the material being dried through the air stream. (See Fig. 12). The driers may be heated directly or indirectly, and the air circulation may be parallel or counter-flow. A variation is the rotating louver type dryer, which introduces the air beneath the flights thus securing very intimate contact.

**Cabinet and Compartment Dryers.** These are generally considered batch dryers wherein each charge is dried to completion before removal.<sup>8</sup> A wide range includes types from the heated loft with only natural convection, and usually poor and non-uniform drying, to the self-contained units with forced draft and properly designed baffles which give positive results. It is also possible to evacuate some of the systems for low temperature drying of delicate or hygroscopic materials. These dryers are usually loaded with material spread in trays to increase the exposed surface. The trays are loaded directly into the dryer or may be stacked on trucks which are wheeled in. (See Fig. 13)

**Tunnel Dryers.** Tunnel dryers are a modification of the compartment dryer, and as a rule are continuous or semi-continuous in operation. Heated air or combustion gas is usually circulated by means of fans, although a few natural draft units are still in use. The material is handled on trays or racks on trucks, and moves through the dryer either intermittently or continuously. The air flow may be parallel, counter-flow or a combination of the two, obtained by center exhaust. Further, the air flow may be across the surface of the trays or up or down through the bed, or in any

FIG. 12. CROSS SECTION AND LONGITUDINAL SECTION THROUGH CIRCULATION DRYER<sup>8</sup>FIG. 13. COMPARTMENT DRYER, SHOWING TRUCKS, WITH AIR CIRCULATION<sup>8</sup>

combination of directions. By reheating the air in this type of dryer or recirculating it, a high degree of saturation is achieved before exhausting the air. This reduces the waste of sensible heat.

A variation of this type dryer is the strictly continuous type having one or more mesh belts which travel through the dryer carrying the product, such as Fig. 14. Innumerable combinations of temperature, humidity and air direction and velocity are possible. The labor requirement is low on such a dryer, as it can be loaded and unloaded mechanically. There is the disadvantage of hot air leaks at the entrance and exit, although these can be minimized by means of baffles or inclined ends where the material enters and leaves from the bottom.

**Spray Dryers.** In recent years the spray dryer has become important for the drying of liquids in many fields, especially in the food industry.

The liquid is atomized by means of pressure nozzles, air jets or centrifugal bowls into the air stream of a tower or chamber. Inlet air temperatures may run from 250-300 F up as high as 1200 F. Drying times are very short because of the minute particle size. Particles as small as 5 to 10 microns are formed in spray dryers. The dry powder is separated from the air by cyclone separators which are sometimes followed by cloth bags or scrubbing towers.

Because of the high inlet temperatures and the relatively large volume of air required, the efficiency of the spray dryer is not too good and, consequently, is seldom used for dilute solutions (less than 30 percent solid). Fig. 15 shows a typical arrangement for a spray drying system.<sup>8</sup>

A common and important feature of all spray processing is the direct conversion of the spray liquid to a granular product suitable for packaging

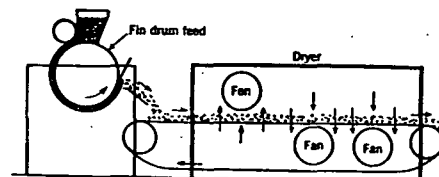
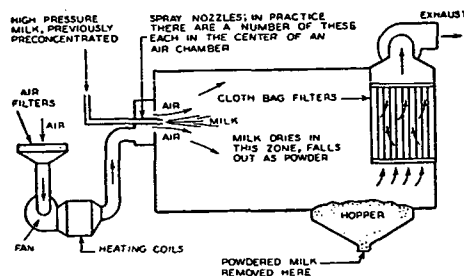


FIG. 14. SECTION OF CONTINUOUS DRYER, BLOW-THROUGH TYPE

FIG. 15. SPRAY DRYER OF THE PRESSURE-SPRAY ROTARY TYPE<sup>8</sup>

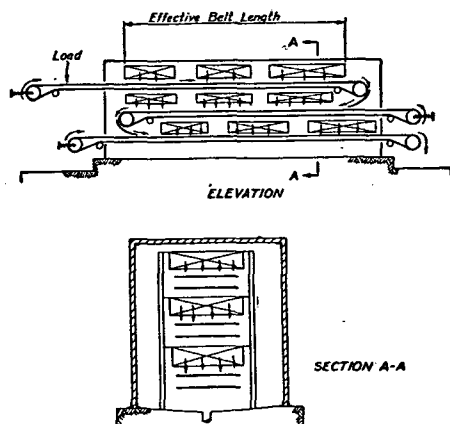
without grinding or other intermediate handling. Another aspect is the unusually high rate of drying attained. In a well designed system 15 to 30 seconds is a fair time for the passage of the sprayed particle through the drying zone; the particle temperature need not rise materially above the wet-bulb temperature of the drying air. This makes the process particularly adaptable to the drying of heat-sensitive material, some of its most important applications being the drying of milk, eggs, potato flour, soap and blood.<sup>9</sup>

### SOLUTION OF TYPICAL DRYING PROBLEM

Since there are so many types of dryers which may be used, and so many special conditions surrounding each particular problem, it is usually recommended that those having experience with the dryer to be used be consulted. The following example, however, will serve as a guide for typical dryer calculations.<sup>10</sup>

**Example 1:** Assume 900 lb per hour of ceramic powder is to be produced. The powder has a specific heat of 0.22 and density of 98 lb per cu ft, wet. Initial moisture content is 19 percent on a wet basis; final moisture content is to be one-half of one percent on a wet basis.

A continuous belt dryer is a logical choice, and previous experience indicates that rubber belts will withstand temperatures up to 200 F, which is also about the highest desirable product temperature. Experience also indicates that a drying time of 45 min is possible at about 160 F dry-bulb and 100 F wet-bulb.

FIG. 16. CONTINUOUS BELT DRYER FOR CERAMIC POWDER<sup>10</sup>

**Step 1:** Let  $x$  = pounds moisture at final condition.

Then, 
$$\frac{x}{900} = 0.005$$

or, 
$$x = 4.5 \text{ lb moisture}$$

and therefore the solid will amount to 895.5 lb.

Likewise the weight of the initial moisture  $x$  can be found

from 
$$\frac{x}{895.5 + x} = 0.19$$

or, 
$$x = 210 \text{ lb.}$$

The weight of moisture to be removed is 205.5 lb per hour, and wet material entering dryer is 1105.5 lb per hr.

**Step 2:** Previous tests indicate that a  $\frac{1}{2}$  in. layer of powder gives satisfactory results, and that a desirable air velocity is 50 fpm applied at a right angle to the belt. Based on 45 min ( $\frac{3}{4}$  hr) drying time, the dryer holding capacity will have to be  $1105.5 \times 0.75 = 830$  lb of wet material or  $\frac{830}{98} = 8.45$  cu ft of material.

Assuming a 48 in. wide belt with an effective 42 in. width for the product, each foot of belt length carries 0.146 cu ft or 14.3 lb of wet material. Hence, the linear feet of belt must be  $\frac{830}{14.3} = 58$  ft and the total area of exposed product is 232 sq ft. Based on 50 fpm velocity directed at a right angle to the belt the total air circulation will be  $232 \times 50 = 11,600$  cfm.

For space economy and in order to expose periodically fresh layers of powder to air, a multiple vertical belt arrangement (Fig. 16) with belts traveling in opposite directions, is selected. Three belts each 19.4 ft long will be required. Fig. 16 illustrates the physical arrangement of the dryer.<sup>10</sup> The housing will be about 25 ft long, 8 ft wide and 7 ft high.

**Step 3:** At the drying conditions of 160 F dry-bulb and 100 F wet-bulb, the air moisture content (from Fig. 6) is 0.028 lb per pound of air. Make-up air will be assumed at 80 F dry-bulb and 72 F dew-point (summer weather), or a humidity of 0.0168 lb per pound of air. The pick-up is therefore  $0.0280 - 0.0168$  or 0.0112 lb per pound of air. Then  $\frac{205.5}{0.0112} = 18400$  lb of air per hour or 307 lb per min.

At the elevated temperature, the total air quantity of 11,600 cfm represents 675 lb of air per min. Hence,

$$\text{Make-up air} = 46 \text{ percent}$$

$$\text{Recirculated air} = 54 \text{ percent}$$

**Step 4:** Although the drying condition and drying rate should preferably be determined from experience or test results, the drying conditions can sometimes be estimated if the regain characteristics of the product or a similar product are known. In this case the regain characteristics of clay could be used as a guide. Inspection of regain data for typical clays indicates that at about one-half of one percent the vapor pressure of the moisture in the product is about 0.7 in. Hg less than the vapor pressure of free moisture at the product temperature. An assumption is made that the product temperature approximates the air wet-bulb temperature. If an assumption is made regarding the percent recirculated air the desired vapor pressure in the dryer can be estimated. For example assume a use of 46 percent outside air or 307 lb per min.

Then the moisture pick-up =  $\frac{205.5}{60 \times 307} = 0.0112$  lb per pound of air, with a consequent total of  $0.0168 + 0.0112 = 0.0280$  lb of moisture per pound of air in the leaving outside air, which has about 1.25 in. Hg vapor pressure. This is assumed to be the vapor pressure of the moisture in the product, and thus the vapor pressure of free water at product temperature can be  $1.25 + 0.7 = 1.95$  in. Hg. The temperature corresponding to 1.95 in. Hg is 100 F, and thus the air wet-bulb can be estimated to be 100 F. At 100 F wet-bulb temperature and 0.028 lb moisture per pound of air, the dry-bulb temperature is 160 F. Obviously, the assumed percentage of recirculated air affects the results, and therefore it is important that it be based on experience. About 50 percent recirculation is reasonable for the type dryer considered in this example.

**Step 5:** The pick-up of moisture per pound for the total air circulated is  $\frac{205.5}{60 \times 675} = 0.0051$  lb.  $0.0280 - 0.0051 = 0.0229$  lb moisture per lb of air for the supply air.

Assuming an existing wet-bulb of 100 F, the supply air dry-bulb will be 182 F. The mixture of recirculated air at 160 F dry-bulb and 100 F wet-bulb, with outside air at 80 F dry-bulb and 72 F dew-point, will be at approximately 120 F dry-bulb and 89 F wet-bulb.

**Step 6:** The heat required may be determined from Equation 26 by substitution of the following values:  $N_a = 307 \times 60 = 18420$  lb of air per hr;  $S = 900$  lb;  $c_s = 24 + 0.45 \left( \frac{0.028 + 0.0229}{2} \right) = 0.251$ ;  $t_1 = 80$  F;  $t_2 = 160$  F;  $t_2' = 100$  F;  $\lambda = 1100$  (approx.);  $W = 0.005$  lb;  $s_1 = 0.22$ .

$$Q = 18420 (0.251) (160 - 80) + 18420 (110 + 160 - 100) (0.028 - 0.0168) + 900 (100 - 80) (0.22 + 0.005) + Q_{rc}$$

$$= 609,000 \text{ Btu per hr} + Q_{rc}$$

The heat input requirement is therefore 609,000 Btu per hr plus radiation and convection losses ( $Q_{rc}$ ) which may be computed from the known construction of the dryer surfaces and the heat transfer coefficients.

Summer conditions were used in *Example 1* in order to obtain the maximum heat requirement which would be the case, except under the unusual condition where radiation and conduction losses are a large percentage of the total. In winter it is usually possible to take advantage of drier makeup air, and either speed up the process or operate at a lower dry-bulb temperature.

Controls for the system selected for *Example 1* would consist of a thermostat in the main return air duct controlling the heat input to maintain constant dry-bulb temperature. A wet-bulb controller in the return circulating duct would maintain constant desired wet-bulb temperature by simultaneous positioning of three sets of dampers in the makeup air, the exhaust air and the recirculated air ducts.

#### LETTER SYMBOLS USED IN CHAPTER 47

- $A$  = area of heat transfer and evaporation, square feet.
- $a$  = drying area, square feet per cubic foot of bed volume.
- $B$  = a constant (for use in Equation 22).
- $B'$  = a constant (for use in Equation 23).
- $c_s$  = humid heat, Btu per (pound of dry air) (Fahrenheit degree).
- $d$  = diffusivity of the liquid or vapor, square feet per hour.
- $D_p$  = average diameter of particle, feet.
- $D_{p1}$  = drop diameter at start of evaporation, feet.
- $D_{p2}$  = drop diameter of dry particle, feet.
- $e$  = Napierian base of logarithms = 2.718.
- $G$  = mass velocity of dry air, pounds per (hour) (square foot).
- $\Delta H_m$  = logarithmic mean of inlet and outlet humidity driving force across the air film adjacent to the particle through which the water vapor diffuses, pound per pound. (The surface humidity is taken as the humidity corresponding to the wet-bulb temperature of the drying air).
- $H_1$  = humidity ratio of entering air, pounds of water vapor per pound of dry air.
- $H_2$  = humidity ratio of leaving air, pounds of water vapor per pound of dry air.
- $h$  = film heat transfer coefficient, Btu per (hour) (square foot) (Fahrenheit degree).
- $h_c$  = coefficient of heat transfer by convection, Btu per (hour) (square foot) (Fahrenheit degree).
- $h_r$  = coefficient of heat transfer by radiation, Btu per (hour) (square foot) (Fahrenheit degree).
- $h_t$  = total gas film heat transfer coefficient, Btu per (hour) (square foot) (Fahrenheit degree).
- $K$  = a constant (a function of the constant drying rate).

- $k_t$  = gas film thermal conductivity, Btu per (hour) (square foot) (Fahrenheit degree per foot).
- $k_g$  = mass transfer coefficient, pounds per (hour) (square foot) (atmosphere).
- $L$  = material thickness, feet.
- $M$  = molecular weight of the diffusing vapor.
- $N_a$  = dry air supplied to the dryer, pounds per hour.
- $\Delta p$  =  $p_s - p_a$  = vapor pressure difference, atmospheres.
- $p_a$  = vapor pressure of water at  $t_s$ , atmospheres.
- $p_s$  = vapor pressure at the particle surface corresponding to the liquid temperature, atmospheres.
- $p_2$  = partial pressure of water vapor in air, atmospheres.
- $p_a$  = vapor pressure of liquid in the drying medium, atmospheres.
- $Q_{rc}$  = radiation and conduction loss, Btu per hour.
- $Q$  = total heat supplied to dryer, Btu.
- $q$  = rate of heat transfer, Btu per hour.
- $R$  = gas constant (cubic feet) (atmospheres) per (Fahrenheit degree).
- $S$  = weight of stock dried in a continuous dryer, pounds per hour.
- $S'$  = weight of stock charged in a discontinuous dryer, pounds per batch.
- $s$  = specific heat of stock, Btu per pound.
- $T$  = absolute temperature of the gas, Fahrenheit.
- $t_a$  = air or gas temperature, Fahrenheit.
- $t_h$  = temperature of the heating medium, Fahrenheit.
- $t_s$  = temperature of particle, solid or surface of evaporation, Fahrenheit.
- $t_w$  = wet-bulb temperature of drying air, Fahrenheit.
- $t_1$  = entering air temperature, Fahrenheit.
- $t_2$  = leaving air temperature, Fahrenheit.
- $t_1'$  = entering stock temperature, Fahrenheit.
- $t_2'$  = leaving stock temperature, Fahrenheit.
- $t''$  = average stock temperature over short interval of time, in batch dryer ( $t_1''$  = entering,  $t_2''$  = leaving) Fahrenheit.
- $\Delta t$  =  $(t_s - t_a)$  = temperature difference between air and surface of evaporation, Fahrenheit.
- $\Delta t_m$  = logarithmic mean between temperature entering and leaving the bed, and the wet-bulb temperature, Fahrenheit.
- $U$  = overall heat transfer coefficient, Btu per (hour) (square foot) (Fahrenheit degrees temperature difference between heating medium and product).
- $W$  = moisture content on dry basis at any time  $\theta$ , pounds of water per pound.
- $W_c$  = critical moisture content, pounds water per pound dry material.
- $W_d$  = water content, dry basis, of the drop as it enters the drying chamber, pounds per pound of dry solid.
- $W_e$  = moisture content at equilibrium with external conditions, pounds per pound dry material.
- $W_o$  = initial moisture or moisture content at start of diffusional period, pounds per pound.
- $w$  = pounds of water.
- $\frac{dW}{d\theta}$  = drying rate, pounds of water per (hour) (pound dry material).
- $\left( \frac{dW}{d\theta} \right)_c$  = constant drying rate, pounds per (hour) (pound dry material).
- $\left( \frac{dW}{d\theta} \right)_f$  = falling rate, pounds water per (hour) (pound of dry stock).
- $\frac{dw}{d\theta}$  = drying rate or rate of evaporation, pounds of water per hour (Eq. 1).
- $\theta$  = time, hours.
- $\theta_c$  = drying time for constant rate period, hours.
- $\theta_f$  = drying time during falling rate period, hours.
- $\theta_t$  = total drying time, hours.
- $\lambda$  = latent heat of evaporation at  $t_s$ , Btu per pound.
- $\mu$  = viscosity of the air stream, pounds per (hour) (square foot).
- $\rho_L$  = density of evaporating liquid, pounds per cubic foot.
- $\rho_s$  = bulk density of dry granular bed, density of dry particle, pounds per cubic foot.

## REFERENCES

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- <sup>2</sup> The Drying of Foods, by W. R. Marshall, Jr. (*Heating, Piping and Air Conditioning*, September to December, 1942, and November and December, 1943).
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## CHAPTER 48

## TRANSPORTATION AIR CONDITIONING

Railway Passenger Car Air Conditioning; Streetcar and Trolley Coach Heating and Ventilating; Passenger Bus Air Conditioning; Automobile Air Conditioning; Aircraft Air Conditioning; Ship Air Conditioning, Heating and Ventilating, Air Conditioned Space Treatment, Systems and Controls

THE principles of air conditioning applying to stores, restaurants, hospitals, theaters, and homes are applicable to railway passenger cars, passenger buses, automobiles, streetcars, trolley coaches, airplanes and ships. However, equipment used for mobile applications differs from that used for stationary purposes in that it must meet additional requirements. Equipment must be compact, accessible for quick inspection and servicing, light-weight and unaffected by vibration and impact. Freedom from vibration which could be transmitted to supporting vehicle and thus to passengers, is essential.

## RAILWAY PASSENGER CAR AIR CONDITIONING

The railway passenger car represents a very difficult air conditioning problem. Space is strictly limited so that all equipment and ducts must be reduced to minimum size. Electric power supply and water supply also are limited. All equipment must withstand severe vibration and shock, and must be very reliable since servicing points are frequently far apart.

During the heating season it is necessary to heat conventional cars with steam from the locomotive at pressures that may vary from 250 psig to only 5 or 10 psig on the last car in long trains. Passengers in window seats must sit only a few inches from cold outside walls and windows, and must also be very close to standing radiation installed along sides of cars. Sudden changes in load may be caused by changes in sun, wind, or train movement. Even in coldest weather, outside doors must be opened frequently.

During the cooling season, the problem is further complicated by a high concentrated internal load due to the passengers. Also, air distribution problems are increased by low ceilings and short air throws.

## Heating

The heating of passenger cars is accomplished by using a split system consisting of an overhead air circulating system with heating and cooling coils, and standing radiation (floor heat) along car sides. The floor heaters, which usually consist of finned tubing, may be made more efficient by using covers designed to increase gravity air circulation, and to direct the warm air from finned heating surface along cold outside walls and car windows. In some new cars, wall convector panels are used and extend the full length of the car, with air intakes along the floor and outlets at window sill height and at window head height in dead-light panels. The heated panel protects passengers from cold outside walls, and the chimney effect of the panel duct increases air flow and improves heating surface efficiency.

Floor heat is supplied by introducing steam into an inner tube within a finned tube or by means of a separate steam-to-liquid heat exchanger.



The liquid (usually an antifreeze) is mechanically circulated through plain finned tubing. When steam is used directly, the tube-within-a-tube construction makes it possible to obtain uniform distribution throughout the length of the car. It is achieved by means of heat transfer between the steam within the inner tube and the condensate returning in the annular space between the tubes.

The finned tubing at the floor must have sufficient capacity to offset effects of cold walls and windows during normal operation, and to heat the entire car to a minimum temperature of 60 F during standby when the overhead system is not operating. The maximum capacity required (determined by standby requirements) varies with car construction and design temperatures, but is approximately 90,000 Btu per hour. This requires a heating capacity in finned tube of approximately 650 Btu per linear foot.

The overhead air heating coil must have sufficient capacity to heat the outside air brought into the car for ventilation, and to supply approximately 20 percent of the internal heat loss of the car so as to permit supply of floor heat at all times at an output that will not be objectionable to passengers sitting near it. The usual capacity of the overhead heating coil is approximately 100,000 Btu based on 2400 cfm of circulated air, with 600 cfm of this being outside air for ventilation. All Btu figures are approximations of actual heating requirements, and do not include heat losses in the trainline (or leakage) or losses in the undercar piping. Recent car designs have enabled the car builder to run the steam supply lines in recesses within the car body, thus greatly diminishing under-car losses.

### Refrigeration

For cooling and dehumidification during summer, refrigeration may be obtained from ice bunkers, steam jet systems, or mechanical compressors (driven directly from car axle by electric motors or by gas engines). Refrigeration required varies with load conditions, but 7½ tons per car is one capacity frequently used. Evaporative type condensers are sometimes used in combination with the usual air condenser on either steam jet or mechanical refrigeration.

When an electric motor (approx. 10 hp) is used to drive the air conditioning compressor, the electric power source is a problem. If the power source is an axle-driven generator, there is an appreciable increase in the drag on locomotive, and the power available for refrigeration, when train is stopped at a station, is limited to storage batteries. One solution to this problem is to use a d-c generator driven by a gas engine. Another is to use a Diesel-driven alternator in a special head-end car to furnish power to the entire train. Recently there have been installations in which a Diesel-driven alternator is mounted on an individual passenger car to supply the power requirements of the car. The attractiveness of this type of installation can be increased by utilizing spare alternator capacity in winter for electric heating. If this capacity is supplemented by exhaust heat from the Diesel engine, there is sufficient capacity to heat the entire car and to provide hot water for wash rooms when outside temperatures are above approximately 30 F. This feature is important on trains using Diesel locomotives, since it eliminates the need for firing the steam heating boiler in the locomotive during a portion of the year.

### Air Distribution and Cleaning

Railway cars present critical problems in air distribution because air space per passenger is small (60 to 190 cu ft), and the sun load is great.

An average passenger car contains approximately 5000 cu ft of air, and may seat as many as 80 passengers. The occupants are continually liberating heat, carbon dioxide, moisture, odors, and some organic matter from their breath, skin and clothing. The heat and moisture can be removed by cooling and dehumidification, but other constituents can be successfully handled only by proper ventilation and air cleansing. In an average car, from 2000 to 2500 cfm are circulated by the air conditioning unit. Some of this air may be recirculated, but a portion of it should always be brought in from outside. The amount of outside air desirable depends upon the type of car, number of passengers, air temperature, humidity, odors, and whether or not the occupants are smoking, and will vary from 15 to 90 percent of the total air circulated.

Careful attention must be exercised in specifying the rate of outside air taken in so as to fit the type of service adequately, and yet not supply more ventilation than is necessary. Conditioning of this outside air is a major factor in determining size of both summer and winter equipment.

For normal conditions, 10 cfm of outside air per passenger are provided. When smoking is permitted, at least 15 cfm should be admitted. In some dining cars, and deluxe sleeping cars, outside air rates as high as 20 to 30 cfm per occupant are used. A ceiling duct lengthwise along the center of the car is usually used to distribute the air to the interior by fans or blowers. A perforated ceiling supplied from an overhead duct, or delivery grilles and plaques designed to give considerable entrainment and mixing, are used to deliver air to the car space.

Smoking rooms present a special problem. The cloud of smoke that usually hangs near the ceiling can be broken up by directing incoming air along the ceiling at a velocity somewhat higher than that used for the rest of car. The air is exhausted through the washroom or lavatory. For compartments, provision is made in the door or partition for removal of used air. Lower berths are provided with a low velocity air outlet.

Recirculating air grilles are usually of straight flow types. Outside air intakes are usually located in the vestibule, on the side of the car, or on the roof, depending upon location of the cooling coils. On many recently air-conditioned cars, there are no dampers or shutters at the outside air intakes; the percentage of the outside air is controlled by adjusting flow through the recirculating grille.

A considerable number of coach cars are now being equipped with return air ducts fitted in the structure of baggage racks. Part of the air circulated is returned to the blower unit through these ducts, and part through the car body. This arrangement reduces quantity and velocity of air returning through the car body, and removes smoke fumes at the source. This, and any other design features aimed at taking recirculated air at the floor and adjacent to both end doors (rather than drawing all recirculated air to one end of the car) also reduces infiltration of cold air in ankle height strata, when doors are opened during the heating season.

All air circulated by the blower is filtered before passing over the cooling and heating coils. In some cars outside air and recirculated air are filtered separately before mixing, while in others air from the two sources is mixed before passing through a common filter. Filters in use are combinations of metal, wool, cloth, spun glass, hemp, paper, hair and wire screen. Most filters have a viscous coating of oil for greater cleaning efficiency. Some types may be cleaned, re-treated, and re-used, while other types are discarded when dirty. Applications are also being made of electric precipitation for air cleaning. In this system the coarser particles are removed



from the air by mechanical separation; finer materials, by electrostatic action.

Activated carbon units sometimes are used in addition to the regular filters for adsorbing odors and other impurities, thus reducing the amount of outside air necessary for ventilation.

### Temperature and Humidity Control

Controls in a passenger car should be as automatic as possible. The regular train crew cannot be relied on to make adjustments for the comfort of passengers. For this reason the latest systems of temperature control have only an off-on switch to be operated by the train crew. When the system is in operation, heating or cooling is provided automatically as required.

When heating, it is important that floor-heat finned tubing be controlled at stable temperatures. Wide fluctuation in its temperature is highly objectionable because of location close to the passengers. Stable operation may be secured by cycling the floor heat on the basis of inside conditions in conjunction with an overhead air-circulating system to maintain final car temperatures.

Because of window condensation and other problems, usually no attempt is made to raise relative humidity in a railroad car in winter time.

When cooling, the steam jet refrigeration system is controlled in an on-off manner. Some means are ordinarily provided for operating mechanical compressor systems at partial capacity. In this case split evaporators are used, so that evaporator surface and compressor capacity can be reduced together under light load conditions.

Attempts have been made in the past, largely on an experimental basis, to control the relative humidity in railway cars. This was done by operating the air conditioning equipment according to outside temperatures and then re-heating the air to an acceptable temperature. This was found to be an expensive method of operating and the results did not justify the cost. A common method of controlling heating and cooling is to provide a thermostat to control heating only and a separate thermostat set at a slightly higher temperature to control the cooling equipment. This gives heating control, ventilation, and cooling control and the reverse, as the case may be. A car in service can go from heating into cooling in a very short time. An example of this is found on the full-dome cars in service on several railroads in the country. In the early morning hours before sunrise, the car may be requiring a considerable amount of heat. Shortly after sunrise, the car may go into the ventilating cycle and as the sun load increases, cooling may be required. On the majority of car heating systems, frequent cycling of the compressor is prevented by the one degree difference between the heating and cooling control points and by lag imposed on the system by applying artificial heat to the heating thermostat when cooling is required. On some car heating systems, a degree of modulation is obtained by the use of split evaporation. This requires two cooling thermostats with one of them set at a somewhat higher temperature than the other. The lower temperature cooling thermostat controls a portion of the cooling capacity and, if unable to maintain the car temperature, the higher thermostat adds the remaining capacity.

### STREETCAR AND TROLLEY COACH HEATING AND VENTILATING

Streetcars and trolley coaches present a special problem in the maintenance of satisfactory comfort conditions because of the frequent opening of the doors and highly fluctuating passenger load. Space limitations for ducts, and a desire to keep outlet grilles well above the floor to facilitate car cleaning, add further problems to the distribution system. Maintaining comfort conditions at the driver's station cannot be overlooked, since his term of occupancy is considerably longer than that of any passenger, and because he is usually dressed more lightly than passengers. A separate source of heat is usually provided for the operator, and is under his control.

#### Heating and Ventilating

Recently-built streetcars and trolley coaches obtain heat from air blown over the main accelerating resistors and track switch resistors, to heat the passenger space. In the modern streamlined streetcars, designated P.C.C., approximately 2400 cfm are drawn from the car and blown over these resistors to dissipate their heat. In trolley coaches, an amount of 800 cfm is customary. The heated air is then delivered to the passenger space or diverted to the outside by means of dampers, as required. If available heat from this source is insufficient, auxiliary electric heaters in the supply ducts may be cut in. The air distribution system is 100 percent recirculating when the maximum heating requirement is being met. At conditions other than maximum heating demand, part of the air drawn from the car is exhausted to the atmosphere. Outside air enters the car, under these conditions, by infiltration at all cracks and through doors when opened at stops.

The most recently-built streetcars have added ventilating fans in the roof structure to introduce outside air through ceiling diffusing grilles. By governing the outside air volume introduced through these roof fans in coordination with the heated air distributing system, it is possible to maintain a slight pressurization of the passenger space and avoid inrush of air when the doors are opened to load passengers. The roof fans also provide an effective means of maintaining lower inside temperature during summer operation. Ventilation tests on P.C.C. streetcars indicate that with 90 F outside temperature and above, 12,000 cfm are required to provide sufficient air change to keep inside temperature within a few degrees of outside air temperature, and to provide enough air movement over passengers for comfort. The best results have been obtained by operating the ventilating fans and keeping the windows closed. New cars provided with adequate ventilating capacity have been built with fixed sash.

#### Control

Temperature control, consisting of equipment especially designed to withstand the vibration present on transportation equipment, is used. Automatically operated dampers are used to control flow of heated air to the passenger space, or to direct heated air to the atmosphere. An automatically operated rheostat or multi-point switch is used to vary the speed of the ventilating fans. Recent control system applications employ one thermostat to operate both heating dampers and ventilating fans in a modulating or graduated manner, with a compensating thermostat in the heat supply duct to correct for wide fluctuations in temperature of air leaving the resistors. Ventilating fans are usually stopped or operated at lowest speed during the heating cycle, and then their speed is gradually increased as the car temperature rises above the heating-cycle control point.

## PASSENGER BUS AIR CONDITIONING

The passenger bus designed for urban transportation operation presents a greater problem to the designer of heating systems than does the inter-urban bus. More frequent stops, and rapidly changing passenger load create this problem on urban vehicles. Provision of heat for the driver independent of the passenger heating system, is a further problem. The inter-urban bus, however, is usually a deluxe vehicle and may require a comfort cooling system. Space and weight limitations and vibration must be considered.

## Heating

Recent designs of bus heating systems obtain improved air distribution. Heat in the engine coolant liquid is used to warm air by means of suitable finned coils and this heated air is distributed throughout the passenger space by ducts and outlets directed toward the floor. Some designs include finned surface near the floor in an application similar to that in railway passenger cars. Forced air circulation over this finned floor heating surface has been provided to increase its effectiveness. Oil burning booster heaters have been applied to many Diesel-powered buses to raise the temperature of the engine coolant for maximum engine operating efficiency, and to provide sufficient heat for the passenger space.

## Ventilation

Air for ventilation is usually brought into a bus at the front, and distributed throughout the length of the passenger space by a duct or ducts near the ceiling. Except for a few designs employing 100 percent outside air for heating, no heating of the ventilating air has been provided. One recently designed distribution system for an inter-urban bus provides for a fixed minimum of outside air, and is arranged to increase the percentage of outside air to 100 percent when the heating or cooling load diminishes. The distribution ducts and diversion damper arrangement of this system make available two supply ducts and one return duct for heating and for cooling, with a changeover to all three ducts to supply air during the intermediate ventilating cycle. This system permits utilization of atmospheric cooling and ventilation to the greatest degree when it can be most economically employed in the interval between the heating and cooling demand.

Conventional throw-away type filters or renewable filters are used in intake air ducts for many vehicles. Electrostatic filters have been successfully used in some installations. The need for elimination of dirt is great, but the problem is complicated by space limitations and limited power.

## Refrigeration

Summer conditioning systems for inter-urban vehicles range in cooling capacity from 36,000 to 48,000 Btu per hour. Mechanical compression systems using refrigerants are used, and are powered by water-cooled gasoline engines of approximately 14 hp.

Complete systems add from 800 to 1300 lb to weight of the coach. Sometimes an auxiliary generator driven by the refrigeration system engine is used and serves to help charge the bus battery, thereby offsetting power drain imposed by the ventilating blower. Belted reciprocating compressors and direct-driven V-type and rotary compressors are used, with engine speeds up to about 1800 rpm. Air-cooled condensers for this service re-

quire about 5000 cfm of outdoor air, and this is provided by either centrifugal or propeller type fans belted or direct-driven by the air conditioning engine. Preventing noise and vibration from affecting passengers is of vital importance. Installations must be made for quick daily engine servicing. In all cases fuel is obtained from the main bus tanks, and in some, the main engine cooling system cools the air conditioning engine.

## Control

Automatic temperature control is receiving more attention in the design of new vehicles. Some municipalities and states have enacted laws requiring that buses operated on their streets and roads be so equipped. The simplest control systems for heating of urban buses consist of a single thermostat to start and stop the blower of the heater unit. Improved heating systems employ a thermostat to control liquid flow to the heater cores by means of modulating valves, in combination with a means of stopping the heating blower when no heat is required. Heating and ventilating control is accomplished by controlling the volume of outside air, over and above the minimum required in accordance with the temperature in the passenger space, by means of automatic modulating dampers in the outside air intake, or by varying the speed of the ventilating air blowers.

In a large proportion of inter-city buses equipped with mechanical refrigeration, a single thermostat is used to start and stop the cooling operation. This may be accomplished by automatically starting an engine-driven compressor on the cooling demand or by engaging a clutch to drive the compressor. Modulated or graduated control of engine-driven compressors may be accomplished by automatic regulation of the engine throttle controlled from a thermostat in the passenger space. Complete control systems are available to coordinate operation of the heating, ventilating and cooling equipment from a single thermostat, with automatic change-over from heating to ventilating to cooling.

## AUTOMOBILE SUMMER AIR CONDITIONING

The first attempts to cool automobiles mechanically were made in south western United States 1930-1940 with systems assembled from commercial components. Between 1939 and 1942 one car manufacturer built about 1500 cars equipped with a mechanical system. Customer acceptance was mixed and the project was dropped to be reactivated again in 1953. In 1952 the major automobile manufacturers decided that time was ripe to offer summer comfort cooling in their higher priced cars. The 1953 models were introduced and well accepted. In 1953 and 1954 about 125,000 units were sold. In 1955 some of the lower priced cars were available with summer cooling systems.

The basic components used are fundamentally the same as in any stationary air conditioning system using the vapor compression cycle. The engineering problem is to design for automobile application in which case the source of power is always a major obstacle to overcome. The best solution to date for automobile applications is to operate the condensing unit by belt drive from the car motor and then control the variable refrigerating capacity caused by the variable car motor speed by suitable means.

One to seven or more horsepower are required. Compressors must be capable of operating at speeds of 4000 to 5000 rpm to last in this service. Refrigeration capacity required is about  $1\frac{1}{2}$  to  $1\frac{1}{4}$  tons. Radiant heat, as well as high conduction heat gain due to single-glazed large glass areas, and

lack of adequate insulation in car bodies require this much capacity. Proper air distribution to avoid undesirable drafts on passengers also requires careful design. Air distribution fans and electrical controls secure power from the car's electrical system which in some cases may require heavier generators and batteries to handle the load. Most systems weigh about 200 lb or less.

Early installations, and many current ones, have the cooling units installed in the rear of the car with the cooled air introduced through the package shelf at the rear of the passenger compartment. Cooled air is then distributed with or without ducts. Warm air is returned through a grill in the package shelf, or below the rear seat, thence through a filter into the cooling units. Refrigerant lines from condensing unit to cooling unit are carried from the engine compartment to the luggage compartment along the car frame under the body.

Current design objectives are to reduce weight and first cost, simplify installation, increase reliability, and improve performance, especially pull-

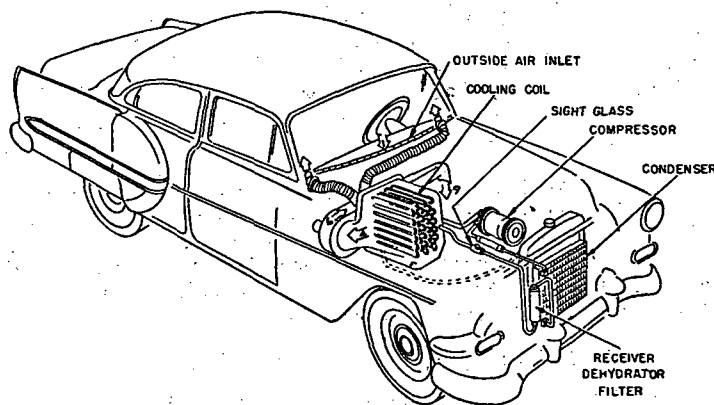


FIG. 1. TYPICAL FRONT END SYSTEM  
(All components ahead of fire wall)

down from a hot car standing in the sun. Recent systems have shown such improvements. Performance at open-road speeds have been very satisfactory (even with early systems—when they were operating properly). Twenty percent or more outside air should be supplied, especially if passenger smoke. This air is picked up by scoops on the side of the car or cowl (See Fig. 1) and carried into the cooling unit and mixed with returned warm air from the car.

Car temperature control, compressor capacity control to compensate for the variable compressor speed, and prevention of ice formation on the evaporators (a common fault of early systems) are accomplished by bypassing compressor discharge gas into the low pressure side of the system, or cycling the compressor with a magnetic clutch. The solenoid bypass valve or a magnetic clutch is electrically operated by a thermostat, usually controlled by the return air to the cooling unit. The bypass is opened or the compressor stopped when the air gets too cold.

A recent development is a complete factory-assembled system, charged with refrigerant and ready to run, which is dropped into position ahead of the fire wall of the car and bolted into place (see Figure 1). Flexible suction, liquid, and discharge lines are used to connect the refrigeration components together. This facilitates initial installation. It also simplifies removal for service and maintenance and eliminates the necessity to open the refrigeration components to the atmosphere with resultant loss of refrigerant or infiltration of moisture into the system.

This system combines winter heating with summer cooling. It also permits use of all or limited quantities of outside air, with or without heating or cooling. Outside air is taken in through cowl openings. This air is then pulled through a combined heating and cooling coil assembly by a fan inside the car on the firewall. Cooled air is discharged from adjustable nozzles on the dash inside the car. Hot air for heating is discharged onto the floor as with conventional car heaters. Dampers change the air distribution from heating to cooling, and dash controls activate or shut off either heating or cooling.

Temperature control, prevention of evaporator icing and compensation for variable compressor speed are controlled by a thermostat with bulb in the air leaving the evaporator. This cycles the compressor on a magnetic clutch.

Public acceptance of current offerings has been excellent. Performance has been very satisfactory. What service difficulties have been encountered have been readily cared for by car dealers who have trained personnel to render this type of service, or by competent refrigeration service organizations. Future demand is estimated as high as 10 percent of total car production by one major manufacturer, while another estimates a million or more of its cars will be equipped in the not too distant future.

### AIRCRAFT AIR CONDITIONING

In the space of a few years, heating, cooling and ventilating of airplanes has progressed from comparatively simple systems to highly complex multi-purpose designs. The attendant control problem has become correspondingly complex. On older, non-pressurized planes, the heating system consisted either of a steam boiler and radiator or a single stage or double stage heat exchanger. On both types, the cabin temperature was adjusted by positioning the face and bypass dampers. While these were sometimes moved by an automatic modulating control, in the majority of cases they were positioned by one of the ship's crew, with results which, while not satisfactory, were passable. As these planes cruised at less than 200 mph and normally operated at low altitudes, changes in outside air temperatures were generally gradual enough so that manual readjustment of controls could maintain reasonably comfortable cabin conditions. Nearly all of these heating systems were marginal in respect to heat available, and the main problem was lack of heat, rather than inadequate control.

### Non-Pressurized Cabins

With the advent of the combustion type heater, and use of larger and faster planes, use of manual controls became impracticable. The combustion type heaters reach full rating in less than a minute after being turned on, and as they are rated at 100,000 Btu per hr and up, and since several heaters are generally used, it would take full time of one crew

member to keep cabin temperature regulated. As ships of this type are not pressurized, the heating system is still comparatively simple.

In one type, two 100,000 Btu heaters are placed in parallel positions and the ram air from an external scoop is passed through the heaters and discharged through a series of distributing outlets located in the cabin ceiling. The cabin air is discharged through grilles located in the bottom walls of the cabin. An auxiliary nose heater is used by the crew to obtain additional heat for the cockpit or for windshield defrosting.

The cabin is maintained at the desired temperature by means of an automatic control which operates both heaters simultaneously. This control consists of two duct thermostats, one being mounted in the air inlet duct between the air scoop and the heaters so that it is affected by outside ambient temperatures, and the other being mounted in the heater outlet duct so that it is affected by the discharge air temperatures. A thermostat in the cabin is so located that a continuous stream of cabin air passes through it. This type of control has been found to respond to a 1 deg temperature change in less than a second. Its theory of operation follows.

As the outside temperature starts to drop, the outside air duct thermostat decreases in resistance, unbalancing an electronic bridge. This unbalance is amplified by vacuum tubes and causes a power tube to close a relay, turning on the combustion heaters. The resulting increase in temperature is sensed by the warm air duct thermostat which increases in resistance, thus re-balancing the bridge and causing the relay to open. If there were no loss by radiation or convection from the aircraft cabin, these two duct thermostats would be sufficient for adequate control. However, the cabin thermostat is given approximately 30 times more influence than the duct thermostats and so acts as the master controller, and the duct thermostats prevent over-heating or under-heating and keep the discharge air from alternating between extreme cold and extreme heat.

In a slightly more elaborate system, two combustion heaters supply a plenum chamber which is maintained at a constant temperature. Air from the plenum chamber is then mixed with outside air to maintain desired cabin temperature. All of the warm air is discharged into the cabin through the walls. The discharge grilles are located on the floor under seats, and a modulating type controller varies proportions of heated and outside air necessary to maintain desired cabin temperature. The same type of control system as previously described is used, except that an amplifier operates a two-phase motor capable of positioning control dampers instead of operating a relay which would merely open and close the fuel valve. An auxiliary duct, running from the plenum chamber, is used by the pilot as a source of windshield defrosting air.

#### Pressurized Cabins

With the advent of the new high speed pressurized transport planes, and the addition of cabin cooling in addition to heating, the control problem becomes more complex. On all of these airplanes, the heat of compression from cabin supercharger must be controlled, the air cycle or expansion turbines must be turned on and also, the heat exchanger or combustion heaters, which are used in the system when cooling is required for additional heat, must be automatically controlled.

Assuming that one of these airplanes is operating in an extremely cold climate, the sequence of operation would be as follows:

The automatic controller for the supercharged-air inter-cooler would be in full

closed position, so that none of the heat of compression would be removed, and the air would by-pass the expansion turbine and its compressor and the secondary after-cooler. An additional automatic controller would be operating the combustion heater and supplying the additional heat necessary to maintain the desired cabin temperature. If a heat exchanger were used as a supplemental source of heat, a modulating control operating a damper on this exchanger would run towards full heat position.

As the airplane enters a warm climate and heat requirements drop, the combustion heater would cease operation or the heat exchanger would go to full cold position, and the modulating control on the supercharger compressor would move towards the cold position. When the outside ambient temperature rises so high that cooling is desired, the cabin supercharger intercooler would be opened wide. If further cooling were required, the air would go into an air cycle turbine, which is modulated to deliver the required amount of cold air to maintain a comfortable cabin temperature.

Pressure in the cabin is maintained by providing a controlled, constant rate of air flow into the cabin sufficient to maintain ventilation, and adjusting the cabin-pressure relief valve setting, by means of a cabin pressure selector, to maintain the desired cabin pressure. Limits on maximum inside to outside pressure may be of the order of 4 or 5 psi, and safety controls should be provided to prevent exceeding this limit. There is a maximum rate at which the cabin can change to a newly selected value, this rate being in some cases also adjustable.

The requirements for controls of this nature are extremely rigid. It is commonplace for ships of this type to experience changes in outside ambient temperatures of as much as 100 deg in a space of 5 min. For this reason, speed of sensing a change and rapidity of response in the control system is essential if satisfactory control is to be accomplished. The older type thermostats cannot be used in airplanes, due to mass of the thermostat and to vibration experienced on all airplanes. All modern controls use some type of bridge system with temperature sensitive resistors as sensing elements. In some types of controls, the bridge system feeds a sensitive balanced relay, which in turn runs a modulating motor or controls an on-off power relay. A recent sensitive and quickly responding type uses an electronic amplifier, which in turn controls a two-phase motor, or, through relays, controls a d-c motor, or merely closes and opens a power relay for on-off applications.

In addition to extreme speed and accuracy which are required of all aircraft temperature controls, they must be able to operate under great extremes of temperature, pressure and humidity, and also withstand continuous extreme vibration. Heaters should have, in addition to control from thermostats, suitable limit controls to prevent over-heating due to failure of air supply, or any other cause. Also, there should be safety devices to shut off fuel in case of flame failure.

On the latest *high speed jet airplanes*, the temperature control problem is still more severe than on the latest transports; as in addition to the accuracy required, control response must be phenomenally fast. For example, on some, the air going to the cabin from the jet engine compressor can change the temperature at the rate of 150 deg per second. This, coupled with the fact that on smaller size pursuit ships air is changed in the cabin as much as four times per minute, makes the instantaneous sensing of change and an extremely rapid control movement essential. Also, in airplanes operating at Mach numbers in excess of 0.7, the control must react to the large adiabatic temperature rises encountered. Some of these problems are so new that controls still have not been developed to meet all of the desired conditions. However, present studies being made by control manufacturers should result in developments of such controls in the near future.

## SHIP AIR CONDITIONING

In air conditioning a ship, the designer is faced with all problems that would normally arise on shore installation plus additional factors. Mechanical ventilation is an absolute necessity for the comfort of passengers and ships' personnel, and for utility and preservation of cargo and stores. Ships are constructed with water-tight bulkheads dividing the vessel into several compartments. This complicates the running of duct work and results in a multiplicity of both supply and exhaust fans. Temperature and humidity requirements of various spaces aboard ship vary widely. Passenger staterooms and public spaces must have year-round air conditioning with is also being applied more and more to the quarters of the officers and crew. Boiler rooms, galleys, laundries, etc., must have ventilation, and some must have tempered air. Cargo spaces are quite likely to need dehumidification in addition to ventilation.

Inasmuch as ventilation is such a necessary factor aboard a ship, the majority of recently built vessels have been utilizing the air distribution system for heating purposes.

A ship is a self-contained structure quite likely to be away from repair ports for long periods. Adequate spare parts, therefore, form an integral part of equipment furnished. The same type of equipment should be used in as many places as possible throughout the ship, in order to reduce the number of spare parts to be carried.

Preliminary system design is simplified by uniformity of conditions which apply to most ships. Among such conditions are: (1) the necessity for the vessel to supply its own power, (2) the availability of an unlimited supply of low cost steam at suitable pressure, (3) limitations of available space and permissible weight.

The problem of heat transfer and insulation must be given careful consideration. The thermal conductivity of ship building material, such as steel, copper and brass, is many times the value of building material used ashore. The length of ducts between heat sources and fans necessitates extra duct insulation. Hull insulation must be of high quality, with attention given to fireproofness, low density, low thermal conductivity, ruggedness, vermin resistance, and ease of application. Board types are most common.

Duct insulation must have the same characteristics as hull insulation. Semi-rigid and rigid board are most common. Corrugated asbestos is not used because in the presence of moisture, it tends to disintegrate. There is a growing use of natural cork on chilled air ducts because of great difficulty in applying an adequate vapor seal due to space limitations.

## SHIP HEATING AND VENTILATING

It is usually most economical in weight and space to use steam duct heaters for heating spaces served by mechanical supply systems. Spaces which do not have mechanical supply, or do not require ventilation in cold weather, are heated by steam convectors or, where the load is large, by unit heaters. Ventilation air, except that supplied to auxiliary and main machinery spaces, is usually preheated to temperatures of 50 to 70 F. No recirculation is used in ventilation and heating systems, but a manual reduction (25 to 50 percent) of air quantity is made during the heating cycle. All heaters are automatically controlled, and preheaters are designed and installed to minimize possibility of freezing of condensate.

Preheaters are frequently located close to the outside air intake in order to conserve insulation and, for the same reason, zone reheaters are located as close as possible to each zone. Where a reheater serves only one space, it is commonly located in the space.

Combinations or variations of duct type and convection or radiant heaters are used, depending upon basic design requirements, such as weight and space limitations, and the economic justification of the cost of the type selected.

Because of many different requirements of various spaces aboard ship, some design temperatures and humidities are given in Table 1. The resulting quantities of air should be checked against typical heating and ventilation practices for ships.\*

TABLE 1. DESIGN CONDITIONS FOR SHIPS

| AREA                  | OUTSIDE DESIGN TEMPERATURES |               |               | INSIDE CONDITIONS |                    |         |
|-----------------------|-----------------------------|---------------|---------------|-------------------|--------------------|---------|
|                       | Heat-<br>ing                | Ventilating   | Cooling       | DB &<br>R.H.      | Effective<br>Temp. |         |
|                       | F                           | F             | F             | F                 | %                  | F       |
| Living Quarters . . . | 0                           | 95            | 95(DB) 80(WB) | 80                | 50                 | 73-74   |
| Public Spaces . . . . | 0                           | 95            | 95(DB) 80(WB) | 80                | 55                 | 73½-74½ |
| Naval Vessels . . . . | +10                         | 88(DB) 80(WB) | 88(DB) 80(WB) | 85                | 50                 | 75-78   |

## Living Spaces

The minimum quantity of ventilation air required for any sleeping or office space, including hospital space, should be that which will limit the temperature rise over the outside air to not more than 10 deg (a rise of 7 deg is more satisfactory), or a minimum of 30 cfm per person, whichever is the greater.

In spaces fitted for eating, recreation, or manual work, the rise may be taken at 10 deg with not less than 20 cfm per person. The same requirement applies to mechanical exhaust, although natural exhaust may be used where only a short run of duct exists.

Heat should be furnished to maintain the following temperatures:

|                                                           |            |
|-----------------------------------------------------------|------------|
| Staterooms, Berthing, Messing and Office Spaces . . . . . | 70 F       |
| Working Spaces and Shops . . . . .                        | 60 F       |
| Hospital Spaces . . . . .                                 | 75 to 78 F |

## Machinery Spaces

The prime purpose of machinery space ventilation is to maintain a habitable temperature for the operating personnel. It is more practicable to use *spot cooling* of personnel at working areas than to attempt to obtain uniform ambient temperature. The permissible temperature rise (above outside) at working stations is usually 15 deg, while the overall temperature rise is usually between 30 and 50 deg.

These spaces must be exhausted adequately, preferably by mechanical means. Every attempt should be made to remove air at or close to the heat sources. The capacity of the mechanical exhaust systems should be greater than the supply, taking into consideration the expansion of the supply air, to insure an indraft through access openings to the space.

Heat is not required for machinery spaces, except for those fitted with

\* See Ventilation and Heating of Maritime Commission Ships, by J. W. Markert (*Heating and Ventilating* Feb. 1943, p. 333).

electrically operated equipment, which may remain inactive during periods while in port when heating to about 50 F will be required.

### Storerooms and Cargo Spaces

The ventilation provided for these spaces depends on the type of vessel, location of space, and nature of cargo.

Ventilation is required for all closed spaces. Even if ventilation is not necessary to preserve the stores or cargo, it is required to prevent the accumulation of toxic or combustible gases and odors. One air change in 15 to 30 min is common practice, except where inflammable liquids or proximity to hot spaces requires additional ventilation. Mechanical supply and natural exhaust are usually used. However, where inflammable gases may exist, natural supply and mechanical exhaust are provided.

Many ships are fitted with dehumidification facilities for eliminating damage to the dry cargo by preventing condensation and dampness. The dehumidification load consists of moisture removed from the ventilation air passed through the dehumidifier, plus the moisture on, or given off by, the cargo, packaging, dunnage, battens, and other materials in the ship's holds. The most severe outside condition requires a moisture removal of 90 grains (140-50) per pound of dry air, with 88 F cooling water. The largest cargo ships are provided with equipment for removing about 250 lb of water per hour.

The dehumidification systems generally utilize silica gel or lithium chloride with inhibitor. (See Chapter 38). In most cases central drying equipment is provided. On large passenger ships consideration is given to the use of two dehumidifying units, because the cargo-carrying spaces are usually concentrated at the extreme ends of the vessel. A simple duct system distributes the dry air to the hold supply ventilation system. These ventilation systems use outside air when weather conditions are favorable. Recirculation and dehumidification are used only when necessary, i.e., when the weather dew-point approaches or exceeds the temperature in the hold. Two control stations are generally provided, one in machinery space and one in chart or wheelhouse. These stations are arranged so that either may change the cargo conditioning system controls from use of outside air to use of conditioned air.

### AIR CONDITIONED SPACE TREATMENT FOR SHIPS

The application of air conditioning to new American passenger ships is well established. All passenger staterooms, except steerage and third class, are usually air conditioned. This includes staterooms for ship's personnel and offices within conditioned passenger areas. Third class staterooms are air conditioned on some ships, depending on the particular trade. Theaters, lounges, smoking rooms, beauty shops, barber shops and similar closed public spaces are usually air conditioned.

All messrooms, recreation rooms, officers' offices, crew's inboard rooms, and those having fixed portlights are usually air conditioned on passenger vessels. The treatment depends on the requirements of the operator and the proposed itinerary of the vessel.

### SHIP SYSTEMS AND CONTROLS

The types of comfort conditioning systems used to date generally have followed conventional lines, except for those serving staterooms, offices, and similar small spaces. Large public spaces are fitted with individual

systems which supply dehumidified and cooled air during the cooling cycle, and warm air during the heating cycle. In many cases these rooms are fitted with large glass windows and doors, and require direct radiation to offset the downdraft which would occur in cold weather. Finned-tube radiation running the full length of the glass area is commonly used for this purpose. Introduction of warm air at the sill, in lieu of direct radiation, is also used.

Systems serving most public spaces are designed to provide all outside air as long as the refrigeration load is less than the capacity of the cooling equipment. Many central systems are simplified by using 100 percent outside air all-year-round. The important problem in ship air conditioning concerns the treatment of the small spaces such as passenger staterooms, offices, and crew quarters. Low headroom, congested quarters, double berths, and unsymmetric arrangements make each space a problem in air distribution and treatment.

The simplest system used for small spaces consists of a central filter bank, supply fan, preheater, and cooling and dehumidifying coil. The preheater steam valve and cooling coil water valve are controlled in sequence by a duct thermostat, in the fan discharge, set to maintain a constant outlet air temperature. Zone reheaters are provided to take care of variations in heating loads. The reheater steam valve is controlled by a sub-master thermostat at the reheater outlet. Control of room temperature is obtained by operating manual dampers in the air supply to the space. A recirculation exhaust fan is frequently provided, and operates in conjunction with automatic dampers to utilize the maximum quantity of outside air consistent with capacity of the cooling coils.

One system utilizes the same central supply equipment and recirculation exhaust system as the one just described, except that zone reheaters are replaced by individual space hot water reheaters. Each reheater is provided with a control valve, controlled by room thermostat. Generally, a forced circulation single pipe hot water system is used. This system is generally used for staterooms and small spaces devoted to first and second class passengers. The average total air per person is about 60 cfm, and average outside air per person is about 18 cfm.

A third system, used to a limited extent, is similar to the system just described, except that each room is provided with an induction unit (floor type where possible) which reheats the primary air supply. Control of heating coil in the induction unit is the same as noted for the system described in the previous paragraph. The average primary air supply is about 40 cfm per person. Recirculation is not always used. The amount of induced air varies with unit design.

A fourth less common arrangement is similar, but makes use of hot water in the induction unit in winter and cold water in the induction unit in summer. Control of the valve on the unit is obtained by use of a summer-winter type thermostat. The unit is provided with drip pan and drain piping to remove condensation. No recirculation is used.

On cargo ships, tankers and vessels not carrying passengers or not having air conditioning, heating of crews' spaces and officers' staterooms is usually obtained through a central system having filters, preheaters and reheaters. A minimum temperature of air leaving the preheater is controlled by a duct thermostat. The reheater is controlled by a sub-master discharge-duct thermostat, reset by outside master control. Relationship between sub-master and master control (wherein discharge temperature is raised as



outdoor temperature drops); is set according to a schedule based on the ship's itinerary.

Duct work for all systems described is designed for conventional velocity. However, if power is available, and suitably strong duct construction and adequate sound absorbing facilities are provided, high velocity systems may be used.

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## CHAPTER 49

## WATER SERVICES

Sizing Cold Water Supply Piping, Procedure for Sizing Cold Water Systems, Cooling Water Piping, Estimating Heating Load and Storage Capacity, Methods of Heating Water, Computing Heat Transfer Surface, Hot Water Supply Piping, Control of Service Water Temperature, Safety Devices, Solar Water Heaters, Domestic Hot Water by Heat Pump

PROPER design of the water distributing system in a building is necessary in order that the various fixtures may function properly. The amount of either hot or cold water used in any building is variable, depending on the type of structure, usage, occupancy, and time of day. It is necessary to provide piping, water heating, and storage facilities of sufficient capacity to meet the peak demand without wasteful excess in either piping or equivalent cost.

### SIZING COLD WATER SUPPLY PIPING

One of the important items that must be determined before any part of the water-piping system can be sized, is the probable rate of flow in any particular reach of piping. The rate of flow in the service line, risers, and main branches, however, will rarely be equal to the sum of the rates of flow of all connected fixtures. In fact, the probability that every fixture in a large group will be in use at the same time is so remote that it would be very poor engineering practice to design the piping to take care of such simultaneous flow.

The demand load in building water supply systems cannot be determined exactly and is not readily standardized. The two main problems to be considered are: (1) the satisfactory supply of water for a given fixture, and (2) the number of fixtures which may be assumed to be in use at the same time.

The minimum flow that will be satisfactory to the consumer depends greatly on the consumer, his standard of living, his professional needs, size of family, garden requirements, and similar factors. Depending on these factors, the per capita water consumption for domestic use usually varies between 20 and 80 gal per day. Experience indicates that the type of dwelling also has considerable influence on the water consumption.

In *apartment houses* the per capita daily water consumption is generally higher than in single-family houses. This is due to the use of a central metering system which is not conducive to the saving of water, and to the long hot water lines which cause high heat losses and an increase in the wasting of the cooled water. In designing water supply systems for apartment houses, a daily per capita water consumption of 50 gal may be considered a safe design figure.

Although a considerable number of *housing projects* have been developed throughout the United States, conclusive water consumption data have not yet been gathered. Nevertheless, it seems that the daily per capita water consumption in housing projects falls in between the consumption in apartment houses and that in single dwellings at the same geographical location.



TABLE 1. PROPER FLOW AND PRESSURE REQUIRED DURING FLOW FOR DIFFERENT FIXTURES

| FIXTURE                                 | FLOW PRESSURE <sup>a</sup> | FLOW gpm           |
|-----------------------------------------|----------------------------|--------------------|
| Ordinary basin faucet.....              | 8                          | 3.0                |
| Self-closing basin faucet.....          | 12                         | 2.5                |
| Sink faucet— $\frac{1}{2}$ in.....      | 10                         | 4.5                |
| Sink faucet— $\frac{1}{4}$ in.....      | 5                          | 4.5                |
| Bathtub faucet.....                     | 5                          | 6.0                |
| Laundry tub cock— $\frac{1}{4}$ in..... | 5                          | 5.0                |
| Shower.....                             | 12                         | 5.0                |
| Ball-cock for closet.....               | 15                         | 3.0                |
| Flush valve for closet.....             | 10-20                      | 15-40 <sup>b</sup> |
| Flush valve for urinal.....             | 15                         | 15.0               |
| Garden hose, 50 ft, and sill cock.....  | 30                         | 5.0                |

<sup>a</sup> Flow pressure is the pressure in the pipe at the entrance to the particular fixture considered.

<sup>b</sup> Wide range due to variation in design and type of flush-valve closets.

In general, a daily per capita water consumption of 40 gal can be used as a safe design figure for *housing projects*.

Table 1 gives the rate of flow desirable for many common types of fixtures, and the average pressure necessary to give this rate of flow. The pressure necessarily varies with fixture design; with some, a much greater pressure is necessary to give the same rate of flow than with others. In general, the lower the quality of the faucet the greater will be the pressure required.

In estimating the load, the rate of flow is frequently computed in *fixture units*. One *fixture unit* is equivalent to 7.5 gal per min. Table 2 gives the demand weights in terms of fixture units for different plumbing fixtures under several conditions of service, and Fig. 1 gives the estimated demand in gallons per minute corresponding to any total number of fixture units. Fig. 2 shows an enlargement of Fig. 1 for a range up to 250 fixture units.

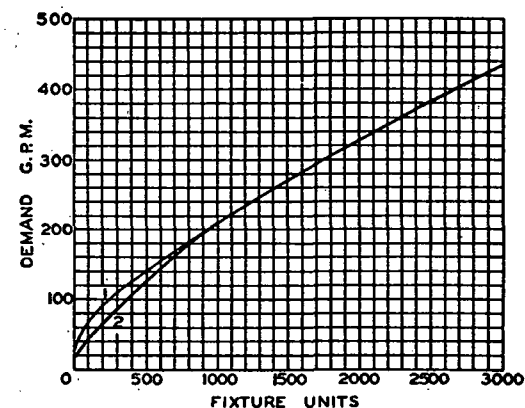
TABLE 2. DEMAND WEIGHTS OF FIXTURES IN FIXTURE UNITS<sup>a</sup>

| FIXTURE OR GROUP <sup>b</sup> | OCCUPANCY                | TYPE OF SUPPLY CONTROL      | WEIGHT IN FIXTURE UNITS <sup>c</sup> |
|-------------------------------|--------------------------|-----------------------------|--------------------------------------|
| Water closet.....             | Public                   | Flush valve.....            | 10                                   |
| Water closet.....             | Public                   | Flush tank.....             | 5                                    |
| Pedestal urinal.....          | Public                   | Flush valve.....            | 10                                   |
| Stall or wall urinal.....     | Public                   | Flush valve.....            | 5                                    |
| Stall or wall urinal.....     | Public                   | Flush tank.....             | 3                                    |
| Lavatory.....                 | Public                   | Faucet.....                 | 2                                    |
| Bathtub.....                  | Public                   | Faucet.....                 | 4                                    |
| Shower head.....              | Public                   | Mixing valve.....           | 4                                    |
| Service sink.....             | Office, etc.             | Faucet.....                 | 3                                    |
| Kitchen sink.....             | Hotel or restaurant..... | Faucet.....                 | 4                                    |
| Water closet.....             | Private.....             | Flush valve.....            | 6                                    |
| Water closet.....             | Private.....             | Flush tank.....             | 3                                    |
| Lavatory.....                 | Private.....             | Faucet.....                 | 1                                    |
| Bathtub.....                  | Private.....             | Faucet.....                 | 2                                    |
| Shower head.....              | Private.....             | Mixing valve.....           | 2                                    |
| Bathroom group.....           | Private.....             | Flush valve for closet..... | 8                                    |
| Bathroom group.....           | Private.....             | Flush tank for closet.....  | 6                                    |
| Separate shower.....          | Private.....             | Mixing valve.....           | 2                                    |
| Kitchen sink.....             | Private.....             | Faucet.....                 | 2                                    |
| Laundry trays (1-3).....      | Private.....             | Faucet.....                 | 3                                    |
| Combination fixture.....      | Private.....             | Faucet.....                 | 3                                    |

<sup>a</sup> For supply outlets likely to impose continuous demands, estimate continuous supply separately and add to total demand for fixtures.

<sup>b</sup> For fixtures not listed, weights may be assumed by comparing the fixture to a listed one using water in similar quantities and at similar rates.

<sup>c</sup> The given weights are for total demand. For fixtures with both hot and cold water supplies, the weights for maximum separate demands may be taken as  $\frac{3}{4}$  the listed demand for the supply.



No. 1 for system predominantly for flush valves.

No. 2 for system predominantly for flush tanks.

FIG. 1. ESTIMATE CURVES FOR DEMAND LOAD

The estimated demand load for fixtures used intermittently on any supply pipe will be obtained by multiplying the number of each kind of fixture supplied through that pipe by its weight from Table 2, adding the products, and then referring to the appropriate curve of Figs. 1 or 2 to find the demand corresponding to the total fixture units. In using this method it should be noted that the demand for fixture or supply outlets other than those listed in the table of fixture units is not yet included in the estimate. The demands for outlets (such as hose connections, air conditioning apparatus, etc.) which are likely to impose continuous demand during times of heavy use of the weighted fixtures, should be estimated separately and added to the demand for fixtures used intermittently, in order to estimate the total demand.

So far, the information presented makes possible the determination of the *design rate of flow* in any particular section of piping. The next general step is to determine the *size of piping*.

As water flows through a pipe, the pressure continually decreases along the pipe, due to loss of energy from friction. The problem is then one of ascertaining the minimum pressure in the street main, and the minimum

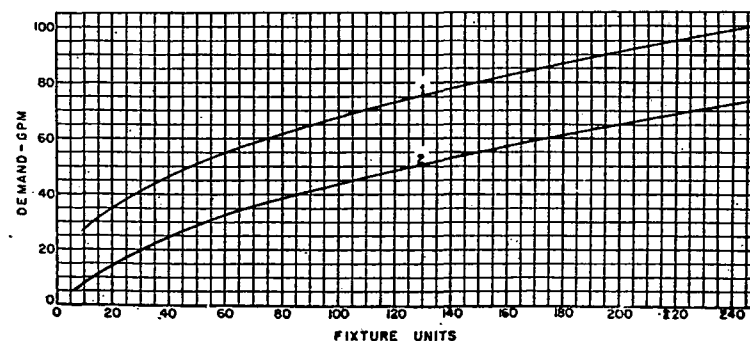


FIG. 2. SECTION OF FIG. 1 ON ENLARGED SCALE

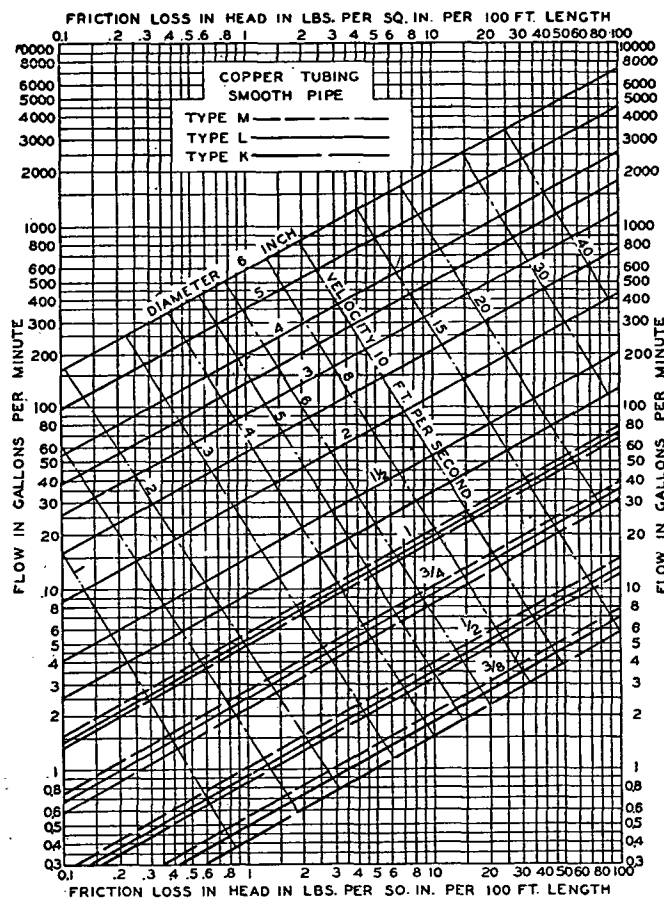


FIG. 3. FLOW CHART FOR COPPER TUBING

pressure required for the operation of the topmost fixture. (A pressure of 15 psi is ample for flush valves, but reference should be made to the manufacturers' requirements. A minimum of 8 psi should be allowed for other fixtures.) The pressure differential thus obtained will be available for overcoming pressure losses in the distributing system, and in overcoming the difference in elevation between the water main and the highest fixture.

The pressure loss, in pounds per square inch, caused by the difference in elevation between the street main and the highest fixture, may be obtained by multiplying the difference in elevation in feet by the conversion factor 0.43.

When water flows through a pipe, friction occurs as the result of the sliding of water particles past one another. If the pipe wall is rough, the roughness projections cause additional friction, owing to the development of increased turbulence in the flowing water. As the water flows along a uniform pipe, the pressure decreases as a result of a dissipation of

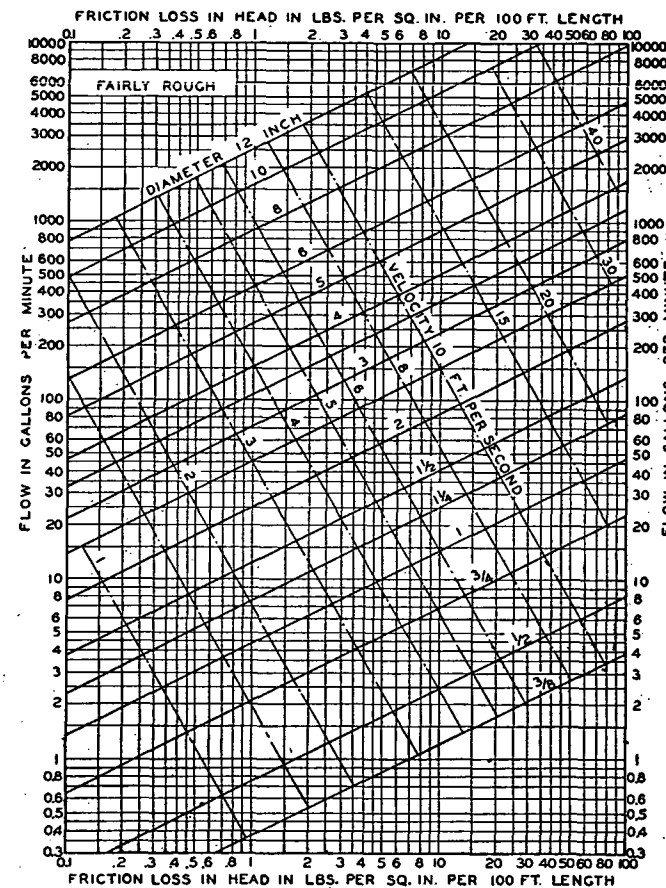


FIG. 4. FLOW CHART FOR FAIRLY ROUGH PIPE

energy arising from the internal friction set up by viscosity of the water. This loss in energy is shown by the loss of pressure. The pressure loss is proportional to the length of straight uniform pipes, and varies greatly with flow velocity, pipe diameter, roughness of pipe, and water temperature.

On the basis of inside surface conditions, pipes may be classified as smooth, fairly rough and rough, as follows:

**Smooth.** The pipe surface shows no perceptible roughness. Pipes made of copper, brass, or lead may usually be classified as smooth.

**Fairly Rough.** All ordinary pipes, such as wrought iron, galvanized iron, steel and cast-iron, after a few years of usage, may be called fairly rough.

**Rough.** Pipes that have deteriorated fairly rapidly for some 10 or 15 years after being laid, are classified as rough.

Figs. 3, 4 and 5 give the pipe friction losses corresponding to these three types of pipes for various nominal diameters for a water temperature of 50 F.<sup>1</sup> Example 1 will illustrate the use of the charts.

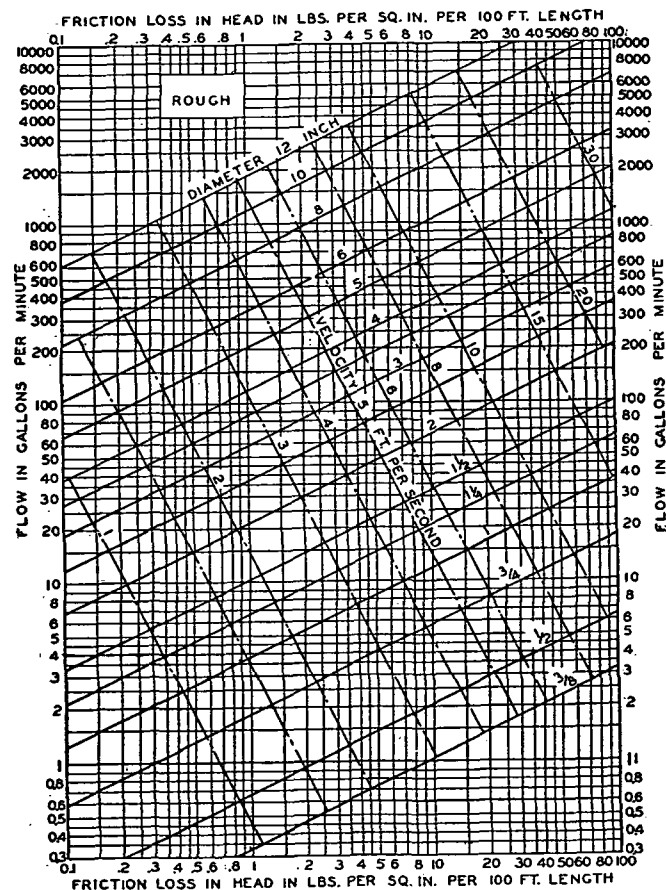


FIG. 5. FLOW CHART FOR ROUGH PIPE

**Example 1:** A  $2\frac{1}{2}$  in. fairly rough pipe supplies 100 gpm of water. Find the friction loss in head if the pipe length is 200 ft.

**Solution:** Enter Fig. 4 at 100 gpm, and move along this line until it intersects the  $2\frac{1}{2}$  in. diameter line. From this intersection point, move vertically down and read 4.5 psi friction loss per 100 ft of pipe length. Then the total friction loss will be  $2 \times 4.5 = 9$  psi.

The pressure losses in the distributing system will consist of the pressure losses in the piping itself, plus the pressure losses in the pipe fittings, valves and the water meter, if any. Estimated pressure losses for disc-type meters for various rates of flow are given in Fig. 6.

Flow limits for disc-type meters, which may be regarded as the limits of recommended ranges in capacities, are given in Table 3. For information on other types of meters, the manufacturers should be consulted.

Fig. 7 shows the variation of pressure loss with rate of flow for various types of faucets and cocks, based on experimental data obtained at the State University of Iowa.

The loss of pressure through any fitting or valve can be expressed in

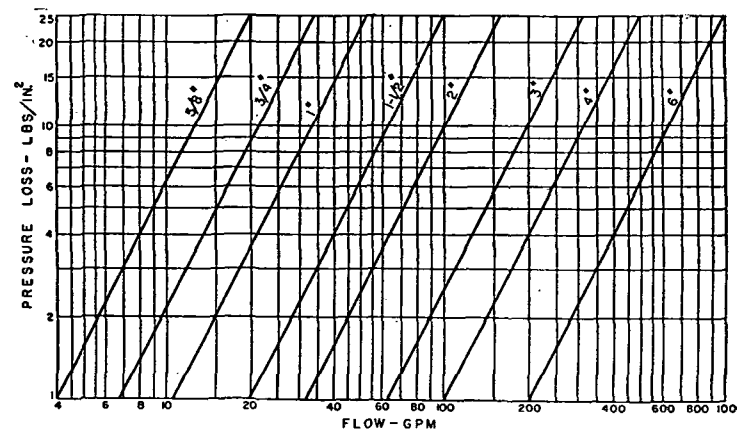


FIG. 6. PRESSURE LOSSES IN WATER METERS

pounds per square inch for any given rate of flow. Experience has shown, however, that the simplest method of expressing losses in fittings and valves is to use the concept of an equivalent length of straight pipe. Thus it has been found, for example, that a 1 in., 90 deg elbow introduces a loss equivalent to 2.2 ft of straight 1 in. pipe. Therefore, for each 1 in., 90 deg elbow, 2.2 ft of 1 in. pipe are added to the total length of 1 in. pipe.

Estimated pressure losses for pipe fittings and valves in terms of equivalent pipe length are shown in Table 4.

Table 5 lists the equivalent lengths for various special types of apparatus and fittings. The loss in water meters varies considerably with the design even in meters of the same nominal size. The values given in Table 5 are ample for the well-known meters now on the market.

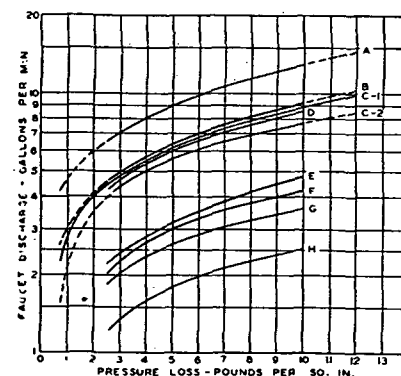


FIG. 7. VARIATION OF PRESSURE LOSS WITH RATE OF FLOW FOR VARIOUS FAUCETS AND COCKS

- |                                                          |                                        |
|----------------------------------------------------------|----------------------------------------|
| A. $\frac{1}{2}$ in. laundry bibb (old style).           | E. Combination compression sink faucet |
| B. Laundry compression faucet.                           | F. Basin faucet.                       |
| C-1. $\frac{1}{2}$ in. compression sink faucet (Mfr. 1). | G. Spring self-closing faucet.         |
| C-2. $\frac{1}{2}$ in. compression sink faucet (Mfr. 2). | H. Slow self-closing faucet.           |
| D. Combination compression bath tub faucets (both open). |                                        |

(Dashed lines indicate recommended extrapolation)

TABLE 3. PERFORMANCE REQUIREMENTS OF WATER METERS\*

| SIZE<br>IN. | NORMAL TEST-FLOW LIMITS<br>GPM | MINIMUM TEST-FLOW<br>GPM |
|-------------|--------------------------------|--------------------------|
| 5/8         | 1 to 20                        | 1/8                      |
| 3/4         | 2 to 34                        | 1/8                      |
| 1           | 3 to 53                        | 1/8                      |
| 1 1/4       | 5 to 100                       | 1 1/2                    |
| 2           | 8 to 160                       | 2                        |
| 3           | 16 to 315                      | 4                        |
| 4           | 28 to 500                      | 7                        |
| 6           | 48 to 1,000                    | 12                       |

\* American Water Works Association Standards:

Registration. The registration on the meter dial shall indicate the quantity recorded to be not less than 98 percent nor more than 102 percent of the water actually passed through the meter while it is being tested at rates of flow within the specified limits herein under normal test flow limits: There shall be not less than 90 percent of the actual flow recorded when a test is made at the rate of flow set forth under minimum test flow.

The water demand for hose bibbs or other large demand fixtures taken off the building main is frequently the cause of inadequate water supply to the upper floor of a building. This condition may be prevented by sizing the distribution system so that the pressure drops from the street main to all fixtures are the same. It is good practice to maintain the building main of ample size (not less than 1 in. where possible) until all branches to hose bibbs have been connected. Where the street main pressure is excessive and a pressure reducing valve is used to prevent water hammer or excessive pressure at the fixtures, it is frequently desirable to connect hose bibbs ahead of the reducing valve.

The principles involved in sizing either up-feed or down-feed systems are the same. The principal difference in procedure is that in the down-feed system, the difference in elevation between the house tank and the fixtures provides the pressure required to overcome pipe friction.

#### Procedure for Sizing Cold Water Systems

The recommended procedure for sizing piping systems is outlined in following paragraphs 1 to 6, inclusive.

1. Draw a sketch of the main lines, risers, and branches, and indicate the fixtures to be served. Indicate the rate of flow of each fixture.

TABLE 4. ALLOWANCE IN EQUIVALENT LENGTH OF PIPE FOR FRICTION LOSS IN VALVES AND THREADED FITTINGS

| DIAMETER<br>OF FITTING<br>IN. | EQUIVALENT LENGTH OF PIPE FOR VARIOUS FITTINGS |                                 |                          |                                             |                     |                      |                      |
|-------------------------------|------------------------------------------------|---------------------------------|--------------------------|---------------------------------------------|---------------------|----------------------|----------------------|
|                               | 90 Deg<br>Standard<br>Elb<br>Ft                | 45 Deg<br>Standard<br>Elb<br>Ft | 90 Deg<br>Side Tee<br>Ft | Coupling<br>or Straight<br>Run of Tee<br>Ft | Gate<br>Valve<br>Ft | Globe<br>Valve<br>Ft | Angle<br>Valve<br>Ft |
| 3/8                           | 1                                              | 0.6                             | 1.5                      | 0.3                                         | 0.2                 | 8                    | 4                    |
| 1/2                           | 2                                              | 1.2                             | 3                        | 0.6                                         | 0.4                 | 15                   | 8                    |
| 3/4                           | 2.5                                            | 1.5                             | 4                        | 0.8                                         | 0.5                 | 20                   | 12                   |
| 1                             | 3                                              | 1.8                             | 5                        | 0.9                                         | 0.6                 | 25                   | 15                   |
| 1 1/4                         | 4                                              | 2.4                             | 6                        | 1.2                                         | 0.8                 | 35                   | 18                   |
| 1 1/2                         | 5                                              | 3                               | 7                        | 1.5                                         | 1.0                 | 45                   | 22                   |
| 2                             | 7                                              | 4                               | 10                       | 2                                           | 1.3                 | 55                   | 28                   |
| 2 1/2                         | 8                                              | 5                               | 12                       | 2.5                                         | 1.6                 | 65                   | 34                   |
| 3                             | 10                                             | 6                               | 15                       | 3                                           | 2                   | 80                   | 40                   |
| 3 1/2                         | 12                                             | 7                               | 18                       | 3.6                                         | 2.4                 | 100                  | 50                   |
| 4                             | 14                                             | 8                               | 21                       | 4.0                                         | 2.7                 | 125                  | 55                   |
| 5                             | 17                                             | 10                              | 25                       | 5                                           | 3.3                 | 140                  | 70                   |
| 6                             | 20                                             | 12                              | 30                       | 6                                           | 4                   | 165                  | 80                   |

2. Using Table 2, compute the demand weights of the fixtures in fixture units.
3. Determine the total demand in fixture units and, using Fig. 1 or Fig. 2, find the expected demand in gallons per minute.
4. Determine the equivalent length of pipe in the main lines, risers, and branches. Since the sizes of the pipes are not known, the exact equivalent length for various fittings, etc., cannot be made. Add the equivalent lengths, starting at the street main and proceeding along the service line, the main line in the building, and up the riser to the top fixture of the group served.
5. Determine the average minimum pressure in the street main and the minimum pressure required for the operation of the topmost fixture. This latter pressure should be 8 to 15 psi.
6. Calculate, by means of Equation 1, the approximate design value of the average pressure drop per 100 ft of pipe in the equivalent length determined in paragraph 4.

$$p = [P - 0.43H - 10] \frac{100}{L} \quad (1)$$

where

$p$  = average pressure loss per 100 ft of equivalent length of pipe, psi.  
 $P$  = pressure in street main, psig.

TABLE 5. EQUIVALENT LENGTHS OF IRON PIPE TO GIVE SAME LOSS AS SPECIAL FITTINGS AND APPARATUS

| FITTING APPARATUS                                 | NOMINAL DIAMETER OF PIPE—INCHES |        |    |       |
|---------------------------------------------------|---------------------------------|--------|----|-------|
|                                                   | 1/2                             | 3/4    | 1  | 1 1/4 |
| 30-gal Vertical hot-water tank, 3/4 in. pipe...   | 4                               | 17     | 56 | —     |
| 30-gal Horizontal hot-water tank, 3/4 in. pipe... | 1.2                             | 5      | 16 | —     |
| Water meters (No valves included)                 |                                 |        |    |       |
| 5/8 in. with 1/2 in. connections                  | 6.7                             | 28     | 90 | —     |
| 3/4 in. with 3/4 in. connections                  | 4.8                             | 20     | 64 | —     |
| 3/4 in. with 3/4 in. connections                  | 3.4                             | 14     | 45 | —     |
| 1 in. with 1 in. connections                      | —                               | 9      | 30 | 115   |
| 1 1/4 in. with 1 in. connections                  | —                               | 4.4    | 14 | 54    |
| Water softener                                    | —                               | 50-200 | —  | —     |

$H$  = height of highest fixture above street main, feet.  
 $L$  = equivalent length determined in paragraph 4, feet.

If the system is of the down-feed supply from a gravity tank, the height of water in the tank, converted to pounds per square inch by multiplying by 0.43, replaces the street main pressure, and the term  $0.43 H$  in Equation 1 is added instead of subtracted in calculating the term  $p$ . In this case,  $H$  will be the vertical distance of the fixture below the bottom of the tank.

7. From the expected rate of flow, determined as in paragraph 3, and the value of  $p$ , calculated as in paragraph 6, choose the sizes of pipe from Figs. 3, 4 or 5.

**Example 2:** Assume a minimum street main pressure of 55 psig; a height of topmost fixture above street main of 50 ft; a developed pipe length from water main to highest fixture of 100 ft; a total load on the system of 50 fixture units; and that the water closets are flush-valve operated. Find the required size of supply main.

**Solution:** From Fig. 2 the estimated peak demand is found to be 51 gpm. From Table 3 it is evident that several sizes of meters would adequately measure this flow. For a trial computation choose the 1 1/2 in. meter. From Fig. 6 the pressure drop through a 1 1/2 in. disc-type meter for a flow of 51 gpm is found to be 6.5 psi.

Then the pressure drop available for overcoming friction in pipes and fittings is  $55 - (15 + 50 \times 0.43 + 6.5) = 12$  psi.

At this point it is necessary to make some estimate of the equivalent pipe length of the fittings on the direct line from the street main to the highest fixture. The exact equivalent length of the various fittings cannot now be determined since the pipe sizes of the building main, riser, and branch leading to the highest fixture are not known as yet, but a first approximation is necessary in order to make a tentative selection of pipe sizes. If the computed pipe sizes differ from those used in determining the equivalent length of pipe fittings, a recalculation will be necessary, using

TABLE 6. COMPUTATION OF BRANCH SIZE IN EXAMPLE 2

| FIXTURES NO. AND KIND | FIXTURE UNITS (FROM TABLE 2 AND NOTE C) | DEMAND (FROM FIG. 2) GPM | PIPE SIZE (FROM FIG. 4) IN. |
|-----------------------|-----------------------------------------|--------------------------|-----------------------------|
| 3 flush valves.....   | 3 x 6 = 18                              |                          |                             |
| 2 bath tubs.....      | $\frac{1}{2}$ (2 x 2) = 3               |                          |                             |
| 3 lavatories.....     | $\frac{1}{4}$ (3 x 1) = 2.25            |                          |                             |
| Total.....            | 23.25                                   | 38                       | 1 $\frac{1}{2}$             |

the computed pipe sizes for the fittings. For the purposes of this example assume that the total equivalent length of the pipe fittings is 50 ft.

Then the permissible pressure loss per 100 ft of equivalent pipe is  $12 \times 100 / (100 + 50) = 8$  psi.

Assuming that the corrosive and caking properties of the water are such that Fig. 4 for fairly rough pipe is applicable, a 2 in. building main will be adequate.

The sizing of the *branches* of the building main, the *risers*, and *fixture branches* follow the principles outlined. For example, assume that one of the branches of the building main carries the cold water supply for 3 water closets, 2 bath tubs, and 3 lavatories. Using the permissible pressure loss of 8 psi per 100 ft, the size of branch determined from Table 2 and Figs. 1 and 4 is found to be 1 $\frac{1}{2}$  in. Items entering the computation of pipe size are given in Table 6.

### COOLING WATER PIPING

Water is very frequently used in refrigeration systems, cooling towers and other similar installations. In designing the piping system of such installations, the principles of hydraulics, as already outlined, are employed. Nevertheless, there are several practical items having particular application to cooling installations. They are outlined in the following paragraphs, and it is important that the designer be familiar with them.

In choosing pipe material, the problem of corrosion should be kept in mind to prevent defects in the system. If the water does not have drastic corrosion characteristics, wrought iron or steel piping may be used; otherwise, galvanized steel piping may be preferred. If sea water is used as the circulating medium, it is advisable to use alloys such as admiralty metal in pipe and tubing. In refrigeration condensers where water is the cooling medium, iron pipe is commonly employed.

In regard to assembly, cast-iron flanges or welded joints are to be preferred to screwed joints wherever possible.

Valves used in circulating systems may be of the globe, gate, or angle

TABLE 7. PIPE SIZES FOR COOLING TOWERS<sup>1</sup>

| RATED TONS OF REFRIG. | COOLING WATER GPM | PIPE SIZES (NOMINAL INCHES) |                   |
|-----------------------|-------------------|-----------------------------|-------------------|
|                       |                   | Inlet to Tower              | Outlet from Tower |
| 3 to 5                | 10 to 18          | 1 $\frac{1}{2}$             | 1 $\frac{1}{2}$   |
| 7 to 15               | 20 to 45          | 2                           | 2                 |
| 20                    | 65                | 2 $\frac{1}{2}$             | 3                 |
| 25                    | 86                | 2 $\frac{1}{2}$             | 4                 |
| 35                    | 115               | 3                           | 4                 |
| 50                    | 170               | 3                           | 4                 |
| 75                    | 225               | 5                           | 6                 |
| 100                   | 300               | 5                           | 6                 |
| 150                   | 450               | 5                           | 8                 |
| 200                   | 600               | 6                           | 8                 |
| 250                   | 750               | 8                           | 8                 |

types. If water is the circulating medium, brass valves are usually used. However, if the circulating medium is an electrolyte, such as brine, then it is preferable to use valves made of the same material as the piping itself.

The friction loss in the piping may be determined from Fig. 4 for fairly rough pipe. If the coolant is brine, a correction for the proper density must be made. Experience indicates that in sizing piping for cooling systems, a pressure drop of the order of 2 to 3 psi per 100 ft of pipe length, and a fluid velocity of 3 to 8 fps, yield most economical results.

In the case of cooling towers, the amount of circulating water is about 3 gpm per ton of refrigeration, when based on a design wet-bulb tempera-

TABLE 8. MAXIMUM DAILY (24-Hr) REQUIREMENTS FOR HOT WATER IN GALLONS

|                                     | No. of Rooms                          | NUMBER OF BATHROOMS |     |     |     |     |
|-------------------------------------|---------------------------------------|---------------------|-----|-----|-----|-----|
|                                     |                                       | 1                   | 2   | 3   | 4   | 5   |
| <i>Apartments and Private Homes</i> | 1                                     | 60                  | —   | —   | —   | —   |
|                                     | 2                                     | 70                  | —   | —   | —   | —   |
|                                     | 3                                     | 80                  | —   | —   | —   | —   |
|                                     | 4                                     | 90                  | 120 | —   | —   | —   |
|                                     | 5                                     | 100                 | 140 | —   | —   | —   |
|                                     | 6                                     | 120                 | 160 | 200 | —   | —   |
|                                     | 7                                     | 140                 | 180 | 220 | —   | —   |
|                                     | 8                                     | 160                 | 200 | 240 | 250 | —   |
|                                     | 9                                     | 180                 | 220 | 260 | 275 | —   |
|                                     | 10                                    | 200                 | 240 | 280 | 300 | —   |
|                                     | 11                                    | —                   | 260 | 300 | 340 | —   |
|                                     | 12                                    | —                   | 280 | 325 | 380 | 450 |
|                                     | 13                                    | —                   | 300 | 350 | 420 | 500 |
|                                     | 14                                    | —                   | —   | 375 | 460 | 550 |
|                                     | 15                                    | —                   | —   | 400 | 500 | 600 |
|                                     | 16                                    | —                   | —   | —   | 540 | 650 |
|                                     | 17                                    | —                   | —   | —   | 580 | 700 |
|                                     | 18                                    | —                   | —   | —   | 620 | 750 |
|                                     | 19                                    | —                   | —   | —   | —   | 800 |
|                                     | 20                                    | —                   | —   | —   | —   | 850 |
| <i>Hotels</i>                       | Room with basin.....                  | 10                  |     |     |     |     |
|                                     | Room with bath—transient.....         | 50                  |     |     |     |     |
|                                     | Room with bath—resident.....          | 60                  |     |     |     |     |
|                                     | 2 Rooms with bath.....                | 80                  |     |     |     |     |
|                                     | 3 Rooms with bath.....                | 100                 |     |     |     |     |
|                                     | Public shower.....                    | 200                 |     |     |     |     |
| <i>Office Buildings</i>             | Public basins.....                    | 150                 |     |     |     |     |
|                                     | Slop sink.....                        | 30                  |     |     |     |     |
|                                     | White collar worker (per person)..... | 2.0                 |     |     |     |     |
| <i>Hospitals</i>                    | Other workers (per person).....       | 4.0                 |     |     |     |     |
|                                     | Cleaning per 10,000 sq ft.....        | 30.0                |     |     |     |     |
| <i>Hospitals</i>                    | Per bed.....                          | 80-100              |     |     |     |     |

ture of about 76 F. Table 7 gives pipe sizes frequently used for various sizes of cooling towers, assuming a hot-water temperature of 95 F and a cold-water temperature of 85 F.<sup>2</sup>

### ESTIMATING HEATING LOAD AND STORAGE CAPACITY

The maximum daily and the maximum hourly hot water demand form the basis for the selection of the heater and the storage tank.

In general, two thirds of the total daily water consumption is hot water. For residential dwellings, a design value of about 20 to 30 gal per capita per day may be assumed, but it should be remembered that the hot water used will depend on the number of rooms and the number of bathrooms in

any house or apartment. Table 8 gives estimates of the maximum hot water requirements in 24 hr in various types of buildings.

In estimating the size of hot water storage tank required, and the heating capacity to be provided, either from the boiler or from an independent domestic hot water heater, it is necessary to know the total quantity of water to be heated per day, and the maximum amount which will be used in any one hour, as well as the duration of the peak load.

In cases where the requirements for hot water are reasonably uniform, as in residences, apartment buildings, hotels, and the like, smaller storage capacity is required than in the case of factories, schools and office buildings, where practically the entire day's usage of hot water occurs during a very short period. Correspondingly, the heating capacity must be proportionately greater with uniform usage of hot water than with intermittent usage, where there may be several hours between peak demands during which the water in the storage tank can be brought up to tempera-

TABLE 9. ESTIMATED HOT WATER DEMAND CHARACTERISTICS FOR VARIOUS TYPES OF BUILDINGS

| TYPE OF BUILDING                     | HOT WATER REQUIRED         | MAX. HOURLY DEMAND IN RELATION TO DAY'S USE | DURATION OF PEAK LOAD HOURS | STORAGE CAPACITY IN RELATION TO DAY'S USE | HEATING CAPACITY IN RELATION TO DAY'S USE |
|--------------------------------------|----------------------------|---------------------------------------------|-----------------------------|-------------------------------------------|-------------------------------------------|
| Residences, apartments, hotels, etc. | 40 gal per person per day* | 1/7                                         | 4                           | 1/5                                       | 1/7                                       |
| Office buildings                     | 2 gal per person per day*  | 1/5                                         | 2                           | 1/5                                       | 1/5                                       |
| Factory buildings                    | 5 gal per person per day*  | 1/3                                         | 1                           | 2/5                                       | 1/8                                       |
| Restaurants                          |                            |                                             |                             | 1/10                                      | 1/10                                      |
| Restaurants 3 meals per day          |                            | 1/10                                        | 8                           | 1/5                                       | 1/10                                      |
| Restaurants 1 meal per day           |                            | 1/5                                         | 2                           | 2/5                                       | 1/6                                       |

\* At 140 F

ture. As a general rule, it is desirable to have a large storage capacity in order that the heating capacity, and consequently the size of the heater, or the load on the heating boiler, may be as small as possible.

In estimating the hot water which can be drawn from a storage tank, it should be borne in mind that only about 75 percent of the volume of the tank is available, since, by the time this quantity has been drawn off, the incoming cold water has cooled the remainder down to a point where it can no longer be considered hot water.

Where steam from the heating boiler is used to heat domestic hot water, the computed load on the boiler should be increased by 4 sq ft EDR (equivalent direct radiation) for every gallon of water per hour heated through a 100 deg rise. The actual requirement is  $(100 \times 8.33)/240 = 3.48$  sq ft per gal heated 100 deg. The value of 4 allows for transmission losses.

There are two methods in common use for estimating the hot water requirements of a building: (1) by the number of people, and (2) by the number of plumbing fixtures installed. Where the number of people to be served can be reasonably estimated, the data in Table 9 may be used.

**Example 3:** Determine the heater size and storage tank capacity for a residence housing five people.

**Solution:** From Table 9, a residence housing five people would have a daily re-

quirement of  $5 \times 40 = 200$  gal. per day, and a maximum hourly demand of  $200 \times 1/7 = 28.5$  gal. The heater should have a storage capacity of  $200 \times 1/5 = 40$  gal, and a heating capacity of  $200 \times 1/7 = 28.5$  gal per hr.

The conditions given in *Example 3* may be cited as average. It is possible to vary the storage and heating capacity by increasing and decreasing one over the other. Such a condition is illustrated in *Example 4*.

**Example 4:** Determine the required heater capacity for an apartment housing 200 people, if the storage tank has a capacity of 1000 gal. What heater capacity will be required if the storage tank is changed to 2500 gal capacity?

**Solution:** Assume an apartment house housing 200 people. From the data in Table 9: Daily requirements =  $200 \times 40 = 8000$  gal. Maximum hours demand =  $8000 \times 1/7 = 1140$  gal. Duration of peak load = 4 hr. Water required for 4-hr peak =  $4 \times 1140 = 4560$ .

If a 1000 gal storage tank is used, hot water available from the tank =  $1000 \times 0.75 = 750$ . Water to be heated in 4 hr =  $4560 - 750 = 3710$  gal. Heating capacity per hour =  $3710/4 = 930$  gal.

If instead of a 1000 gal tank, a 2500 gal tank had been installed, the required heating capacity per hour would be  $\frac{4560 - (2500 \times 0.75)}{4} = 671$  gal.

Table 10 may be used to determine the size of water heating equipment from the number of fixtures. To obtain the *probable maximum demand*, multiply the total quantity for the fixtures by the *demand factor* in line 11. The heater or coil should have a water heating capacity equal to this *probable maximum demand*. The storage tank should have a capacity equal to the *probable maximum demand* multiplied by the storage capacity factor in line 12. *Example 5* will illustrate the procedure.

**Example 5:** Determination of heater and storage tank size for an apartment building from number of fixtures.

|                       |               |                 |
|-----------------------|---------------|-----------------|
| 60 lavatories.....    | $\times 2 =$  | 120 gal per hr  |
| 30 bathtubs.....      | $\times 20 =$ | 600 gal per hr  |
| 30 showers.....       | $\times 75 =$ | 2250 gal per hr |
| 60 kitchen sinks..... | $\times 10 =$ | 600 gal per hr  |
| 15 laundry tubs.....  | $\times 20 =$ | 300 gal per hr  |

|                              |                      |                   |
|------------------------------|----------------------|-------------------|
| Possible maximum demand..... | =                    | 3870 gal per hr   |
| Probable maximum demand..... | = $3870 \times 0.30$ | = 1161 gal per hr |
| Heater or coil capacity..... | =                    | 1161 gal per hr   |
| Storage tank capacity.....   | = $1161 \times 1.25$ | = 1450 gal        |

Although, in private dwellings a water temperature of 140 F is reasonable for dishwashing, in public places sanitation regulations call for 180 F water. Most of the dishwashing machines now available on the market require 180 F water. The amount of 180 F water needed in restaurants per day may be determined according to the method outlined by the *American Gas Association*,<sup>3</sup> in the following paragraphs:

1. Multiply the number of meals per day by the number of dishes per meal (6 for low-price restaurants, 8 for medium-price restaurants, and 10 for high-price restaurants) to determine the total number of dishes per day.
2. Divide the total number of dishes per day, as determined by method in paragraph 1, by the average number of dishes per rack to find the number of racks per day.
3. Multiply the number of racks per day by the gallons of 180 F water (using 1.5 for single tank machines and 0.75 for two tank machines). This product will give the gallons of 180 F water per day for rinse sprays.
4. Multiply the number of meal periods per day (one, two or three) by the dish-

washing tank capacity in gallons, giving the gallons of 180 F water per day necessary to fill the tanks.

5. Add values from paragraphs 3 and 4 to obtain the total number of gallons of 180 F water required per day.

For purposes other than dishwashing, a considerable amount of 140 F water is also used. To find the daily 140 F water requirement in a restaurant, multiply the total number of meals served per day by the gallons of 140 F water per meal. Low priced restaurants on the average utilize 0.9 gal of 140 F water per meal, while medium- and high-price restaurants use 1.2 and 1.5 gal per meal, respectively.<sup>a</sup>

### METHODS OF HEATING WATER

Hot water may be heated either by the direct combustion of fuel, by an intermediate carrier such as steam or hot water, or by electrically heated

TABLE 10. HOT WATER DEMAND PER FIXTURES FOR VARIOUS TYPES OF BUILDINGS  
Gallons of water per hour per fixture, calculated at a final temperature of 140 F

|                                          | APART-<br>MENT<br>HOUSE | CLUB   | GYM-<br>NASIUM | HOS-<br>PITAL | HOTEL  | INDUS-<br>TRIAL<br>PLANT | OFFICE<br>BUILD-<br>ING | PRIV-<br>ATE<br>RESI-<br>DENCE | SCHOOL | Y.M.<br>C.A. |
|------------------------------------------|-------------------------|--------|----------------|---------------|--------|--------------------------|-------------------------|--------------------------------|--------|--------------|
| 1. Basins, private lavatory              | 2                       | 2      | 2              | 2             | 2      | 2                        | 2                       | 2                              | 2      | 2            |
| 2. Basins, public lavatory               | 4                       | 6      | 8              | 6             | 8      | 12                       | 6                       | ....                           | 15     | 8            |
| 3. Bathtubs                              | 20                      | 20     | 30             | 20            | 20     | 30                       | ....                    | 20                             | ....   | 30           |
| 4. Dishwashers                           | 15                      | 50-150 | ....           | 50-150        | 50-200 | 20-100                   | ....                    | 15                             | 20-100 | 20-100       |
| 5. Foot basins                           | 3                       | 3      | 12             | 3             | 3      | 12                       | ....                    | 3                              | 3      | 12           |
| 6. Kitchen sink                          | 10                      | 20     | ....           | 20            | 20     | 20                       | ....                    | 10                             | 10     | 20           |
| 7. Laundry, stationary<br>tubs           | 20                      | 28     | ....           | 28            | 28     | ....                     | ....                    | 20                             | ....   | 28           |
| 8. Pantry sink                           | 5                       | 10     | ....           | 10            | 10     | ....                     | ....                    | 5                              | 10     | 10           |
| 9. Showers                               | 75                      | 150    | 225            | 75            | 75     | 225                      | ....                    | 75                             | 225    | 225          |
| 10. Slop sink                            | 20                      | 20     | ....           | 20            | 30     | 20                       | 15                      | 15                             | 20     | 20           |
| 11. Demand factor                        | 0.30                    | 0.30   | 0.40           | 0.25          | 0.25   | 0.40                     | 0.30                    | 0.30                           | 0.40   | 0.40         |
| 12. Storage capacity factor <sup>a</sup> | 1.25                    | 0.90   | 1.00           | 0.60          | 0.80   | 1.00                     | 2.00                    | 0.70                           | 1.00   | 1.00         |

<sup>a</sup> Ratio of storage tank capacity to probable maximum demand per hour.

surfaces. The simplest method is to have the fire on one side of a metal barrier and water on the other. In such a method, if the surfaces for transferring heat are small, and if the water carries a heavy proportion of precipitable salts, the water passages may soon become clogged with resultant cracking or burning of the surface. A familiar example of such trouble is the water back in the kitchen stove, or the pipe coil inserted into the firebox of a warm air furnace or small boiler. The critical water temperature at which the lime, magnesia, etc., collect on hot surfaces, varies with the character and proportions of the solids, but generally such deposits are not a serious trouble below 140 F.

Coal-burning, direct-fired water heaters may be constructed of cored cast-iron sections, or of steel. In some cases the external appearance of the cast-iron sections is the same as in heating boilers, but internally the cores are changed to enable the sections to withstand the city water pressure. In small capacity water heaters, efficiency is not considered so important as low first cost and ability to maintain a fire at a low rate of combustion, and consequently, such heaters are generally built with a dry

section or fire-brick lining at the base of the fire-pot to prevent too much chilling of the fuel. While mud and scale will eventually clog the waterways of any direct-fired heater, increased life may be obtained by providing a three-way cock in the return line between the heater and the bottom of the storage tank, so that water can be blown through the heater or the tank separately, at full line pressure, to clean out loose sediment. Clean-out openings in the bottom of the heater are advantageous, if used by operators of water heaters for periodic cleaning out of sediment.

Oil-burning, direct-fired water heaters usually are of steel, and operate with higher flame temperature and better efficiency than commensurate sized coal-burning heaters. As they have the same tendency as coal boilers to accumulate lime deposits, the water passages should be large in cross-section and accessible for periodic cleaning.

Gas-burning, direct-fired water heaters may be of the instantaneous or storage type. Instantaneous heaters are generally constructed of spiral water tubes of copper, around which the products of combustion circulate upward from high capacity burners. Storage-type heaters may include

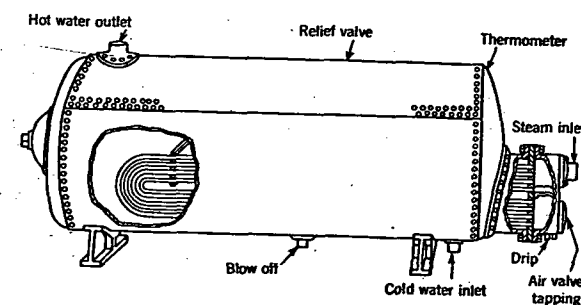


FIG. 8. INDIRECT WATER HEATER

in one unit an insulated storage tank, a combustion chamber, flues, burner equipment, and controls, or may consist of a separate storage tank and external direct-fired water heater, which may be a so-called *side-arm* heater for small capacity, or a gas-fired boiler for larger capacity. Gas boilers used for direct hot water supply must be able to withstand the city water operating pressure. While direct-fired gas heaters are used generally for residences and small installations of 100 gal storage capacity or less, indirect heaters are recommended for larger installations.

Chimney connections for all direct-fired, fuel burning water heaters are an important consideration. Refer to Chapter 17.

Electric water heaters for domestic hot water supply are described in the section Heating Domestic Water by Electricity in Chapter 42.

In the indirect method, either steam or hot water is used for heating the water. With steam, the water to be heated is preferably circulated around the outside of the steam tubes which are submerged within a tank. A typical indirect heater using steam is shown in Fig. 8. The coils usually are of copper, and are U-shaped to permit expansion and contraction. The shell may be of steel, with a protective coating or with a special inside protective lining, or may be of copper or copper alloy. Where straight heating tubes are used, one end of the tube is usually expanded into a floating head to take care of expansion. The coils should be capable of



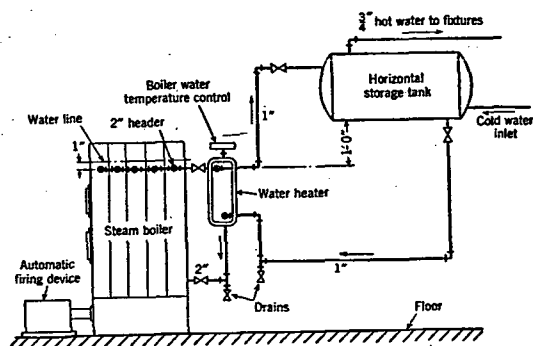


FIG. 9. INDIRECT WATER HEATER MOUNTED ON SIDE OF BOILER

easy withdrawal for inspection and for removal of scale. Instead of steam, the heating medium may also be hot water inside the tubes.

Another method of transferring heat from a heating boiler to the domestic water is illustrated in Fig. 9. The water heater is generally a cast-iron shell within which there is located a spiral copper coil. Hot water from the boiler circulates inside the shell and around the coil, and returns to the boiler, while domestic water from the storage tank circulates inside the coil. The storage tank should be installed with the bottom of the tank as far above the boiler as possible. Horizontal storage tanks of less than 18 or 20 in. diameter are not recommended because of the difficulty of preventing the hot and cold water from mixing, and especially is this an important consideration when large quantities of water are withdrawn. In Fig. 10 the heat transfer surface is placed inside the boiler instead of in a separate vessel, but otherwise the operation is similar to that of Fig. 9. This arrangement with vertical tank is commonly used for small domestic installations.

Sometimes the heating element is located inside of the larger type fire tube boilers and small residential boilers. In this case the heat transfer surface is in the form of a number of straight copper tubes, with rear U-bends or a floating head, inserted through a special opening in the boiler. While the coil may be placed in the steam space above the water line of a steam boiler, it is usually placed below the water line. Long coils of small diameter tubing, immersed in the water, are widely used without storage tanks. The rate of flow through the coil is limited by the friction loss in the coil,

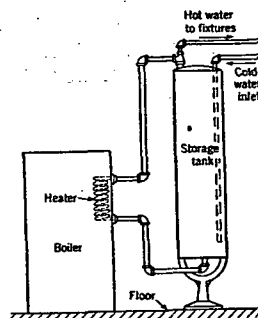


FIG. 10. INDIRECT WATER HEATER PLACED IN BOILER

and by fittings and restrictions, so that the water attains the desired temperature in one passage through the coil. This arrangement is frequently found in oil burner installations where the heating boiler, either steam or hot water type, is used to supply hot water during the summer. A thermostatic three-way mixing valve is frequently used to maintain a uniform temperature of the hot water supply to the plumbing fixtures.

In order to reduce clogging by precipitated solids, water heating plants sometimes develop steam in a closed circuit, transferring the heat through a tubular heater to the domestic water. The water in the primary heater, exposed to the high temperature of the fire, is repeatedly used and hence, has no appreciable tendency to deposit scale, while the domestic water, heated by steam at a much lower temperature than that of the fire, also exhibits a much reduced tendency to precipitate dissolved salts. Water characteristics, the effect of impurities and means of improving the quality of the water are important items, as brought out in Chapter 43.

### COMPUTING HEAT TRANSFER SURFACE

The area of the inside surface of a heating coil may be determined from Equation 2.

$$A = \frac{Q \times 8.33(t_2 - t_1)}{U \times t_m} \quad (2)$$

where

$A$  = surface area of coil, square feet.

$Q$  = quantity of water heated, gallons per hour.

$t_2$  = hot water outlet temperature, Fahrenheit.

$t_1$  = cold water inlet temperature, Fahrenheit.

$U$  = coefficient of heat transmission, Btu per (hour) (square foot) (Fahrenheit degree logarithmic mean temperature difference).

For copper or brass coils  $U = 240$  (steam) and 100 (hot water).

For iron coils  $U = 160$  (steam) and 67 (hot water).

$t_m$  = logarithmic mean of the difference between the temperature of the heating medium and the average water-temperature, and is approximately:

$$t_m = \frac{(t_2 - t_1)}{2}$$

$t_m$  = temperature of the heating medium, Fahrenheit.

Equation 2 may be used to check the heating coil ratings under temperatures other than those stated in the manufacturer's published ratings.

**Example 6:** What area of copper transfer surface will be required to heat 70 gal of water per hour from 40 to 180 F with boiler water at 220 F?

**Solution:**

$$t_m = \left[ 220 - \frac{(180 + 40)}{2} \right] = 110 \quad A = \frac{70 \times 8.33(180 - 40)}{100 \times 110} = 7.42 \text{ sq ft}$$

For instantaneous submerged heaters, the surface required will depend upon (1) the velocity of water in the tubes, (2) the boiler water temperature, (3) the inlet water temperature, (4) the outlet water temperature, (5) the cleanliness of the coil surface, and (6) the condition of the boiler water surrounding the coil. If the heater is located in the water of an ac-

tively steaming part of a boiler, the heat transfer may be twice as great as would be obtained if the water surrounding the coil were circulating slowly. Ratings of instantaneous water heating coils will therefore vary greatly, depending upon the assumptions made regarding the conditions of operation. The values of the coefficient of heat transmission for instantaneous heaters, shown in Table 11, are conservative.

For a coil in which heat is transferred from steam to water, the value of  $U = 300 \sqrt{v}$  may safely be used ( $v$  = velocity of water in feet per second).

The rate of heat transfer, between steam or water as the carrier, and the domestic water, is influenced by the rate of movement of both the carrier and the water which receives the heat. For this reason, where the transfer occurs from heating system water to domestic water, it is good practice to install a circulating pump to insure rapid movement of the boiler water.

In view of the high condensation rates obtained when steam is used with gravity circulation from the boiler, as when there is a sudden demand followed by an inflow of cold water, the bottom of a steam heating transfer element always should be at least 30 in. above the boiler water line, and the steam and condensate return pipes should be of liberal size. Otherwise,

TABLE 11. COEFFICIENT OF HEAT TRANSFER OF INSTANTANEOUS WATER HEATERS  
 $U = \text{Btu per (hr) (sq ft) (Fahrenheit degree logarithmic mean temperature difference)}$

|                               |     |     |     |
|-------------------------------|-----|-----|-----|
| Boiler water temperature..... | 210 | 200 | 180 |
| $U$ .....                     | 225 | 175 | 150 |

water hammer and reduced capacity may result, due to imperfect drainage of condensate.

When connecting a transfer-type hot water heater below the waterline of a cast-iron steam boiler having vertical sections, there should be a separate tapping for water circulation into every section of the boiler, as shown in Fig. 9, unless the boiler has large top nipple ports providing inter-sectional circulation. If the top nipples are entirely within the boiler steam space, no internal circulation occurs between sections. Steaming may then occur in the boiler sections not connected to the heater and, further, the unconnected sections will not deliver any heat to the water heater.

### HOT WATER SUPPLY PIPING

It is common practice to provide circulating piping in all hot water supply systems in which it is desirable to have hot water available continuously at the fixtures. In average-sized and small residences and systems, in which the piping from the heater to the fixtures is short, return circulating piping is generally omitted in order to reduce installation cost, and to reduce heat loss from the piping, particularly during periods of no water demand.

The hot water supply may be distributed by either an up-feed or down-feed piping system. Three common methods of arranging the circulating lines are shown in Fig. 11. Although the diagrams apply to multi-story buildings, the arrangements (a) and (b) are sometimes used in residential designs.

A check valve should be provided in the run-out from each return riser to prevent temporary reversal of flow in the piping when a faucet is open. Proper air venting of a circulating system is extremely important, particularly if gravity circulation is employed. In Fig. 11 (a) and (b), this is ac-

complished by connecting the circulating line below the top fixture supply. With this arrangement, air is eliminated from the system each time the top fixture is opened.

Where an overhead supply main is located above the highest fixture as in Fig. 11 (c), an automatic float type air vent is installed at the highest point of the system, or a fixture branch is connected to the top of the main where air venting is desired, and then dropped to the fixture outlet.

It is sometimes necessary to make an allowance for pressure drop through the heater when sizing hot water lines, particularly where instantaneous hot water heaters are used and the available pressure is low.

The principles involved in the sizing of the hot water supply pipes are the same as those for the sizing of cold water supply lines. For small and medium sized installations a  $\frac{3}{4}$ -in. hot water return will be ample. For larger installations, the size of the hot water return may be computed from considerations of the heat losses in the hot water piping.<sup>4</sup> A throttling

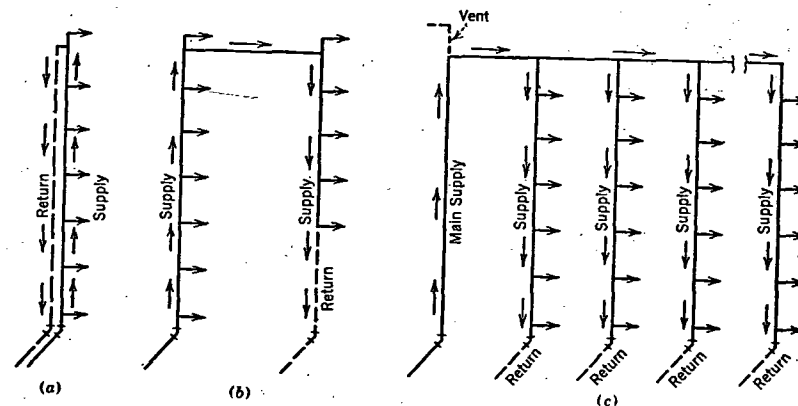


FIG. 11. METHODS OF ARRANGING HOT WATER CIRCULATION LINES

valve should be placed in the hot water return pipe so that the rate of circulation may be adjusted.

Where the hot water piping system is exceedingly long, a water circulator is frequently installed and controlled from an immersion thermostat (in the return line) set to start and stop the pump over approximately a 20 F deg temperature range.

### CONTROL OF SERVICE WATER TEMPERATURE

Coal-fired boilers are usually controlled by an immersion thermostat (located in the heated water) which opens or closes draft dampers at the boiler to adjust the rate of fuel combustion. With oil or gas-fired boilers, the immersion thermostat controls the oil burner or the automatic gas valve. The gas pilot flame usually burns continuously. With electric heaters, the immersion thermostat operates a switch on the source of energy.

When steam or hot water is the medium for heating the water in the tank, an immersion thermostat is used to control a valve in the steam or hot water supply line. In small residence installations, using water as the carrier, a combined immersion thermostat and butterfly valve in one simple

fitting may be installed in the transmitting circuit to prevent over-heating of the service water.

In residences heated by pump circulated hot water, the house temperature is controlled by operating the circulating pump intermittently, while domestic hot water is warmed by transfer from the house boiler, independent of the pump operation. The domestic water is heated from the heating boiler the year 'round. Under such an arrangement, to prevent overheating the house by thermal circulation when the pump is not running, it is usual to insert a weighted check-valve in the house heating main so that no circulation to the house heating system can occur unless the pump operates. In summer the fire may be controlled to maintain a boiler water temperature lower than when heating, and generally about 20 F warmer than that desired in the domestic hot water system.

The immersion thermostat in a hot water storage tank should be located no higher than the center of the tank, and possibly should be even closer to the bottom, since water in a tank stratifies proportionally to the temperature. When hot water is removed, the cold water entering to replace it quickly reduces the temperature in the lower parts of the tank.

### SAFETY DEVICES FOR HOT WATER SUPPLY SYSTEMS

There are still numerous plumbing codes which do not have regulations for the prevention of hot water storage tank explosions.

An ordinary storage tank is under certain water pressure, depending on the static pressure in the system. When the water in the tank is heated by circulation through an external heater, or by heating units in the tank, it gradually expands. For instance, if the entire contents of a 30-gal storage tank are heated from 70 F to 160 F, there will be an increase in volume of about one-half gallon. If the tank is connected to some supply without any intervening check valve, the increase in volume causes part of the water to be pushed back into the supply line. If the hot water reaches the water meter, it may ruin the composition discs.

If back-flow cannot occur, as for example, due to the use of a check-valve or a pressure-reduction valve in the line, or because of temporary shut-off of the cold-water line, the pressure in the tank rises as heating continues. Such a pressure rise, if the heating continues for any length of time, may result in rupturing of the tank.

If the tank water is not confined, continued heating would, of course, cause no increase in pressure beyond ordinary line pressure. However, the temperature would continue to increase. If this should happen at elevated temperatures, the flashing of the water into steam might cause a serious tank explosion.

In order to guard against the development of excessive pressure inside a hot water storage tank (owing to the thermal expansion of the water), it is customary to install a spring-loaded pressure-relief valve which is set to open at a pressure about 20 psi higher than the normal line pressure.

The amount of water discharged by any pressure-relief device is usually quite small, since it takes only a small quantity of water to relieve any pressure rise due to the thermal expansion of the water. The rate of discharge should be such as to limit the pressure rise for any given heat input to 10 percent of the pressure at which the valve is set to open. For any given installation, the discharging capacity should be in excess of the water to be discharged by the heater. The heater discharge  $Q_m$  in gallons per minute may be computed by Equation 3:

$$Q_m = 0.00005b$$

(3)

where  $b$  is the heat input of heater in Btu per minute.

To prevent danger of overheating, temperature-relief devices should be used. One type of such a device has a fusible plug of metal which melts at about 212 F. The hot water then runs from the opening until the device is serviced. A better type of relief device is one which incorporates a bellows or bimetallic disc, which opens at a temperature of 210 F and closes when the temperature drops to approximately 160 F.

Another type of safety device is a fuel cutoff switch or valve in which a fusible plug is melted by excessive water temperature. The fuel supply is cut off until the fusible plug is replaced.

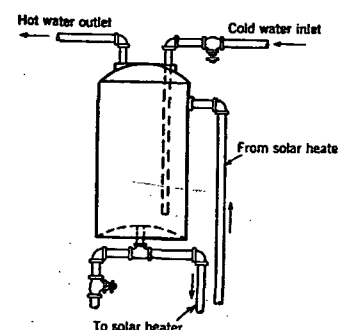


FIG. 12. SOLAR HEATER TANK CONNECTIONS

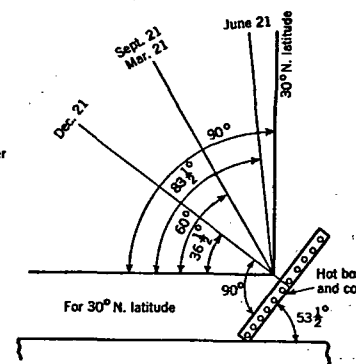


FIG. 13. SOLAR HEATING COIL INCLINATION

The capacity of temperature relief devices may be calculated by Equation 4:

$$Q_m = 0.0008b$$

(4)

where  $Q_m$  and  $b$  denote the same quantities as in Equation 3.

Pressure relief valves should be installed in the cold water line near the tank out of contact with the hot water in order to prevent excessive corrosion and lime deposit on the valve seat. Temperature relief valves, in general, must be installed at the point of maximum water temperature.

### SOLAR WATER HEATERS

Solar heaters utilize the energy of the sun for heating water. The successful operation of such heaters requires the availability of sunshine practically every day in the year, which has limited their use to Florida and the southern portions of California. When supplemented with some other means of gas, coal, or oil water heating, solar heaters may be used in climates where sunshine may be more or less intermittent. They have been used in summer homes as far north as Chicago. When properly installed and proportioned, solar water heaters render satisfactory service, especially in climates where the outside temperatures are high and extremely hot water is not necessarily desirable. Such installations consist essentially of a storage tank, heating coil, and hot box. The coil is installed in the hot box, and is arranged to circulate water to and from the storage tank. The advantage in the use of this type of heater is the fact that it

requires no fuel. The same materials should be used for the coil, circulation lines, and tank. A copper coil is more efficient in absorbing heat in the box, but galvanized iron or steel may be substituted, depending on the local water conditions, cost, and other considerations.

The storage tank must be able to store sufficient heated water for the night period of about 16 hr when the coil is not functioning, or is operating under such poor sun conditions as to make its heating effect negligible. Due to the fact that the *no sun* period includes the night period when little or no hot water is used, an available storage of 50 percent of the average daily usage is considered adequate. Since about 25 percent of stored hot water cannot be drawn out of a storage tank before the incoming cold water reduces the temperature of all of the water in the tank to an unsatisfactory point for usage, the equation for calculating the storage capacity of the tank becomes:

$$S = \frac{Q_d \times 0.50}{0.75} = 0.666Q_d \quad (5)$$

where

$S$  = storage capacity of tank, gallons.  $Q_d$  = average daily usage, gallons.

Thus, for a family of four persons using an average of 40 gal of hot water per (person) (day), the size of the tank would be 4 persons  $\times$  40 gal  $\times$  0.666 or 106 gal, and the nearest standard size of tank would be used. The tank should be well insulated to prevent undue loss of heat during the 16-hour period when the coil is inoperative, and it should be located as high as possible in the building (under the peak of the roof if such exists) so as to secure a maximum circulation head from the coil. The hot water supply line to the house, as shown in Fig. 12, is connected to the top of the tank and serves to vent the air from the tank through the hot water faucets as fast as it accumulates.

The coil should be of the return-bend type (square or slightly rectangular in form), and should have the pipes running east and west, with the coil on the south side of the building where it can receive the full sun effect all day long without shadows from the building itself, or from the adjacent obstructions such as trees or other structures. The coil should be placed as low as possible in relation to the storage tank level, such as on a porch roof, the roof of a one-story extension or, if necessary, even on the ground. Both the coil and the circulation lines should be designed to facilitate the circulation flow as much as possible, using long radius copper fittings or recessed galvanized iron fittings to match the materials of the coil, circulation lines, and tank. The coil should be inclined, as shown in Fig. 13, so that the north end is raised above the south end to secure an angle with the horizontal of about 53 deg. This will result in the inlet end of the coil being on the south side (or bottom), and the outlet end being on the north side (or top). This will satisfy conditions along the 30-deg N latitude, which includes the portions of Florida and Southern California where these heaters are most frequently used.

The hot box is usually constructed of wood on the four sides and bottom, and is insulated. Glass sash are placed over the top of the box, and the box should be constructed as air-tight as possible. The interior surfaces should be painted white to reflect the heat, while the coil should be painted black to absorb the heat. The box need not be deeper than necessary to house the coil and to protect it from the weather.

TABLE 12. SUGGESTED SOLAR HEATER DESIGN DATA\*

| DESIGN ITEM                             | BASED ON RATE OF 30 GAL PER DAY PER PERSON |     |     |      |      |      |      |      | BASED ON RATE OF 40 GAL PER DAY PER PERSON |     |     |     |     |     |     |      |
|-----------------------------------------|--------------------------------------------|-----|-----|------|------|------|------|------|--------------------------------------------|-----|-----|-----|-----|-----|-----|------|
|                                         | 1                                          | 2   | 3   | 4    | 5    | 6    | 7    | 8    | 1                                          | 2   | 3   | 4   | 5   | 6   | 7   | 8    |
| No. of Occupants in Residence           | 1                                          | 2   | 3   | 4    | 5    | 6    | 7    | 8    | 1                                          | 2   | 3   | 4   | 5   | 6   | 7   | 8    |
| Hot Water Used at Night, gal per person | 15                                         | 15  | 15  | 15   | 15   | 15   | 15   | 15   | 20                                         | 20  | 20  | 20  | 20  | 20  | 20  | 20   |
| Hot Water Used at Night, gal total      | 15                                         | 30  | 45  | 60   | 75   | 90   | 105  | 120  | 20                                         | 40  | 60  | 80  | 100 | 120 | 140 | 160  |
| Retained in Tank, 25 per cent, gal      | 4                                          | 8   | 11  | 15   | 19   | 23   | 27   | 30   | 5                                          | 10  | 15  | 20  | 25  | 30  | 35  | 40   |
| Tank Capacity Required, gal             | 20                                         | 40  | 59  | 75   | 94   | 113  | 130  | 150  | 25                                         | 50  | 75  | 100 | 125 | 150 | 175 | 200  |
| Hot Water Used During Day, gal          | 15                                         | 30  | 45  | 60   | 75   | 90   | 105  | 120  | 20                                         | 40  | 60  | 80  | 100 | 120 | 140 | 160  |
| Total Water to be Heated:               |                                            |     |     |      |      |      |      |      |                                            |     |     |     |     |     |     |      |
| Gal per 8 hr period                     | 35                                         | 70  | 104 | 135  | 169  | 203  | 235  | 270  | 45                                         | 90  | 135 | 180 | 225 | 270 | 315 | 360  |
| Gal per hour                            | 4.5                                        | 9   | 13  | 17   | 21   | 25   | 29   | 34   | 6                                          | 12  | 17  | 23  | 28  | 34  | 39  | 45   |
| Copper Coil Required:                   |                                            |     |     |      |      |      |      |      |                                            |     |     |     |     |     |     |      |
| Surface area, sq ft                     | 25                                         | 50  | 75  | 100  | 121  | 145  | 168  | 192  | 32                                         | 64  | 96  | 128 | 160 | 192 | 224 | 256  |
| Equivalent length 1 in. coil, ft        | 100                                        | 200 | 300 | 400  | 484  | 580  | 664  | 768  | 128                                        | 256 | 384 | 512 | 640 | 768 | 896 | 1024 |
| Box Size:                               |                                            |     |     |      |      |      |      |      |                                            |     |     |     |     |     |     |      |
| Area, sq ft                             | 25                                         | 50  | 75  | 100  | 121  | 145  | 168  | 192  | 32                                         | 64  | 96  | 128 | 160 | 192 | 224 | 256  |
| Width, ft                               | 4                                          | 6   | 7   | 8    | 9    | 10   | 10   | 11   | 4                                          | 6   | 8   | 9   | 10  | 11  | 12  | 12   |
| Length, ft                              | 6                                          | 8   | 11  | 12.5 | 13.5 | 14.5 | 16.5 | 17.5 | 8                                          | 10  | 12  | 14  | 16  | 18  | 19  | 21   |

\* Sun Effect and the Design of Solar Heaters, by H. L. Alt (A.S.H.V.E. TRANSACTIONS, Vol. 41, 1935, p. 131).

The addition, on the bottom of the box, of a light gage copper plate to which the pipe of the coil is soldered for good metallic contact, will add to the amount of heat received by the coil, due to the fact that this plate will receive all of the sun's rays which fail to directly strike the coil. The heat from this source is transmitted to the coil through the plate rather than from the heated air surrounding the coil. Otherwise, only part of the heat enters the coil, the balance being transmitted through the glass.

Design data given in Table 12 may be used with judgment in selecting the size of solar heater coil and box for a particular application. These data are based on consumptions of 30 and 40 gal of hot water per day per person.

### DOMESTIC HOT WATER BY HEAT PUMP

Hot water may suitably be obtained by using a heat pump installation. The hot water heater may be either a heat exchanger installed just ahead of the compressor of a heat pump installation, or may be a self-contained domestic-water heat pump.

Various designs of self-contained domestic water heat pumps are available, and one particular arrangement is shown in Fig. 14.

Hot water heating by means of a heat pump is not yet advisable where

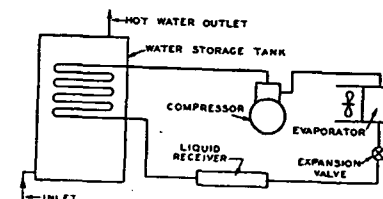


FIG. 14. HEAT PUMP ARRANGEMENT FOR HOT WATER SUPPLY

high water temperatures are desired. This is due to the fact that higher water outlet temperatures result in lower coefficients of performance.

For coefficients of performance of 4 or higher, the heat pump water heater may be more economical to operate than a conventional water heater.

Although the first cost of domestic hot water heat pumps is somewhat high, they have the advantages of eliminating products of combustion, odors and soot, and not needing a chimney. A further advantage is that they may be used for cooling purposes. With a coefficient of performance of  $2\frac{1}{2}$  to 3, water temperatures of 140 to 150 F may be obtained.<sup>5</sup>

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#### CHAPTER 50

### RESIDENTIAL SUMMER AIR CONDITIONING

Equipment Capacity Selection, Types of Equipment, Types of Application, Room Air Conditioners, Central Systems for Summer, Central Systems for Heating and Cooling, Location of Cooling Equipment, Noise, Air Distribution Methods, Operating Costs, Effects on Future House Design

IN RECENT years, summer air conditioning in residences has developed to the stage where it has become a major factor in the air conditioning field and has created a heavy interest among home-owners, builders, architects and business men. Residential cooling, particularly for the small home, received its initial impetus when equipment specifically designed for such purposes became available in the 1930's. Recently it has caught the public fancy resulting in a tremendous increase in the number of sales and installations.

The first installations were made by using the commercial and industrial methods as the estimating basis and did not prove as satisfactory as the installer or designer desired. Actually, the difference between estimating the residential summer air conditioning and commercial summer air conditioning loads is in the design temperature differences used, the type of internal load in the conditioned area, and the method of calculating equipment size.

#### EQUIPMENT CAPACITY SELECTION

With cooling, as with heating, the proper equipment capacity selection is that which, when properly installed, maintained, and operated, will satisfy the customer. Although at present an indoor design temperature of 75 F is used only on deluxe installations, it is felt that eventually this temperature will be used as the basis for design for both heating and cooling systems. At the present time, however, most summer air conditioning installations are designed on the basis of an 80 F indoor temperature. The outdoor design conditions commonly used in each locality are those listed in Chapter 13.

In calculating residential cooling loads, internal loads are not taken into consideration as much in domestic summer air conditioning as in commercial or industrial summer air conditioning. Lighting, electrical appliances, and so on, are not considered except in the cases where unusual loads are added to the conditioned area by means of certain types of appliances. These appliances, such as clothes dryers, and water heaters, should be vented to the atmosphere in order to limit their effect on the summer cooling load.

Although the methods of calculating the cooling load which are presented in Chapter 13 may be used for calculating residential cooling load, it has been found<sup>1</sup> that the load so calculated is much greater than that which is actually experienced in most residences. This is objectionable from at least two viewpoints: (1) it increases the capacity and consequently the

cost of the equipment installed, and (2) because of the increased size it results in less desirable humidity conditions within the residence.

A number of manufacturers, as well as several organizations, have been working on methods of calculating summer air conditioning loads for domestic applications. One of these is the method developed by the *National Warm Air Heating and Air Conditioning Association* in conjunction with the *Air-Conditioning and Refrigeration Institute*. This method is based on a load at a particular time of the day and takes into consideration the amount of solar radiation and heat gain due to the temperature difference between the conditioned area and the outside area on the assumption that the peak cooling load occurs from 3:00 to 4:00 o'clock in the afternoon.

Another method<sup>2</sup> evaluates the daily average cooling load on the design day rather than the maximum instantaneous heat gain. During the time the peak load occurs the room air temperature is allowed to rise from 72 F to about 78 F, thereby taking advantage of thermal storage in the structure and furnishings.

### TYPES OF EQUIPMENT

#### Low Side

Three types of low sides (the equipment that actually removes the heat from the conditioned space) have been developed for residential work as follows: (1) water-cooled coil, (2) chilled-water coil, and (3) refrigerated coils.

The water-cooled coil using water directly from the supply sources, such as city water or a well is the most simple type of installation. Cold water is circulated directly through the coil while air from the conditioned space is passed over the coil to remove heat and moisture. After the water has passed through the coil, it is wasted. To operate satisfactorily, an installation of this type requires water of sufficiently low temperature to chill the air enough to remove the desired amount of heat and moisture. Where a large supply of water at a cold temperature is obtainable, the water-cooled coil will operate with satisfactory results. As a general rule a water-cooled coil should not be used unless there is a supply of 52 F or colder water at the peak of the cooling season and in sufficient quantities to take care of the cooling load with a temperature rise of no more than 10 deg. Where water is not obtainable in sufficient quantities or at the required temperatures, it is necessary to chill the water to the desired temperature by using mechanical refrigeration. This is known as a chilled-water system.

In a chilled-water system, water is circulated through a closed circuit containing two coils. In one coil the water removes heat and moisture from the air in the conditioned space. In the other coil (water chiller) the heat is removed from the water by mechanical refrigeration. This type of system is called a duplex system in that the heat is picked up by chilled water and later removed from the water by means of a refrigeration system.

The third method of absorbing heat from the conditioned air is by means of direct evaporation of the refrigerant in a coil with the air to be conditioned passing over the outside of the coil surface. The heat is passed directly from the air into the refrigerant for removal.

#### High Side

The high side of a conditioning system, the section of equipment that removes the heat from the refrigerant and reclaims the refrigerant for further use in the system may be either the air or water-cooled type. The air-cooled high side is so constructed that the heat is removed from the

compressed or hot refrigerant by passing it into a cooling coil over which outside air (air taken from outside the conditioned area and returned to outside of the conditioned area) is circulated.

The major advantage of air-cooled equipment is that no water is required to accomplish the removal of heat from the refrigerant and only an electrical supply is needed. The disadvantage is that operating pressures are higher because of the inability to cool the refrigerant as much by air as by water. This results in an increase in electrical input to the compressor motor.

Water-cooled equipment can be of two types. In one type the water drawn from a well or from city mains is passed through the condenser of the high side and is allowed to flow to a drain, swimming pool, a wetted roof, or to other means of disposal. Where the water supply is sufficient and at low cost, this type of water-cooled unit is the better type installation because of lower equipment cost and lower operating costs and quieter operation. In a second type, if water is in short supply or is expensive, about 95 per cent of the cooling water can be reclaimed by evaporating sufficient water to rid the remaining water of the heat picked up in the condensing unit. This can be done by the use of an evaporative condenser or a cooling tower. These units are described in Chapters 35 and 37.

### TYPES OF APPLICATION

The common methods of cooling residences today make use of room air conditioners, central systems for cooling only, or central systems designed for both summer cooling and winter heating. The choice between these methods is largely one of cost and the relative heating and cooling loads.

### ROOM AIR CONDITIONERS

Window and cabinet-type air conditioning units can be used to cool small sections of a house.

The window units fit into an opening of a standard double-hung window and vary in size from  $\frac{1}{3}$  to 1 ton of cooling capacity. Room air is circulated through the unit where it is cooled, dehumidified, and filtered. No water pipes are necessary since the condenser is air-cooled; nor is a drain necessary inasmuch as the moisture condensed from the air is evaporated into the outdoor air. Electrically operated, the units can generally be plugged into existing electrical outlets although a voltage of 220 is required for units having one-horsepower motors.

Cabinet units stand on the floor and require an opening in the wall through which air to cool the condenser is brought in and discharged.

The room cooler is popular for use in offices or residences where the existing heating system does not contain provision for summer cooling or where cooling is not required in the entire space.

### CENTRAL SYSTEMS—SUMMER ONLY

In some areas there is little or no need for heating but there is a distinct need for summer cooling. Both air- and water-cooled package cooling units are available for such installations, ranging in size from one ton to at least 15 ton capacity. To install these units it is only necessary to make plumbing and electrical connections and add the duct work required to convey air to and from the conditioned space. These units can also be used to provide



central air conditioning to residences having heating systems which do not contain provision for attaching summer cooling equipment.

### CENTRAL SYSTEMS—HEATING AND COOLING

A summer air conditioner can be installed beside or near an existing warm-air furnace and can be connected to the duct work if the duct system has ample capacity for the cooling operation. If it does not, additional ducts and supply outlets will be required. The conditioner is about the same size or slightly smaller than a conventional forced warm-air furnace.

Year-round air conditioners require less space than a separate heating plant plus a separate summer conditioner. Usually the heating and cooling portions of a year-round air conditioner operate independently of each other. The air circulated by the fan passes through the cooling or heating portion of the equipment, only one of which is in operation at any one time.

Cool air supplied to rooms is usually 15 to 25 deg lower than the temperature of the rooms to be cooled. The size of the ducts of year-round air conditioning systems are often larger than those of equivalent winter heating systems because large quantities of cool air at 55 F to 65 F must be circulated through them. Duct systems should be designed and installed by competent engineers in accordance with such authoritative information as the design manuals of the *Air-Conditioning and Refrigeration Institute*<sup>3</sup> and the *National Warm Air Heating and Air Conditioning Association*.<sup>4</sup>

The cooled air is admitted to the room from the ducts through supply outlets. Since this air is colder, and therefore, heavier than the air within the room, it has a natural tendency to fall toward the floor. Unless the supply outlets are properly selected, located, and adjusted, the air distribution is likely to result in (1) a low velocity of cool air falling on the occupants, or (2) a high velocity stream of cool air striking a wall or other obstruction and splashing on the occupants. Research is being conducted to determine the most advantageous type and location of supply outlets.

The most commonly used outlets are registers with either fixed or adjustable vanes, and diffusers. Registers distribute the cooled air throughout the room. They are usually located either high or low in the sidewall or in the baseboard.

The diffuser type of outlet can be used in ceiling, wall, or floor. Different designs are available for each of these locations. The floor, baseboard, and sidewall diffusers blanket the walls with a curtain of cool air (or warm air in winter); the ceiling diffuser blankets the ceiling.

Air conditioning can be installed in homes having a hot-water heating system either by use of:

1. *Room units* resembling convectors and containing both heating and cooling coils. These units are used in place of the conventional radiator or convector. They can be installed in all rooms of the house to provide complete summer cooling, or they can be used in only one or two rooms. This arrangement is shown in Fig. 1.
2. A *split* system. The cooling coil is located in a duct through which air from the rooms is circulated, cooled, and returned to the rooms. The coil can be used for winter heating, or conventional radiators, convectors, or panels can be used to bring the heat to the rooms.

The cooling equipment is located in the basement or utility room near the boiler. Valves are provided so that the same piping system can be used to circulate heated water in winter and chilled water in summer. The piping must be insulated to prevent sweating when circulating cold water.

### LOCATION OF COOLING EQUIPMENT

The location of the summer cooling equipment will depend upon the type of unit. In a combination self-contained type unit, the location will depend upon accessibility to the duct system, the fuel supply, and the electrical supply. Too often, a heating or cooling unit is located by giving consideration to installation only, without considering the usability of the basement. This may result in breaking up the basement area to such an extent that it becomes practically useless for other purposes. In a remote type combina-

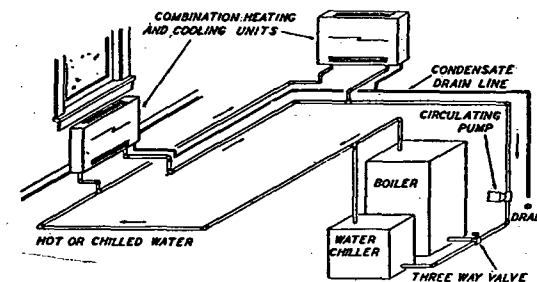


FIG. 1. COMBINATION SUMMER AIR CONDITIONING AND HOT WATER HEATING SYSTEM

tion unit, consideration must be given to the location of the condensing unit, whether it is located in the basement area or whether the unit is located in a remote area such as the garage breezeway. Preferences of the family and their habits of living must be given consideration so as to keep all space as useful as possible and still locate the equipment in such a place that it can do its intended job and be accessible.

### NOISE

One of the prime problems of domestic air conditioning is operating noise. Due consideration must be given to location of summer air conditioning equipment, with respect to areas under bedrooms or other rooms requiring very low noise levels. Equipment is often installed without due consideration to blower and duct sizes, with a resulting increase in noise level. Consideration should be given to the use of vibration absorbers in refrigerant and water lines, to anti-vibration padding under equipment, and to flexible duct connectors to isolate operating sounds.

### AIR DISTRIBUTION METHODS

Where cooling is installed with ducts and air outlets which serve the cooling function only, the practice and experience of comfort air conditioning for offices and commercial buildings apply directly to residential installation. Although cooling and heating by means of the same duct work and air outlets has been common practice in commercial and industrial applications, greater care must be taken in residential applications. It has been found that low air-flow rates are desirable for warm-air heating systems,<sup>5</sup> much lower than would be used for cooling systems. It is therefore recommended that in a residence located in a moderate or cold climate, provision be made for different air-flow rates for summer and winter. In warmer



climates, however, where air conditioning is the primary consideration, the summer air-flow rate may be used the year around.

The registers may be placed either in the high sidewall or in the perimeter location. For the high sidewall applications, it is necessary that the deflection of the air be different for summer than it is for winter to prevent the jet from dropping into the living zone (60 in. above the floor and below) where the velocity should be not greater than 35 fpm. For registers located at the perimeter of the residence,<sup>6</sup> it is not necessary to change the deflection from summer to winter.

The air distribution system should be designed for the largest air-flow rate which is to be used, as outlined in Manual No. 11<sup>4</sup> of the *National Warm Air Heating and Air Conditioning Association*. For small-pipe perimeter systems, it is necessary to have more outlets than for the larger duct systems. In some applications, it may be necessary to close off some registers during the winter so that adequate register-air velocities will be obtained. These registers would then be opened during the summer to give a sufficient number of outlets.

Recent investigations have shown<sup>7</sup> that the use of perimeter duct systems for air conditioning gives excellent results, and that objectionable air motion does not occur within the living zone except in the immediate vicinity of the registers. Care must be taken, however, to use only registers or diffusers that are specifically designed for perimeter application. This is necessary to permit the introduction of the air into the room in a pattern which does not cause drafts. Floor diffusers which distribute the air in a fan-shaped pattern along the wall or low sidewall diffusers which blanket the wall are recommended. For supply-air temperatures not more than 15 deg below room-air temperatures, diffuser face velocities of 500 fpm are recommended.<sup>8</sup> For supply-air temperatures 20 deg below room-air temperature, the diffuser face velocity should not be less than 700 fpm.

### OPERATING COSTS

The operating cost of residential cooling equipment during a particular summer depends on variables such as the amount of sunshine and rain, the number of abnormally hot or cool days, the efficiency of the equipment, and the local power rate. It is also influenced by human factors such as operation of equipment only during the hottest weather, opening windows at night<sup>9</sup>, and difference in preferred indoor temperatures. Nevertheless, it is important that lending agencies and prospective buyers of equipment be given a reasonably accurate estimate of the operating cost during normal summer weather and under usual operating conditions. Adjustments can then be made for any special conditions anticipated.

The basis of a method reported<sup>10</sup> is that the power cost  $S$  of residential cooling equipment, expressed in dollars, is predicted from the equation

$$S = \frac{RPT}{100} \quad (1)$$

where

$R$  = power rate, cents per kilowatt hour.

$P$  = average power input to the equipment over the season, kilowatts.

$T$  = predicted total operating time of equipment, hours.

Note: Symbols for Equations 1 and 2 are those used in paper.<sup>10</sup>

For a given application, the power rate is obtained from the local public utility. The average power input depends on the particular make of

equipment and condensing method, and consequently must be obtained from the manufacturer.

The operating time  $T$  to be used in Equation 1 is found from the equation

$$T = \frac{24HD}{C(t_m - 70)} \quad (2)$$

where

$D$  = number of cooling degree-days above 70, Fahrenheit.

$H$  = average hourly cooling load over the 24 hours comprising the design day, Btu per hour.

$C$  = average total cooling capacity (sensible plus latent) of equipment over the season, Btu per hour.

$t_m$  = design mean temperature = design outdoor dry bulb minus one half the daily range, Fahrenheit.

Tabulated values of cooling degree-days above 70 F for various localities are not yet available. Until they are, approximate values can be obtained from degree-day maps.<sup>11, 12</sup> Values of  $C$  must be obtained from the equipment manufacturer, whereas values of the daily range for computing  $t_m$  are given in the literature.<sup>13</sup>

It is emphasized that the value of  $H$  in Equation 2 is not the maximum instantaneous heat gain but the *average hourly cooling load over the 24 hours comprising the design day*. Consequently, it should be evaluated by a method similar to the one reported.<sup>2</sup> To facilitate application of the method, the original paper<sup>10</sup> contains charts from which values of  $T$  and  $S$  can be obtained directly.

If the evaporator fan cycles with the compressor, the power cost  $S$  also represents the total operating cost for air-cooled condenser applications. For continuous fan operation the value of  $T$  is subtracted from the number of hours in the cooling season to obtain the extra hours of fan operation. Equation 1 is then used with the appropriate value of  $P$  for the fan motor only, and the result is added to the power cost during compressor operation.

For water-cooled condenser applications the water cost, as determined from the operating hours, water rate and manufacturer's data on equipment water usage, is added to the power cost to obtain the predicted total operating cost.

### EFFECTS ON FUTURE HOUSE DESIGN

Air conditioning, like automatic heating, has brought about improved practice in residential construction, particularly in those regions where cooling is of primary importance. Although it is true that construction practices which reduce the heating load also reduce the cooling load, there are certain considerations which are unique in their effect upon the cooling load. Special attention must be paid to window orientation and means of shading the windows. South windows may be shaded by awnings or roof overhangs, but it is not practicable to shade large window areas having an east or west orientation except by exterior solar screening of some type. The use of insulation in the walls and ceiling of the residence will reduce the cooling load appreciably. In addition, attention should be paid to adequate ventilation of the attic. Double-glazed and weatherstripped windows, heat-absorbing glass, planned shade tree locations, and light colored exterior wall and roof surfaces, also help to reduce the cooling load.

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## CHAPTER 51

## SCHOOLHOUSE HEATING AND VENTILATING

General Considerations; Factors Affecting Design: Classrooms, Other Spaces, Government and Fire Safety Regulations, Economic Considerations; Systems in Use: Open Window, Gravity and Mechanical Exhaust, Forced Air, Unit Ventilators, Panel Heating; Maintenance and Operation

SCHOOL buildings present certain special problems due to diversity of use of various spaces, differing times of occupancy, recent trends in building construction, and additional sources of odors. A school is generally a composite building, containing classrooms, large public meetings rooms which also serve as teaching spaces, offices and administrative areas, health departments, locker rooms, toilet rooms, laboratories, shops, cafeterias, and miscellaneous other spaces such as corridors, stairways and service areas. The heating and ventilating requirements are different for each type of space.

## GENERAL CONSIDERATIONS

The uses of spaces in schools vary widely in normal operation. The usual classrooms, assembly rooms, lecture halls, auditoriums, and other similar areas have occupants of relative inactivity. Consideration must also be given to areas such as music rooms, laboratories, shops, basketball courts and gymnasiums where various degrees of activity are found. All of these areas have different temperature and ventilation requirements. Most state laws require relatively large glass areas in classrooms, thereby imposing a real heating problem upon the designer. The lower mean radiant temperatures make these rooms particularly susceptible to objectionable drafts which the heating and ventilating system should be designed to combat or overcome.

The areas having higher levels of activity will require lower temperatures and, due to the increase in body odor, should have relatively more ventilation.

A major aspect of time of use of the various spaces is the dual use of the building by the school and by the community, not only of the auditorium and gymnasium, which may be planned for physical segregation during the evening, but also of any of the classrooms or the cafeteria. The room used by the board of education may be in use at any hour or time, and may require air conditioning.

The type of construction and its effect on comfort and condensation must be considered. The tendency, particularly in the Southern States, to encourage the use of one-story schools with outside corridors and concrete slabs on the ground has introduced many new heating problems. This construction greatly enhances the use of natural or window ventilation because the rooms are equipped with high windows on one side, usually the north or northeast, and low windows on the opposite side. The amount of ventilation air is thus regulated by the adjustment of the windows.

In the extreme South there is some tendency to design schools with very light wall construction and to omit any wall insulation, thus producing a

wall having a low heat capacity to obtain a fairly rapid heat dissipation. This results in more comfortable conditions on warm sunny days, but also imposes a requirement for more heating capacity on cool cloudy days. The roof constructions for these buildings are also designed for low heat capacity, but do require insulation because of the extended period of sun exposure. The exposed surfaces should be light in color for maximum reflection, and the under surfaces must be arranged so that the ventilation will remove the heat which penetrates through the construction. All parts of the structure must avoid high heat retention so that the heat of the afternoon sun will not be released into the building during the following morning.

The time of use, number of occupants, temperatures required, and degree or quantity of ventilation to be provided should of necessity be studied for each space, and equipment provided to maintain proper conditions. A complete analysis should be made of the requirements, and methods should be adopted that will provide for as many of the following functions as are indicated to be necessary: heating, ventilating, cooling, odor control, humidity control (to prevent or limit condensation).

Schools are usually constructed only after permissive referendums, approved by the taxpayers. School districts are mostly local public enterprises under state regulation but operating more or less individually in raising funds by taxation for school construction and operation. Most school district boards of education consider one of their greatest problems that of having the citizens of their communities vote the necessary taxes. Most boards are very susceptible to criticism from their constituents for seemingly (if not actually) spending large sums of money for *luxury* items. This one consideration alone has been a great factor leading to economy in construction and design. Heating and ventilating design is still strongly influenced by this consideration.

It should also be remembered by the designer of heating and ventilating equipment for school buildings that such equipment requires maintenance. The maintenance required may vary from merely dusting and cleaning to wholesale replacement of parts. The trend of modern architecture to reduce *wasted* space is frequently over-emphasized, and causes the spaces wherein mechanical equipment is to be installed to be so classified and consequently inadequate or inaccessible. The designer should always bear in mind that lengthy repairs to heating and ventilating equipment are always considered expensive nuisances.

#### FACTORS AFFECTING DESIGN

Some of the factors affecting design are the type and use of classrooms, types of other spaces, governmental and fire safety regulations, and economic considerations.

##### Classrooms

The number of occupants and sudden changes in occupancy should receive adequate consideration. In departmentalized schools, rooms may be unoccupied for a period and then be filled to over-ideal capacity within a few minutes. All rooms should be at the desired temperature when the students enter at the start of the school day. They should maintain such temperature when an internal heat gain is suddenly introduced in the form of body heat and lights.

Lighting in a typical classroom can be the equivalent of at least 8150 to 10,000 Btuh, depending on the type of lighting. Maximum heat gain from

lighting will not coincide with maximum sun load, but the modern tendency is to keep at least the row of lights farthest from the window *on* in order to compensate for loss of illumination.

Because of the large glass areas, solar heat is usually the largest single item of heat gain. Classrooms usually have separate shades for tops and bottoms of windows. In the South sunshades are increasingly being provided in the building construction. These shades often take the form of horizontal louvers, particularly on south exposures, and are so arranged that little, if any, direct sun rays reach the glass surfaces. The louver windows on the south exposure are often shielded from the sun by an outside corridor. Tinted glass, heat reflective glass, and glass blocks arranged with light reflective prisms are used to some extent.

The orientation of these windows requires careful study in order to take the greatest advantage of the shading devices during the normal period of occupancy. Some serious consideration must be given to the direction of the prevailing wind during the school term. Where there is a wide variation of direction during the school months, provision should be made to take advantage of the changes in wind direction.

In all climates the problem of compensation for lighting loads, sun loads, and occupant loads imposes a variable demand on all heating and ventilating systems. These can only be compensated for by adequate thermostatic controls.

It should be noted that while the heat gains are not too much affected by the passage of the seasons the heat losses mentioned are for the design condition only.

Due to the fact that there is no sun load on cloudy days and that before schools opens in the morning there are no lights or occupants, none of the heat gains mentioned can be deducted from the required design load. It is very desirable to have a classroom at required temperature when school starts, but these loads must be compensated for by control of the heating and ventilating equipment or by manual adjustment of windows.

Humidity conditioning is typical of dense occupancy applications, except that larger than average areas of low temperature surfaces make failure to control in cold weather more serious. Even in a room with an ideal occupancy of about 25, an hourly moisture gain of almost 26,000 grains must be removed.

Odor control is also required of dense occupancy applications with the additional sources of wet coats and packed lunches, if brought. It is advisable to locate exhaust inlets or relief openings adjacent to coat racks. Where wardrobes are used, their doors are undercut, and these inlets should be located in the wardrobes. This problem is particularly acute in schools of the *campus plan* type.

For the foregoing reasons classrooms should be provided with heating and ventilating installations that will respond rapidly to rapid changes in load.

##### Other Spaces

Auditoriums, laboratories, shops, office areas, service areas, kitchens (cafeteria and home economics), janitor's closets, swimming-pool rooms, toilets and locker rooms, present problems that are typical of similar spaces in other types of buildings. Chemical laboratories in high schools usually are equipped with fume hoods and have storage rooms that should be adequately ventilated. Shops in high schools may have special require-

ments, such as dust-collecting systems in woodworking shops, explosion-proof exhaust systems in wood-finishing rooms, and underfloor exhaust gas conveying systems in automobile shops. Locker rooms and toilets may be used in connection with outdoor sports activities during the summer.

Gymnasiums require lower temperatures and adequate ventilation without drafts. Ventilating and heating systems should take into account the ability to divide the gymnasium in half by means of folding partition, if provided. High school gymnasiums are often furnished with collapsible bleachers, indicating a greater occupancy and higher levels at which drafts should be avoided. Combination gymnasium-auditoriums (*general purpose* rooms) and gymnasium-cafeterias (*eating space*) should be treated so as to meet the requirements of each use. Football uniform drying rooms present a special problem of drying and odor control.

*Listening* rooms (for listening to records), an adjunct to the library, are usually interior rooms and, because of sound transmission, must be sound-proofed as well as ventilated. Visual-aid rooms should receive careful attention in ventilating or air conditioning because of the necessity for excluding light during use.

Panel heating is frequently used in kindergarten floors, since so much of the activity in these rooms takes place on the floor.

The room used by the board of education for its meetings is often air conditioned even in the northern part of the country, and even when it is the only space so treated. This is necessary because the board works during all months of the year. This room should be ventilated as recommended elsewhere for *smoking* conditions.

### Governmental Regulations

Almost every state or territory, and in some cases counties, cities, and towns as well, as its own set of regulations governing the heating and ventilating of school buildings. Unfortunately, most of these regulations have not been coordinated through any one central source, and consequently they vary tremendously. Each designer of heating and ventilating installations for schools should completely familiarize himself with the regulations of the locality in which the building is to be built and satisfy these regulations.

The regulations usually specify the minimum requirements. The designer can refer to Chapter 6, Table 1, for recommended air changes, to Chapter 11 for other ventilation requirements, and to Chapter 13, Table 3 and page 278 for recommended air changes for various types of occupancy.

### Fire Safety Regulations

Many states have fire safety regulations which limit the routing and arrangement of ducts and vary the requirements of fire dampers. Most of these regulations are based upon the *National Board of Fire Underwriters'* Pamphlet No. 90 which covers the regulations for the installation of air conditioning, warm air heating, air cooling, and ventilating systems. All installations should be made in accordance with these requirements.

### Economic Considerations

School building program budgets are often extremely marginal, especially if a succession of increases in building costs have occurred since the appropriation was voted. Under such circumstances, the board of education, its architect, and its engineers, in order to get the school built, are not

infrequently forced to adopt courses of action that are obviously not the most desirable or the most economical over the life of the building. Needless to say, the design of the mechanical systems should be consistent with the budget. However, the board is entitled to know precisely what penalty it will be paying for each departure from the optimum design.

### SYSTEMS IN COMMON USE

There are several different methods of complying with the foregoing requirements. All methods are not acceptable in all states, but all methods have been used in one form or another in this country.

#### Open Window Ventilation

The term *open window ventilator* usually means that there is no mechanical or gravity ventilating equipment. Air movement is caused by opening one or more windows at the top and raising some windows at the bottom. Where classrooms have windows only on one side this is not very effective and cannot be recommended for any part of the country. When the classroom has windows on two sides, particularly when they are at different levels, satisfactory conditions can be maintained if the teacher acts as the thermostat. In climates where heating is required for a large percentage of the time, open window ventilation should not be used.

#### Gravity Exhaust Ventilation

This is the next step in producing satisfactory conditions. Exhaust grilles are placed in the ceiling or wall away from the windows, and are connected to exhaust ducts or plenum spaces connected to roof ventilators. Due to the differential pressure, air is exhausted through these ventilators. It is, of course, necessary to open the windows in order to replace the exhausted air and the heating system must be designed to heat the air as it enters the windows. Satisfactory air changes can be obtained by this method, but it usually results in objectionable drafts. This type of system is reasonably satisfactory in mild climates but cannot be recommended where the design temperature is lower than 10 F.

#### Mechanical Exhaust Systems

A reasonably satisfactory arrangement for any mild climate can consist of a mechanical exhaust system where motor driven exhaust fans are connected to the exhaust grilles as previously described. With this arrangement, the fans can be operated on a schedule depending upon the outside temperature. When windows are closed the replacement air is drawn from the corridor or is greatly reduced.

This method usually consists of providing direct radiation along the window wall of a space to be heated and ventilated, and providing some means of positively exhausting air from the space to obtain ventilation. To make up the exhausted air, the windows are usually opened. To minimize drafts from open windows they are constructed with inside hoppers or baffles at the bottom to cause the incoming air to deflect upward and avoid blowing directly on the room occupants at desk level. To provide sufficient heat for tempering the incoming air, the radiation is designed for the total of the normal transmission plus the amount needed to offset the chilling effect of the entering air. The air quantity calculated to require such tempering is assumed to be the same amount as the amount exhausted. The amount of air exhausted from each space is established in each state code. The control of these systems is usually all manual or a combination

of manual and automatic operation. When they are all manual, the exhaust fans are started from some remote point, the teacher controls the opening and closing of the windows, and the radiation is either left uncontrolled or is manually controlled, again by the teacher. When controls are *manual-automatic*, all of these functions are controlled as described except that an automatic valve is installed to control the steam or hot water flow to the radiation in an attempt to maintain room temperature conditions. With this system, odors and humidity are presumed to be controlled by increasing or decreasing the window opening to admit more or less outdoor air (up to the amount being exhausted). Cooling is provided in a similar manner. The results, while passable, are frequently haphazard, drafty, or stuffy, and depend to a great extent on the individual preference of the teacher.

### Direct Radiation

Many schools employ direct radiation or, in some cases, convectors or continuous fin-type heating pipes in connection with all of the systems of ventilation described. The radiation should be well distributed along the outside wall. Where possible a radiator should be placed under each window or made practically continuous. Unless thermostatic control is to be installed, hand valves must be provided so that each teacher can regulate the amount of radiation being used.

The automatic control of these types of heating systems can be arranged by zones (where rooms have common orientation and common use) with the disadvantage of attempting to find the room with the average conditions, or by separate control for each room.

### Forced Air Systems (Central Direct-Fired)

Since schools require forced ventilation in many areas, many different types of central systems have been utilized. All of the available warm air furnaces have been used. These systems for schools are divided into as many zones, each having its own control, as possible. In addition to the common central system similar to the type used in homes without zoning, the two types most frequently used in school building have been:

1. The type which takes a mixture of outdoor and return air through a fan and filter, and discharges it in either of two paths, over the surfaces of a warm air heater or through a by-pass around the heater, with mixing at the outlet of the heater to control the temperature of the air supplied to the rooms. This requires one supply duct from the heater to each room or zone so controlled.
2. The type of system known as the double duct system which has in it one main duct from the heater and another one which has by-passed the heater, both ducts being run parallel to each other to a point just behind the room supply outlet where dampers are installed to mix warm air and cool air to obtain the desired outlet temperature.

These systems usually operate with a fixed (manually variable) outdoor air quantity, the balance of the air being obtained by returning it from the spaces. The air is released into the spaces either through wall grilles, ceiling outlets, or outlets in the window sills discharging upward. Excess air is removed from the spaces, or rather is allowed to escape from the spaces in many instances, through relief grilles into the corridors, the corridors returning the air to central points where connections are made to the suction side of the central fan unit. In some states return of air is not permis-

sible. Under these conditions the excess air is removed from the building through either gravity ventilators or power exhaust fans.

There have been some installations in which the return air is allowed to escape from the room, through wall grilles, into the corridors and thus back to the unit. While this arrangement is less expensive, it is not recommended because in case of fire all the smoke is drawn through the corridors which should be kept clear for the escape of the students and teachers. Corridor return is prohibited in many states and cities.

Proper design should avoid drafts from cold wall surfaces and from duct outlets. Air discharged toward cold surfaces should be designed for a terminal velocity of 50 fpm at approximately one-quarter the distance from a cold wall. Grille outlet velocities in excess of 600 fpm under 9 and 10 ft ceilings are likely to cause drafts at some points in the occupancy zone.

### Forced Air Systems (Central Steam)

In these systems the air supplied for ventilation is tempered by automatically controlled steam coils and the normal heat loss for each room is supplied by direct radiators or convection. Provision is made for exhaust equal to the amount of outdoor air supplied. There are many variations of these systems, and they may include any features of central systems described in Chapter 30. Hot water may also be used as the heating medium.

This type of system can also be designed to provide the entire heating requirement without using any direct radiation. This arrangement is quite satisfactory, but must be controlled for zones of similar occupancy which have exactly the same orientation. Where used as a two-duct system as described under Forced Warm Air Systems in preceding section, much more satisfactory results can be expected.

### Unit Ventilator Systems

Unit ventilators are used for supplying heat and ventilation for individual classrooms. These units and their controls are described in Chapters 25 and 39. They can be combined or furnished with storage cabinets, book shelves, extensions for additional direct radiation, and extended grilles to discharge upward along the window sills.

As in previous systems described, the excess air must be provided a means of escape.

### Panel Heating Systems

A number of schools have employed panel heating of various designs. It is particularly adaptable in the *slab-on-ground* type of school to overcome the cold floor. It is also quite adaptable to the *open corridor* type of school using natural or window ventilation in the warmer climates. In the cold climates it should be augmented by a tempered-air ventilating system as previously described.

Design data are given in Chapter 24, but the designer must include ample thermostatic control which employs some means of varying the water temperature in inverse ratio to the outside temperature. With well-insulated walls and ceilings this feature usually results in an appreciable anticipation of the heating requirements. Several control systems are outlined in Chapter 39. Individual room control is desirable but not mandatory. A separate zone control for each exposure and for each floor is absolutely necessary for satisfactory results.

When coils are installed in the floor slab, these systems must be operated continuously (day and night). Night setback is not desirable, but when used it must be placed on the room thermostats and the setback must not exceed 10 deg. Generally room temperatures, read on wall thermometers placed 60 in. from the floor, can be one to two deg lower than with other types of systems for equal comfort.

Floor temperature must not exceed 85 F on design days except that a perimeter band, not exceeding 15 in. from the walls, may have a surface temperature of 100 F. Floor panels should not be expected to warm the large volumes of air required for school ventilation, and for this reason a tempered air supply is required in all except mild climates.

### MAINTENANCE AND OPERATION

Controls, boilers and combustion equipment, fans and mechanical heating devices, traps and valves, all need attention at least annually. Every designer must use extreme care in selecting equipment that will require a minimum of attention, and see that it is accessible for service.

While school custodial forces may be competent, they frequently have more work than can be handled during normal working hours. Unusual maintenance problems may therefore result in deterioration of equipment and systems. While first cost is important, final selection of equipment should not be made without consideration of the overall cost which includes maintenance and service.

## CHAPTER 52

### INSTRUMENTS AND MEASUREMENTS

Temperature Measurement, Pressure Measurement, Air Flow Measurement, Air Change Measurement, Humidity Measurement, Heat Transfer Through Building Materials, Evaluation of Thermal Environment, Combustion Analysis, Smoke Density Measurements, Determination of Air Contaminants, Sound and Vibration Measurements

**H**HEATING and air conditioning engineers and technicians require instruments for both laboratory and field use. Somewhat more precision is attainable and essential in the laboratory, where research and development are undertaken, than in the field, where acceptance and adjustment tests are conducted. Some instruments have attained an adequate state of development, while others fall far short of the desirable. For instance, temperatures can now be measured readily with ample accuracy for most purposes, while a convenient and precise method for determining or comparing the dustiness of atmospheres is lacking, and improvement in existing hygrometers and humidity controllers is essential.

Codes and standards covering different types of heating and air conditioning devices and apparatus have been promulgated by various authoritative organizations, and instruments essential for performance or compliance testing are enumerated in the relevant publications.<sup>1, 2, 3, 4</sup> The present purpose is to discuss the use and characteristics of the more important instruments.

#### TEMPERATURE MEASUREMENT<sup>5, 6</sup>

##### Thermometers

Any device capable of indicating temperature is a thermometer, but in common usage the term *thermometer* without qualification has come to signify the ordinary mercury-in-glass temperature indicating device. This type has a useful range from -40 F, the freezing point of mercury, to about 1000 F, at or near which the glass usually softens. Lower temperatures can be measured with alcohol-filled thermometers for which the range is about -94 F to +248 F. The better thermometers have their scales, either Fahrenheit or Centigrade, etched with acid into the glass which forms their stems. The probable error for etched stem thermometers is plus or minus one scale division, and calibration is desirable for much test work. Thermometers are calibrated during manufacture at not less than two temperatures—the freezing and boiling points of water—and calibration is often accomplished with the instrument completely immersed in a bath at the known temperature. The intervening scale divisions are then applied to the stem. When such a thermometer is used with the stem incompletely immersed, a correction known as the stem correction is neces-



sary for accurate measurements, and its magnitude is usually computed by means of the following formula:

$$K = 0.00009 D (t_1 - t_2) \quad (1)$$

where

$K$  = correction to be added, Fahrenheit degrees.

$D$  = number of degrees on the thermometer scale which are not immersed.

$t_1$  = temperature indicated on the thermometer, Fahrenheit.

$t_2$  = temperature of the non-immersed mercury column, Fahrenheit.

0.00009 = difference in the coefficient of expansion of the mercury and glass.

When a thermometer is used in a liquid or in air or gas near room temperature, the effects of radiation can often be ignored, but when the temperature of hot air or gas is desired, means are usually provided for minimizing the effect of radiation.<sup>7</sup> These include bright metallic shields around the thermometer bulb, and the use of aspirated thermometers in which a stream of the air or gas is drawn at considerable speed across the bulb and increases the influence of the gas temperature on the thermometer indication. In any case, to prevent errors in temperature measurements, there should be ample circulation so that the thermometer will indicate a true temperature of the medium under observation, and ample time should be allowed for the thermometer to reach the same temperature as the medium. In reading a thermometer the eye should be at the same level as the top of the liquid to avoid parallax.

Industrial-type thermometers are available for permanent installation in pipes or ducts. These instruments are fitted with metal guards to prevent breakage, and are useful for many purposes. However, the considerable heat capacity and conductance of the guards or shields prevent such thermometers from following closely the fluctuations in a medium of varying temperature.

### Thermocouples

When two wires made of dissimilar metals are joined by soldering, welding or merely by twisting, a thermocouple or thermo-junction is formed. An electromotive force, which depends upon the temperature of the junction, is found to exist between the wires. When the wires are joined at two points a thermocouple circuit is formed. If one junction is kept at a temperature different from the other, an electric current flows through the circuit due to the difference in emf developed by the two junctions. This phenomenon is employed for temperature measurements in thermocouple systems, one junction being ordinarily kept at a constant temperature, as in an ice bath, while the other junction is placed at a point at which it is desired to observe the temperature. In practice it is desirable to utilize emf to indicate temperature because, at small or zero current flow, the resistance of the circuit is unimportant. A high resistance millivolt meter is useful in some cases but the potentiometer yields better results. In the potentiometer the electromotive force generated by the thermocouples is balanced against an electromotive force from the battery so that observations are made with no flow of current through the thermocouple circuit. A conventional arrangement is illustrated in Fig. 1. The thermocouple leads A-B are so connected that their polarity opposes that of battery C. If the position of E on the graduated slide wire rheostat DF is adjusted until galvanometer G shows no current flowing, resistance DE will indicate directly the voltage generated by the thermocouple. In order to calibrate

the instrument, switch S is thrown over to the standard cell circuit while rheostat R is adjusted so that the galvanometer shows zero current. Battery C then exerts the known voltage of the standard cell at DH.

The act of adjusting rheostat D-F (Fig. 1) for zero current flow is known as balancing the potentiometer. Automatic self-balancing instruments of both the indicating and recording types are on the market. They usually contain an automatically compensating cold junction to avoid the use of an ice bath, and special thermocouple wire is furnished with them from the factory.

The choice of materials for thermocouple wire is determined by the range of temperature to be measured, the protection from corrosion afforded the couple, and the precision and service life required. In general, copper *vs.* constantan is suitable for temperatures up to 700 F, iron *vs.* constantan up to 1500 F, and chromel *vs.* alumel up to 2200 F. Higher temperatures re-

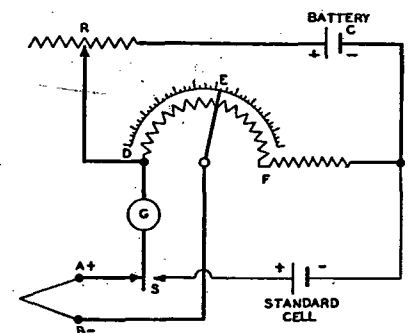


FIG. 1. BASIC CIRCUIT AND CONNECTIONS FOR THERMOCOUPLE AND POTENTIOMETER

quire the use of noble metal thermocouples (platinum *vs.* platinum-rhodium). In addition to the higher initial cost of a noble metal couple, it does not develop as high an emf as the base metal couples do. Impurities make large differences in the performance of thermocouple wires and for this reason calibration of samples from each spool of wire is essential for precise work. Data on wire can usually be obtained from the manufacturer.

With a suitable potentiometer, small wires serve as well for thermocouples as large ones, and the fineness of the wires is limited only by consideration of mechanical strength and convenience in handling. Small couples respond more promptly to changes in temperature and are less affected by radiation than large ones. Heavy gage couples, however, are necessary for high temperature work where corrosion of the wire is a problem. For use in heated air or gases, thermocouples are often shielded,<sup>8</sup> as are thermometers, and aspirated thermocouples are sometimes used. An arrangement has been described for avoiding error due to radiation. It involves several thermocouples of different sizes, the true temperature being estimated by extrapolation of readings to zero diameter.<sup>9</sup>

By the use of thermocouples, temperatures at remote points may be indi-



cated or recorded on conveniently located instruments; average temperature may be readily obtained by connecting several couples in parallel or in series; and temperatures may be obtained within thin materials, narrow spaces, or otherwise inaccessible locations.

Thermocouples in series with every alternate junction maintained at a common temperature will give an emf which, divided by the number of couples to give the average emf<sup>10</sup> per couple, may be used to find the average temperature. This series arrangement of thermocouples, often called a thermopile, can have extreme sensitivity and is useful in detecting very small changes in temperature.

Thermocouples in parallel, having the similar metals of a number of couples connected together and run to a common cold junction, will cause an indication on a potentiometer which is the true average emf only if the electrical resistances of the parallel junctions are the same.<sup>10, 11</sup>

Temperatures of surfaces below red heat are difficult to determine by any other means than thermocouples. For this purpose, a thermocouple of fine wires is preferable to minimize the possibility of error due to the conduction of heat along the wires. It may be attached to a metal surface in any of several ways. For permanent installations, soldering, brazing, or peening may be desirable. A small hole is drilled for the peening operation; the thermocouple is inserted and the metal is peened to retain it. The fact that the thermocouple is in electric contact with the surface is unimportant in usual circuits. For temporary arrangements, couples may be attached by means of surgical or cellophane tape. For many boiler or furnace surfaces, furnace cement serves very well. The thermocouple may be attached by means of the cement when the surface is cold, and must be treated gently and usually supported until the cement dries, due to heat, and hardens—after which it has ample strength. It is good practice to use as little cement as possible, and also to plaster the wires to the surface for an inch or so from their junction to avoid errors due to heat conduction along the wire. Electric insulation between the wires should be perfect except at the junction since, otherwise, the indicated emf will be between those existing at the junction and at the short circuit.

### Resistance Thermometers

Resistance thermometers depend for their operation upon the change of electric resistance of metal with change in temperature. The resistance generally increases with rising temperature. Their use largely parallels that of thermocouples, although readings tend to be unstable above 950 F. Two-lead temperature elements are not recommended, since they do not permit correction for lead resistance. Three leads to each resistor are necessary to obtain consistent readings.

A typical circuit used by several manufacturers is shown in Fig. 2. In this design a differential galvanometer is used, in which coils L and H exert opposing forces on the indicating needle. Coil L is in series with the thermometer resistance AB; and coil H is in series with the constant resistance R. As the temperature falls, the resistance of AB decreases allowing more current to flow through coil L than through coil H. This causes an increase in the force exerted by coil L, pulling the needle down to a lower reading. Likewise, as the temperature rises the resistance of AB increases, causing less current to flow through coil L than through coil H. This forces the indicating needle to a higher reading. Rheostat S must be adjusted occasionally to maintain a constant flow of current.

As compared to the thermocouple, the resistance thermometer does not require a cold junction, and it can be simply scaled for more accurate measurements; but, generally because of its construction it is more costly and is apt to have considerable lag. It gives best results when used to measure steady or slowly changing temperature. For accurate results the entire thermometer coil must be exposed to the temperature to be measured.

### Pyrometers

The pyrometer is the usual instrument for measuring high temperatures such as those of incandescent bodies or furnace interiors. There are two types. In the radiation pyrometer the radiant energy from an observed surface falls on a thermopile, and the emf generated by the pile, measured

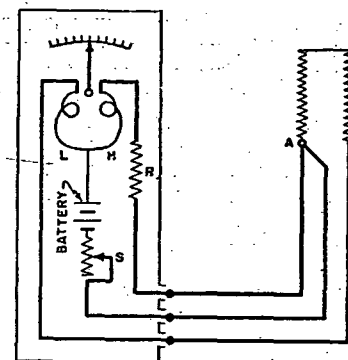


FIG. 2. TYPICAL RESISTANCE THERMOMETER CIRCUIT AND CONNECTIONS

by a galvanometer or potentiometer, is an index of the surface temperature. With the optical pyrometer a narrow spectral band, usually red, emitted by the surface, is matched visually with the filament of a special electric lamp. The emf necessary to cause the filament to match the surface in brightness is the index of the temperature of the surface. Pyrometers are calibrated by means of various metals with known melting or freezing points. Portable as well as laboratory models are manufactured.

### Color Indicating Crayons

Crayons are available, the marks of which change color or melt at specified temperatures. Such crayons have been sold in boxes covering the range from about 100 F to about 800 F in 100 deg steps, with a precision of some 10 deg. They are a rough but convenient means of determining temperatures, and of locating isothermal lines on surfaces below red heat.

## PRESSURE MEASUREMENT

### Pressure Gages

The Bourdon is the most common type of pressure gage, and its appearance probably is familiar to any one having an acquaintance with power plants or laboratories. The essential element of such a gage is the Bourdon

tube, a metal tube of oval cross-section curved along its length to form almost a complete circle. One end is closed and the other is connected to the vessel in which the pressure is to be measured. With an increase of pressure, the tube tends to straighten, and vice versa. The resulting motion of the closed end is communicated by suitable linkages to a needle moving over a graduated dial. If the range is above about 20 psi, such gages are usually calibrated by means of a *dead weight tester*, whereby known pressures are produced in a fluid by imposing known weights on a piston of known area. Gages are commonly set to read accurately at or near the pressure of probable use. Gages of several different types or qualities are available on the market.<sup>12</sup> Suction gages and pressure gages with ranges below about 20 psi are ordinarily calibrated against mercury manometers.

### Manometers

The manometer is a simple and useful means for measuring partial vacuum and low pressure. It is, moreover, a primary instrument; it does not require calibration, and it is often used as a standard for the calibration of other instruments. It is so universally used that both the inch of water and the inch of mercury have become accepted units of pressure measurement. In its simplest form, the manometer consists of a U-shaped glass tube partially filled with a liquid. A difference in height of the two fluid columns denotes a difference in pressure in the two legs, which is proportional to the difference in height.

For converting manometer readings into other pressure units, certain proposed standard factors are applicable for precise work. These are based on a standard gravitational acceleration of 32.1740 ft per (sec) (sec) and are as follows:

$$\begin{aligned} 1 \text{ Standard Atmosphere} &= 14.696 \text{ lb per sq in.} = 29.921 \text{ in. mercury at } 32^\circ \text{ F} \\ &= 33.96 \text{ ft water column at } 68^\circ \text{ F} \end{aligned}$$

For most ordinary purposes, the following figures are of ample accuracy:

$$\begin{aligned} 1 \text{ Atmosphere} &= 14.7 \text{ lb per sq in.} = 29.9 \text{ in. mercury} \\ &= 34.0 \text{ ft (408 in.) water column} \end{aligned}$$

Manometer tubes should be chemically clean. The bore is not important, except insofar as it affects the meniscus through wetting or surface tension. Bores of at least  $\frac{1}{8}$  in. for rough, and  $\frac{1}{4}$  in. for more precise, measurements are recommended. Liquids other than water are sometimes used for low pressure measurement and, when this is done, the readings must be corrected for the density of the fluid used.

For measuring pressure differences of a few inches of water, or less, U-gages are often set at an angle for scale amplification. In many gages of this type, commonly termed draft gages or inclined manometers, only one tube of small bore is used and the other leg is replaced by a reservoir. The scale is calibrated to read in inches of water, and it is necessary to use a fluid having the same gravity as that for which the gage was originally calibrated, or to apply a correction if another fluid is used. Such gages may be checked one against another. For more accurate calibration the gage may be checked against a micromanometer or a calibrating device known as a hook gage.<sup>13</sup> The accuracy of a draft gage is dependent on the slope of the tube, and consequently the base of the gage must be leveled carefully. It is not desirable to use a slope of less than 1 in 10. Where pressures are read under extreme conditions of temperature, and calibration is possible only at normal temperature, it is necessary to correct for the change in density of the

liquid in the manometer.<sup>14</sup> For measuring low pressure differences to within 0.001 in. of water, very sensitive micromanometers are available, such as the Illinois or Wahlen, the Meriam, the Trimount, and the Emswiler.<sup>15, 16</sup>

When using a manometer or other pressure gage for measuring air flow, by means of orifices, the type of duct openings used for manometer connections and their location are important. Where velocities are low, as in some plenum chambers, or where the flow is free of large eddies and parallel to the walls of a duct, a drilled hole cleared of burrs and at right angles to the stream, is satisfactory.<sup>17</sup> For higher velocities, it is common practice to provide four holes or taps around the periphery of the duct. Diamet-

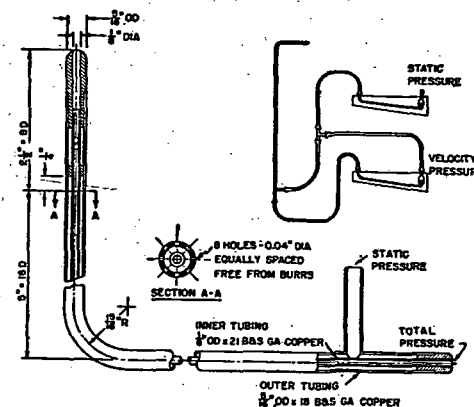


FIG. 3. STANDARD PITOT TUBE

rically opposite pairs of taps are connected together, and then such pairs are manifolded together.

An alternate method involves the use of the Pitot tube, shown in Fig. 3. This instrument should be pointed up-stream, parallel with the air flow. Where the flow is not axial or parallel to the side walls of the duct, a very close approximation of the static pressure and the flow direction can be obtained by a Fechheimer tube.<sup>18</sup>

### Barometer

The simplest and earliest type of barometer consists of a glass tube somewhat more than 30 in. long filled with mercury, and inverted in a cup partially filled with mercury. The height of the mercury column in the tube above the mercury surface in the cup is a measure of the existing atmospheric pressure, except for the slight pressure of the mercury vapor in the space above the mercury in the tube. This can ordinarily be ignored.

Elaborate mercury barometers, fitted with vernier scales, are available. For precise work, corrections must be made for the thermal expansion of the mercury and of the scales.<sup>19</sup> The instruments are usually calibrated for 32 F mercury and 62 F scale temperature, and the correction

C to be subtracted from the observed barometer's height is obtained by means of Equation 2.

$$C = \frac{h(t - 28.630)}{(1.1123t - 10978)} \quad (2)$$

where

C = correction to be subtracted, inches of mercury.

h = observed height, inches of mercury.

t = observed temperature of the barometer, Fahrenheit degrees.

Standard atmospheric pressure at sea level is 29.921 in. Hg, and since normal atmospheric pressure decreases about 0.01 in. Hg for each 10 ft increase in elevation, it is important to make a correction if the elevation of the barometer is not that of the test apparatus. In many cases the barometric reading may be obtained from a nearby Weather Bureau Station, in which case inquiry should be made as to whether the value is for station or sea level pressure.

Atmospheric pressure may also be measured by an aneroid barometer which is easily portable. In this type, variations in atmospheric pressure deflect the thin surface of a sealed diaphragm capsule. Most commercially available aneroid barometers are not as accurate as the mercurial type, and the best require occasional recalibration. Open-scale aneroid barometers are more expensive than common mercurial barometers. Most of the pressure gages used in engineering work indicate gage pressures, that is, the difference between the pressure being measured and the atmospheric pressure. Such pressures are called gage pressures. Absolute pressure may be obtained by adding barometric pressure and gage pressure algebraically.

### AIR FLOW MEASUREMENT

The theory of various means for measuring the flow of fluids is discussed in Chapter 4, Fluid Flow. Heating and air conditioning engineers are called upon to measure the flow of air more often than that of other gases, and usually the air is measured at or near atmospheric pressure. Under this condition, the air can be treated substantially as an incompressible fluid which implies that simplified formulas can be used with sufficient accuracy for the solution of many problems.<sup>20</sup>

#### The Pitot Tube

The construction of the Standard Pitot Tube<sup>13</sup> is shown in Fig. 3. The formula for velocity used in conjunction with it, is as follows:

$$V_m = 1096.5 \sqrt{\frac{h_{aw}}{\rho}} \quad (3)$$

where

$V_m$  = velocity, feet per minute.

$h_{aw}$  = velocity pressure (Pitot tube manometer reading), inches of water.

$\rho$  = density of air, pounds per cubic foot.

Since the velocity in a duct is seldom uniform across any section, and since a Pitot tube reading indicates a velocity at only one location, a *traverse* is usually made to determine the average velocity so that the flow can be computed. Suggested Pitot tube locations for traversing round and rectan-

gular ducts are shown in Fig. 4. In general, the velocity is lowest near the edges or corners, and greatest at or near the center. For this reason a large number of readings should be taken (in the case of round ducts not less than 20) along two diameters at centers of equal annular areas. In rectangular ducts the readings should be taken in the center of equal areas over the cross-section of the duct. The number of spaces should not be less than 16, and need not be more than 64. When less than 64 are taken, the number of equal spaces should be such that the centers of the areas are not more than 6 in. apart. In determining the average velocity in the duct from the readings given, the calculated individual velocities or the square roots of the velocity heads must be averaged. It is incorrect to use the average

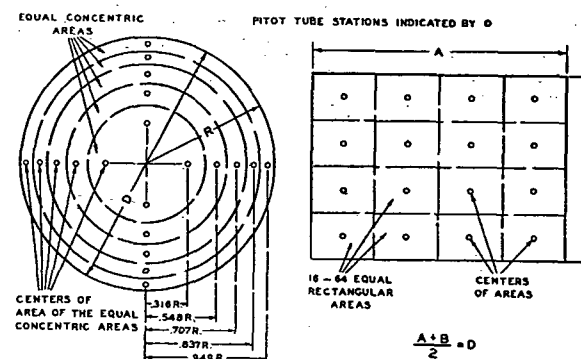


FIG. 4. PITOT TUBE TRAVERSE FOR ROUND AND RECTANGULAR DUCTS

velocity head for this purpose. Pulsating or disturbed flow will give erroneous results and therefore, if possible, the Pitot tube should be located at least  $7\frac{1}{2}$  diameters down-stream from a disturbance such as that caused by a turn; or a criss-cross type of flow straightener should be installed in the duct  $1\frac{1}{2}$  diameters ahead of the Pitot tube.<sup>13</sup> Flow straighteners do not equalize flow velocity across a duct. They merely serve to improve the precision of measurements. Equalization can be effected, if desirable, for measuring purposes by the use of wire netting, perforated plates or cloth screens across the duct.

Many forms of Pitot tubes, other than the one described, have been used and calibrated.<sup>21</sup> A double-ended tube,<sup>22</sup> one end pointing down-stream, and one up-stream, is sometimes used for low velocities, but it should be carefully calibrated for accurate results. A special form of this tube design consists of two straight  $\frac{1}{8}$  in. tubes soldered together, closed at the end, and with a 0.04 in. hole in each tube opposite the line of contact. This tube is useful in exploring velocities in exhaust inlets, such as hoods placed around grinding wheels. To meet special conditions, different sized Pitot tubes which are geometrically similar to the standard tube can be used.

#### Plate Orifices

Application of the Pitot tube is often inconvenient when velocities are low, because the resultant velocity pressures become so small that extraordinary means are necessary for measuring them. In addition, velocity

surveys of the whole cross-sectional area of a duct are inexpedient when numerous test runs are in prospect. Chiefly for these reasons orifices are favored for much test work. There are two types: the plate orifice and the shaped orifice or nozzle. Plate orifices are simple to construct and convenient to use, in that a frame can be made to support them in the duct such that one can be removed and another inserted when it is desirable to use an orifice of a different size.

### Formulas for Orifices

In the heating and air conditioning fields it is usually convenient to obtain orifice pressure drops in inches of water column, temperatures in Fahrenheit degrees and barometric pressure in inches of mercury. The air flow is usually desired in cubic feet per minute at the existing condition, so that velocities in various ducts can be computed, and in pounds per hour so that computations of heat transferred by the air can be based on weight, temperature change and specific heat. Equation 4 is applicable.

$$Q_M = 5.2KYD^2 \sqrt{\frac{T_i}{B_i} h_w} \quad (4)$$

where

- $Q_M$  = air flow, cubic feet per minute.
- $K$  = orifice coefficient.
- $Y$  = expansion factor, see Fig. 5.
- $D$  = orifice diameter, inches.
- $d$  = pipe diameter, inches.
- $T_i$  = temperature of air at orifice, Fahrenheit, absolute.
- $B_i$  = absolute pressure ahead of orifice, inches of mercury.
- $B_a$  = absolute pressure after orifice, inches of mercury.
- $h_w$  = pressure drop through orifice, inches of water.

As most laboratories are less than 1000 ft above sea level, precision is adequate in many cases if standard atmospheric pressure, 29.92 in. Hg, is assumed. Equation 4 then becomes

$$Q_M = 0.95 KYD^2 \sqrt{T_i h_w} \quad (5)$$

After the flow in cubic feet per minute is determined, it can be expressed in pounds of air per hour by means of the relation

$$W = 60 \frac{PQ_M}{RT_i} \quad (6)$$

- $P$  = pressure, pounds per square inch, absolute.
- $R$  = 53.3, the gas constant for air.
- $T_i$  = temperature of the flowing air, Fahrenheit, absolute.

The thin-plate square-edged orifice often has a discharge coefficient  $K$  near 0.60. The exact value depends on the location of the connections, the pressure drop, the diameter ratio of orifice to pipe, and the sharpness of the edge.<sup>23, 24</sup> Other information on orifices and their use is contained in Chapter 4, Fluid Flow.

Shaped orifices or nozzles have the advantage, if well made, that their discharge coefficients are close to unity so that the probability of large errors is less. Orifices of this type have been adopted for several specific

purposes, and designs are described in the Unit Heater Code<sup>1</sup> and Unit Ventilator Code,<sup>2</sup> and in A.S.R.E. Circular 13<sup>3</sup> entitled Standard Methods of Rating and Testing Air Conditioning Equipment. In some instances nozzles are used in multiple so that the capacity of the testing equipment can be changed by shutting off the flow through one or more nozzles. An apparatus designed for testing the air flow and capacity of air conditioning equipment is described by Wile<sup>25</sup> in an article in which pertinent information on nozzle discharge coefficients, Reynolds numbers, and the resistance of perforated plates is also presented. Such apparatus in some laboratories is commonly referred to as a *code tester*.

The Venturi meter is like the nozzle, except for the addition of a downstream transition section that reduces the pressure drop through the measuring apparatus.

In some cases air velocity through a duct, heater coil, or heating unit may

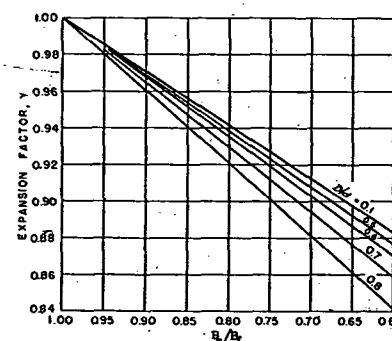


FIG. 5. EXPANSION FACTOR FOR AIR AND OTHER DIATOMIC GASES APPLICABLE TO FLANGE, RADIUS AND VENA CONTRACTA TAPS

be most conveniently estimated by computation from the heat given up by the coil, and the temperature rise (measured by thermocouples) of the air passing through. It is essential to have a uniform flow over the entire inlet and outlet of the heater at the plane of temperature measurement.

### Propeller or Revolving Vane Anemometer

The propeller or revolving vane anemometer consists of a light revolving wind-driven wheel connected through a gear train to a set of recording dials that read the linear feet of air passing in a measured length of time. It is made in various sizes, 3 in., 4 in., and 6 in. being most common. Each instrument requires individual calibration. At low velocities the friction drag of the mechanism is considerable. In order to compensate for this, a gear train that overspeeds is commonly used. For this reason the correction is often additive at the lower range and subtractive at the upper range, with the least correction in the middle range of velocities. Most of these are not sensitive enough for use below 200 fpm. Anemometers of this type are practically standard for wind measurements, and may be used in large

ducts where the air flow is not seriously altered by the presence of the instrument itself.

### Deflecting Vane Anemometer

The deflecting vane anemometer consists of a pivoted vane enclosed in a case. Air exerts a pressure on the vane as it passes through the instrument from an up-stream to a down-stream opening. The movement of the vane is resisted by a hair spring and a damping magnet. The instrument gives instantaneous readings of directional velocities on an indicating scale. With fluctuating velocities, it is necessary to average visually the swings of the needle to obtain average velocities. This instrument is very useful for studying motion of the air in a room,<sup>26</sup> and in locating objectionable drafts. Various attachments are available, such as the double tube arrangement for determining velocities in ducts, and a device for measuring static pressures. Each instrument, and the attachments for it, must receive individual calibration. For determining average velocity in a duct, it is necessary to *traverse* the duct as is done when using the Pitot tube.

### Measurement of Velocities at Inlets and Outlets of Ducts

In the field it is often desirable to make volume measurements at the face of the supply openings. It is rare to have access to the interior of duct sections where the flow is sufficiently uniform for measurement. For accuracy, the instrument and its application should be checked on a similar approach and grille in the laboratory before use in the field.

Tests have shown that the propeller type anemometer can be used successfully on most of the common types of supply grilles.<sup>27, 28</sup> The core area is divided into equal squares, and the anemometer is held against the face of the grille for the same length of time in each. To obtain the air volume in cubic feet per minute, the average corrected velocity in feet per minute thus obtained is multiplied by the average of the gross and net free area of the grille (core) in square feet.

On exhaust openings, the anemometer traverse is made as described previously. The air volume may be determined by multiplying the corrected velocity in feet per minute by the gross core area of the grille in square feet, and by a coefficient for average conditions of 0.85.<sup>2</sup>

When a propeller type anemometer is held in a stream of varying velocities, it tends to indicate higher than the true average, that is; the speed of the propeller is nearer to the top velocity in its area than it is to the minimum velocity. This is the main reason for the large difference in ratings of unit ventilators by the anemometer method, and by air volume measurements in a duct approach to the inlet.<sup>30</sup>

Anemometers can be used within their range at the face of supply grilles when properly applied. In principle, it is a case of finding the velocity at many points, and using the average thus found with the correct discharge area at that cross-section. The deflecting vane anemometer equipped with a jet on the end of a rubber tube has been found especially convenient and accurate on supply grilles.<sup>31</sup> On modern air conditioning grilles, the core area is used without a correction coefficient when the jet is held one inch away from the face of the grille. At this distance, the constriction due to the thin bars has disappeared, since the small air jets have reunited and the air stream has not yet spread beyond the core dimensions. With deflecting grilles the exploring jet should be turned to the angle giving a maximum reading. With suitable traversing tips and calibration, this instrument

may also be used on exhaust grilles if proper grille factors are applied.<sup>32</sup> Those contemplating such measurements should consult the references cited.

Smoke is a qualitative tool which is very useful in studying air movements. Satisfactory smoke can be obtained from titanium tetra-chloride (which, however, is very irritating to nasal membranes) or by mixing potassium chlorate and powdered sugar (a non-irritating smoke) and firing the mixture with a match. This latter process evolves considerable heat, and it should be confined in a pan away from flammable materials. The titanium tetra-chloride smoke lends itself to spot determinations, particularly for leakage through casings and ducts, as it can be easily handled in a small pistol-like ejector. The fumes of aqua ammonia and of sulfuric acid, if permitted to mix, form a white precipitate which is useful for some purposes. Two bottles, one containing ammonia water and the other acid, are connected to a common nozzle by means of rubber tubing. Air is forced over the surfaces of the liquids in the bottles by means of a syringe, and the two streams, upon mixing at the nozzle, form a white cloud.

### The Kata Thermometer

The measurement of air current velocities within enclosed spaces, such as the rooms of a house, is usually a tedious undertaking. However, useful data can be obtained by using the instruments described in following paragraphs if they are maintained in calibration, and the user understands the operation and limitations of the instruments.<sup>33</sup>

One of the instruments useful for determining the velocity of air currents in free spaces is the Kata thermometer which is essentially an alcohol thermometer with a large bulb. The instrument is heated above 100 F, and then the time in seconds required for it to cool from 100 to 95, when located in the air current, gives a measure of the air speed. It is important to have the Kata thermometer dry before taking the reading. Each Kata has its own factor etched on the stem, and this factor must be used with its cooling formula or chart for obtaining the velocity. The Kata thermometer is useful in exploring ventilated spaces to determine whether the proper air movement and distribution are being maintained. It is also used in determining the cooling power of the atmosphere, since it loses heat by radiation and convection when dry, and by radiation, convection, and evaporation when the bulb is equipped with a wetted cloth covering.<sup>34</sup>

### Thermal Anemometers

If a suitable sensing element is heated electrically at a fixed rate and exposed to an air stream, the temperature difference between the element and the stream becomes a measure of velocity by calibration. In the *hot-wire anemometer*, a very fine heated wire is employed as a resistance-thermometer element whose temperature may be determined accurately.<sup>35, 36</sup> In the *heated-bulb thermometer* type, a heating wire is wound around the bulb of a mercury-in-glass thermometer, and the temperature difference between this thermometer and a similar unheated one serves as an index of air speed.<sup>37</sup> The *heated-thermocouple anemometer* is calibrated to give velocity in terms of the differential *emf* between heated and unheated thermo-junctions exposed to an air stream.<sup>35, 38</sup> Combined measurements of air temperature and velocity are particularly useful for air distribution studies, and automatic recording potentiometers or resistance-thermometer devices facilitate spatial traverses. A correct calibra-

tion of thermal anemometers requires consideration of the effects of temperature, humidity and pressure upon the air properties which influence convective heat transfer.<sup>38</sup> With sensing elements of simple shapes for which convection data are known, thermal anemometers may be designed, both thermally and electrically, for desired characteristics. Directional sensitivity is controllable. Thermal anemometers are convenient and practical for low velocities.

#### Infiltration or Air Change Measurement

The total air leakage into an existing building caused by wind and temperature difference forces can be determined with considerable accuracy by determining the decrease in concentration of a tracer gas. Hydrogen and helium have both been used rather successfully as tracer gases in conjunction with a sensitive thermal conductivity comparator.<sup>39</sup> About one percent of tracer gas by volume is introduced into the room or building, and the tracer gas is thoroughly mixed with the air. The decrease in concentration of the tracer gas is observed at regular time intervals with a thermal conductivity meter as infiltration dilutes the mixture. The following formula is used to calculate the infiltration from the observed concentration measurements:

$$C = C_0 e^{-\frac{kt}{v}} \quad (7)$$

where

- $C_0$  = initial tracer gas concentration, percent.
- $C$  = concentration of tracer gas after  $t$  minutes, percent.
- $v$  = volume of room or building, cubic feet.
- $k$  = infiltration rate, cubic feet per minute.
- $e$  = 2.718, for natural logarithms.

Closets and cupboards should be left open during such infiltration tests so the entire space will have the same rate of change of tracer-gas concentration.

### HUMIDITY MEASUREMENT

#### Psychrometers

Any instrument capable of measuring the humidity or hygrometric state of the air is a hygrometer. A psychrometer is a particular kind of hygrometer which consists of two mercury thermometers, one of which has a cloth wick or sock applied to its bulb. For use, the wick is wetted with water and ventilated with air moving at a recommended rate of 900 fpm or more, relative to the instrument.<sup>40</sup> In the simpler and more common type, known as the sling psychrometer, the two thermometers are mounted side by side on a frame fitted with a handle by which the device can be whirled through the air. The motion is arrested for reading the thermometers, and continued until the thermometer readings become steady. Due to evaporation, the wet-bulb thermometer will indicate a lower temperature than the dry-bulb thermometer, and the difference is known as the wet-bulb depression. Charts and tables are available showing the relation between the thermometer readings and the humidity.<sup>19, 41</sup> Data are usually based on a total pressure of one standard atmosphere. For precise work, a correction is necessary for barometric pressure and is usually made by multiplying the observed relative humidity by the ratio of the observed to the standard atmospheric pressure.

For air temperatures below 32 F, the water on the wick may either freeze or super-cool, and its state must be known and a proper table or chart used,

since the wet-bulb temperature is different for ice and for water. Some operators remove the wick from the wet-bulb for freezing conditions and dip the bulb in water a few times, allowing the water to freeze on the bulb between dips and to form a film of ice. Since wet-bulb depression is slight at low temperatures, precise temperature readings are essential.

In the ventilated or aspirated psychrometer, the thermometers remain stationary, and a small fan or blower or a syringe is used to move the air across the thermometer bulbs. Various designs have been employed in the laboratories, and several commercial models are available.

#### The Dew-Point Hygrometer

In the usual form of these instruments, means are provided for cooling, and of observing the temperature of, a surface which is exposed to air. The temperature at which visible condensation occurs on the surface is considered the dew-point of the air. With the dew-point temperature known, the relative humidity and other properties of the air can be taken from tables and charts (See Chapter 3). A bright surface or metallic mirror is usually employed to improve the visibility of the dew deposit, and various means are used to cool the mirror from the back, including evaporating ether or another refrigerant, or a stream of air passed through dry ice. Dew-point temperatures, in some cases, are observed by means of thermometers in fluids in contact with the back of the mirror, but in modern instruments thermocouples are used, and are soldered or welded to the mirror itself. The dew-point apparatus is not so commonly used as the psychrometer, probably because it is less convenient. It is usable, however, for higher temperatures than the wet- and dry-bulb psychrometer, and should be considered for dew-points near or above the boiling point, as in the case of flue gases. Special apparatus for high precision has been constructed, in which the photronic cell and a light source are used for dew or frost detection instead of visual inspection.

#### Hair Hygrometers

Many materials, especially organic materials, change in dimensions with changes in humidity, and many devices have been designed in efforts to utilize this action in simple and effective humidity indicators, recorders and controllers. Unfortunately, no material has been found which can be relied upon to perfectly reproduce its action when exposed to repeated identical changes in humidity. The field has been well explored, and instrument and control manufacturers are practically unanimous in the selection of human hair for this service.

The hair hygrometer consists of from one to several strands of hair with a mechanism whereby changes in length of the strands, due to changes in humidity, cause an indicator to move across a dial. In the recording instrument, a pen is moved across and marks a moving paper ribbon, indexed in relative humidity. In a controller, or humidistat, the motion makes or breaks an electric contact governing the air conditioning equipment. Such devices require initial calibration and, for precise work, frequent recalibration or setting, especially if they are exposed to extremes of either high or low humidity. For continuous operation, with only slight changes in humidity, some operators report satisfactory reproducibility of results.

#### Electrolytic Hygrometers

The dampness, and therefore the electrical resistance of a salt film, varies with the humidity of the atmosphere to which the film is exposed, and at



least two types of instruments based on this fact have been developed. The Dunmore hygrometer was originally designed for use in radio-sondes or small balloons, and means were devised whereby the device transmits humidity data back to earth in the form of a radio signal. In the more usual form, this hygrometer consists of a dual winding of small wire on a non-conducting tube. The whole is coated with an electrolytic film, usually containing a salt such as lithium chloride, which forms an electric connection between the windings. Means are provided for determining the electrical resistance of the film, which is an indication of the humidity. In the radio-sonde, variations in the resistance of the film affect the frequency of an oscillating circuit. These hygrometers are usually calibrated by comparison with a wet- and dry-bulb psychrometer. For calibration for some purposes, particularly for use at sub-zero temperatures, means have been provided for producing atmospheres of known humidity.<sup>42</sup> Advantages of instruments of this type for some scientific and industrial purposes are becoming apparent, and some forms of them are on the market.

The Weaver type hygrometer is particularly useful for determining the humidity of air or other gas in pipes or closed vessels at various pressures and temperatures. It consists of a threaded plug carrying a central electrode insulated from the plug, except for a gelatinous electrolytic film. The film is exposed to the air or gas from the pipe or vessel, and provision is made for determining its electrical resistance. The hygrometer, or detector, is mounted in a manifold equipped with valves whereby the film can be alternately exposed to the test gas, and to a standard gas having a known absolute humidity. The pressure of the standard gas is varied until contact with it establishes the same resistance in the film as the test gas, and the humidity of the test gas is then determined by computation based on the gas laws.

### Chemical Hygrometry

The humidity of an atmosphere can be measured directly by extracting and weighing the water vapor from a known sample. For precise laboratory work, powerful desiccants such as sulphuric acid and phosphorus pentoxide are used for the extraction process, while for some purposes, calcium chloride, lithium chloride or silica gel are satisfactory. Freezing the water vapor out of a measured stream of air or gas with solid carbon dioxide, and weighing the resulting ice, is a similar operation. A thermal conductivity method for gas analysis can be used for temperatures above 212 F, or for very low humidities.<sup>43</sup>

## HEAT TRANSFER THROUGH BUILDING MATERIALS

### Thermal Conductivity

The thermal conductivity ( $k$  value) of an insulation, as defined in Chapter 9, is a unit heat transfer factor. Practically universally accepted for the conductivity determination of flat insulation is the guarded hot plate, which is described in *ASTM* test method C-177.<sup>44</sup> In its simplest form it consists of an electrically heated plate and two water cooled plates. Two identical specimens or slabs of a material are required for a test, and one is mounted on each side of the hot plate. A cold plate is then pressed against the outside of each specimen by a clamp screw. The heated plate is divided into two portions: the central or measuring section, and the outer or guard section. During tests the two sections are maintained as nearly as possible at the same temperature. The purpose of the guard section is to minimize errors due to edge effects. The electric energy required to heat the meas-

uring section is carefully observed and, converted to Btu per hour, is divided by the area and the temperature gradient to obtain the conductivity of a material tested. Hot plate apparatus accommodating specimens on the order of one foot square and an inch or more thick, is common. The apparatus at the *National Bureau of Standards* takes specimens 8 in. square, while plates as large as 3 ft square have been used. The thermal conductivity of cylindrical or pipe insulation (Chapter 28) is determined in a similar manner except that an equivalent thickness must be calculated to account for the cylindrical shape.<sup>45</sup>

Recently there has been considerable development of transient state conductivity apparatus utilizing a slender probe.<sup>46, 47, 48, 49</sup> These instruments are commercially available and have the advantages of rapidity and requiring a small test specimen. While useful as research and development tools, the probe has not been generally accepted as have the guarded hot plate and pipe insulation apparatus.

### Wall Conductances

The thermal conductances ( $C$  values) of many walls can be satisfactorily estimated from the conductivities of their components and their dimensions, but some walls are complicated by the inclusion of metal, for instance, and tests for conductance are required. The apparatus is required to accommodate large specimens representing actual construction. The shielded hot box apparatus was developed for this purpose.<sup>50</sup> Specimens for the apparatus at the *National Bureau of Standards* are 5 ft long and 8 ft high, while others require different sizes, some larger, others smaller.

The guarded hot box is described in the *ASTM* Standard Test Code for Built-up Sections, C-236-54T.<sup>50</sup> The apparatus consists essentially of three boxes: a cold box, cooled by a refrigerating machine; a hot box, heated electrically; and a metering box also heated electrically. Each box has an open side to be placed against the specimen. The cold box is clamped against one side of the specimen, and the hot box against the other. The hot box encloses the metering box and is kept at the same temperature to minimize heat exchanges to or from the metering box, except through the specimen. The electric energy necessary to heat the metering box is measured, converted to Btu per hour, and divided by the area and the temperature difference through the wall, from surface to surface, to yield the conductance of the wall. The transmittance or  $U$ -value of the wall is then computed by means of the surface coefficients from Chapter 9.

A heat flow meter is sometimes useful for measuring steady heat flow through a wall or other building member.<sup>51, 52, 53</sup> In essence, this meter consists of a plate or slab of material of known thermal resistance having attached thermocouples on both sides. For use, the device is pressed against or cemented to the wall to be tested. At steady state, the temperature difference through the slab, measured with the thermocouples, with the known thermal resistance of the slab, indicates the heat flow through the slab and hence, through the wall covered by it. For best results, such meters are calibrated by means of a guarded hot plate or other suitable apparatus. The chief precaution is to assure that the heat flow is steady at the time of measurement.

## EVALUATION OF THE THERMAL ENVIRONMENT

Advocates of radiant heating emphasize the fact that comfort depends on radiant heat exchanges, as well as air temperature. For this reason sev-



eral instruments have been devised to evaluate the comfort or warmth of rooms, taking radiant as well as convective effects into account. Prominent among these are the eupatheoscope, the globe thermometer, the thermal integrator and the heated globe.<sup>54, 55</sup> Descriptions are contained in the references, and are omitted here because these devices are not widely used in America for several reasons, among which is the fact that radiant heating with high temperature sources is not a chief method of comfort heating in this country.

### COMBUSTION ANALYSIS

There are two approaches to the problem of measuring the capacities of fuel burning devices, such as boilers and furnaces. The direct or calorimetric test consists in measuring the change in enthalpy or heat content of the fluid, air or water, heated by the device and multiplying by the flow rate in pounds per hour to arrive at the capacity in Btu per hour.<sup>56</sup> The indirect test consists in determining the heat lost in the flue gases and deducting it from the heat evolved by combustion of the fuel.<sup>57</sup> A heat balance consists in the simultaneous application of both tests to the same device. The indirect test almost invariably indicates the greater capacity, and the difference is credited to radiation from the boiler or furnace casing and *unaccounted for loss*.

In the case of some small equipment, the expense of the direct test is not considered justifiable, and the indirect test is relied upon with an arbitrary *radiation and unaccounted for factor*.<sup>57</sup>

### Flue Gas Analysis

The Orsat apparatus is commonly used for analyzing flue gases. In its ordinary form, it consists of three pipettes and a means for isolating a sample of flue gas in a graduate. After measuring, the sample is expelled from the graduate into the first pipette where the carbon dioxide is extracted by potassium hydroxide. The sample is then remeasured and successively passed into the second and third pipettes, where the oxygen and the carbon monoxide are respectively extracted by potassium pyrogallate and cuprous chloride.

For field testing and burner adjustment, simpler portable devices are available for carbon dioxide determination only. From curves, based on typical hydrogen content of several common fuels, efficiencies may be estimated from the carbon dioxide value obtained. More elaborate laboratory equipment is sometimes provided for precise determination of carbon monoxide content by burning the carbon monoxide to carbon dioxide in presence of a catalyst.<sup>58, 59</sup> In large plants, carbon dioxide recorders are used to obtain a continuous indication of the plant's efficiency.<sup>60</sup>

### SMOKE DENSITY MEASUREMENTS

*Ringelmann charts* are widely used for evaluating the density of smoke discharged from chimneys or stacks, and smoke ordinances are based on them in some cities. Each chart is composed of a series of crossed black lines on white paper which, at a distance of about 50 ft, is visually compared with the smoke under observation. Four charts are used with different degrees of blackness as shown in Table 1. The smoke density is specified by Ringelmann numbers from 1 to 4.

The *photoelectric cell* is used in some apparatus developed for smoke density recording in large plants. The same device is included in the test-

ing equipment for domestic oil burners described in *National Bureau of Standards, Commercial Standard CS75-42*.<sup>61</sup> Under *Laboratory Tests* this publication contains the following section: "Smoke Determination.—After combustion has reached equilibrium, the amount of smoke in the flue gases, when viewed lengthwise through 4 feet of the smoke pipe in accordance with the *Underwriters' Laboratories, Inc.*, Standard for Domestic Oil Burners (Subject 296), March 1934 and subsequent revisions, shall not reduce the output of a standard photoelectric cell from 9 microamperes, with a clear smoke pipe, to less than 8 microamperes." The Commercial Standard also requires that during a test after installation, the burner shall operate without visible smoke at the chimney top.

A method of evaluating smoke produced by pot type oil burners was developed for the *Institute of Cooking and Heating Appliance Manufacturers* by R. N. St. John. A glass rod is interposed between a light source and a photo-sensitive cell, both before and after being exposed to the flue

TABLE 1. RINGELMANN SMOKE CHART SPACINGS

| NUMBER OF CARD | THICKNESS OF LINES, MM | DISTANCE IN CLEAR BETWEEN LINES, MM |
|----------------|------------------------|-------------------------------------|
| 1              | 1.0                    | 9.0                                 |
| 2              | 2.3                    | 7.7                                 |
| 3              | 3.7                    | 6.3                                 |
| 4              | 5.5                    | 4.5                                 |

gases from a heating device. The diminution of the light transmitted by the rod, due to the deposit of soot on its surface, causes a reduction in the cell emf which is taken as an index of the concentration of smoke in the flue gases. A description of the method is contained in *National Bureau of Standards Commercial Standard CS104-46*.<sup>67</sup>

### DETERMINATION OF AIR CONTAMINANTS

Two measures of air dustiness are in use: particles per unit volume of air, and weight per unit volume of air. A comparative method consists in drawing known samples of air through a known area of filter cloth or paper, and comparing the density of the resulting spots with blackness charts or with spots from other sources.

For counting, particles are captured in a device such as the Smith-Greenburg impinger, the Owens jet dust counter, or in an electrostatic or a thermal precipitation device designed for the purpose.<sup>62</sup> Counting is done with a microscope, and the method yields important results when the nature or constituents of the dust are of interest.

For a weight determination, a known volume of air is drawn through a porous crucible or thimble, and the weight gained by the thimble during the operation is the weight of the dust captured from the air sample.<sup>63</sup> For precise work, the thimble must be dried in a desiccating chamber before weighing each time.

A test method based on weight determination was used in the A.S.H.V.E Code for Testing and Rating Air Cleaning Devices Used in General Ventilation Work.<sup>64</sup> This code was withdrawn by the Society in 1955 when it was evident that no manufacturer of filters was using equipment such as that specified in the code. This withdrawal was accompanied by a statement that it did not imply that any other code

was recommended to take its place. The subject of air cleaning is under investigation in cooperative research now being conducted at the University of Minnesota.

At the National Bureau of Standards a test method was developed for interested Government agencies, under which measured samples of the uncleaned air and of the air cleaned by a device under test are passed through filter papers.<sup>65</sup> The ratio of the flow rates through the two filter papers is adjusted during successive tests, until the resulting dust spots approach equality in density as shown by a photometer. The ratio of the flow rates is then indicative of the effectiveness of the cleaner in arresting dust. A statement of an air cleaner's efficiency by any test method, is meaningless unless the test dust is specified. Other instruments for determining gaseous and particulate air contaminants are described in industrial hygiene literature.<sup>62, 66, 67, 68</sup>

### SOUND AND VIBRATION MEASUREMENTS

Approximate measurements of sound intensity can be made by aural methods. The ear is used to compare the measured noise with sounds of known strength.

Electrical devices, in which the ear plays no part, furnish the most satisfactory means of measuring noise intensities. The sound meter consists essentially of a microphone coupled to an amplifier designed with an ear-like response. The output of the microphone is read on a sensitive direct current milliammeter graduated to read directly in decibels. Instruments of this type, if connected with suitable band pass filters, can be used to study the intensity of the sound over its entire range of frequencies.

Electrical instruments are available for measuring the frequency, amplitude and acceleration of a vibrating mass. They are usually more convenient and accurate than the vibrating reed tachometer, the seismic type displacement meters or the accelerometers which can also be used for this purpose. Sound level meters are discussed in several text books<sup>69, 70</sup> and standards.<sup>71</sup>

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- <sup>9</sup> Investigation of Warm Air Furnaces and Heating Systems, by A. C. Willard, A. P. Kratz and V. S. Day (Illinois Engineering Experiment Station, Bulletin No. 120).
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- <sup>11</sup> Parallel-connected Thermocouples for the Testing of Gas Appliances, by Walter B. Kirk and George J. Pacanovsky (Gas, September, 1939, p. 51).

- <sup>12</sup> American Standard for Indicating Pressure and Vacuum Gages, Round Dial Type, with Elastic Pressure Chamber. B. 40.1-1930 (American Standards Association).
- <sup>13</sup> Standard Test Code for Centrifugal and Axial Fans, 1938 (A.S.H.V.E. and N.A.F.M.) published by N.A.F.M. as Bulletin No. 110.
- <sup>14</sup> Fan Engineering, Buffalo Forge Company, 5th Edition, p. 165.
- <sup>15</sup> Illinois Micromanometer (University of Illinois, Engineering Experiment Station Bulletin No. 120, p. 91).
- <sup>16</sup> The Weather-tightness of Rolled Steel Windows, by J. E. Emswiler and W. C. Randall (A.S.H.V.E. TRANSACTIONS, Vol. 34, 1928, p. 527).
- <sup>17</sup> Pressure Measurement (A.S.M.E. Power Test Code 1938, Part 2, Chapter 2).
- <sup>18</sup> The Measurement of Static Pressure, by C. J. Fechheimer (Mechanical Engineering, August, 1927).
- <sup>19</sup> Psychrometric Tables for Vapor Pressure, Relative Humidity and Temperatures of the Dew-Point (U. S. Department of Agriculture, Weather Bureau, Washington, D. C.).
- <sup>20</sup> For technical data refer to Fluid Meter Reports, Parts 1-1937, 2-1931; and 3-1933 (American Society of Mechanical Engineers).
- <sup>21</sup> Technical Notes No. 546 (National Advisory Committee for Aeronautics, November, 1935).
- <sup>22</sup> The Characteristics of Double Pitot Tubes, by F. R. Ingram, E. Dies-Canseco and L. Silverman (A.S.H.V.E. JOURNAL SECTION, Heating, Piping and Air Conditioning, November, 1942, p. 708).
- <sup>23</sup> Discharge Coefficients of Square Edged Orifices for Measuring the Flow of Air, by H. S. Bean, E. Buckingham and P. S. Murphy (Bureau of Standards Journal of Research, Vol. 2, 1929, p. 561).
- <sup>24</sup> Flow Measurement by Nozzles and Orifice Plates (A.S.M.E. Power Test Codes, Chapter 4 of Part 5, 1940).
- <sup>25</sup> Air Flow Measurement in the Laboratory, by D. D. Wile (Refrigerating Engineering, June, 1947, p. 515).
- <sup>26</sup> A.S.H.V.E. RESEARCH REPORT No. 1204—Entrainment and Jet-Pump Action of Air Streams, by G. L. Tube, G. B. Priester and D. K. Wright, Jr. (A.S.H.V.E. TRANSACTIONS, Vol. 48, 1942, p. 241).
- <sup>27</sup> A.S.H.V.E. RESEARCH REPORTS Nos. 857, 911 and 986—Measurement of the Flow of Air Through Registers and Grilles, by L. E. Davies (A.S.H.V.E. TRANSACTIONS, Vol. 36, 1930, p. 201, Vol. 37, 1931, p. 619, and Vol. 39, 1933, p. 373).
- <sup>28</sup> A.S.H.V.E. RESEARCH REPORT No. 1162—Air Flow Measurements at Intake and Discharge Openings and Grilles, by G. L. Tuve and D. K. Wright, Jr. (A.S.H.V.E. TRANSACTIONS, Vol. 46, 1940, p. 313).
- <sup>29</sup> A.S.H.V.E. RESEARCH REPORT No. 1092—The Flow of Air Through Exhaust Grilles, by A. M. Greene, Jr. and M. H. Dean (A.S.H.V.E. TRANSACTIONS, Vol. 44, 1938, p. 387).
- <sup>30</sup> A.S.H.V.E. RESEARCH REPORT No. 936—Investigation of Air Outlets in Class Room Ventilation, by G. L. Latson, D. W. Nelson and R. W. Kubasta (A.S.H.V.E. TRANSACTIONS, Vol. 38, 1932, p. 463).
- <sup>31</sup> A.S.H.V.E. RESEARCH REPORT No. 1076—Air Distribution From Side Wall Outlets, by D. W. Nelson and D. J. Stewart (A.S.H.V.E. TRANSACTIONS, Vol. 44, 1938, p. 77).
- <sup>32</sup> Measuring Air Flow, by G. L. Tuve (Heating, Piping and Air Conditioning, December, 1941).
- <sup>33</sup> A.S.H.V.E. RESEARCH REPORT No. 1140—The Use of Air Velocity Meters, by G. L. Tuve, D. K. Wright, Jr. and L. J. Siegel (A.S.H.V.E. TRANSACTIONS, Vol. 45, 1939, p. 645).
- <sup>34</sup> Temperature, Humidity and Air Motion Effects in Ventilation, by O. W. Armspach and Margaret Ingels (A.S.H.V.E. TRANSACTIONS, Vol. 28, 1922, p. 103).
- <sup>35</sup> A.S.H.V.E. RESEARCH REPORT No. 1165—Development of Instruments for the Study of Air Distribution in Rooms, by A. P. Kratz, A. E. Hershey and R. B. Engdahl (A.S.H.V.E. TRANSACTIONS, Vol. 46, 1940, p. 351).
- <sup>36</sup> Development of Testing Apparatus for Thermostats, by D. D. Wile (A.S.H.V.E. TRANSACTIONS, Vol. 42, 1936, p. 349).
- <sup>37</sup> The Heated-Thermometer Anemometer, by C. P. Yaglou (Journal Industrial Hygiene and Toxicology, Vol. 20, October, 1938, No. 8).
- <sup>38</sup> A Simple Heated-Thermocouple Anemometer, by H. B. Nottage (A.S.H.V.E. TRANSACTIONS, Vol. 56, 1950, p. 431).
- <sup>39</sup> Measurement of Ventilation Using Tracer Gas Technique, by J. B. Dick (A.S.H.V.E. JOURNAL SECTION, Heating, Piping and Air Conditioning, May, 1950, p. 131).
- <sup>40</sup> The Temperature of Evaporation, by Willis H. Carrier (A.S.H.V.E. TRANSACTIONS, Vol. 24, 1918, p. 25).
- <sup>41</sup> A Review of Existing Psychrometric Data in Relation to Practical Engineering Problems, by W. H. Carrier and C. O. Mackey (A.S.M.E. Transactions, January, 1937, p. 33; Discussion A.S.M.E. Transactions, August, 1937, p. 528).
- <sup>42</sup> Divided Flow Low Temperature Humidity Test Apparatus, by Arnold Wexler (National Bureau of Standards, Research Paper No. 1894).
- <sup>43</sup> Gas Analysis by Measurement of Thermal Conductivity, by H. A. Daynes (Cambridge Press, 1933).
- <sup>44</sup> Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate adopted July, 1942, by A.S.H.V.E. (A.S.T.M. Designation C177 - 45).

- <sup>43</sup> Tentative Method of Test for Thermal Conductivity of Pipe Insulation (A.S.T.M. Designation C 335-54T).
- <sup>44</sup> A Study of Transient Heat Method for Measuring Thermal Conductivity, by D. D'Eustachio and R. E. Schreiner (A.S.H.V.E. TRANSACTIONS, Vol. 58, 1952, p. 331).
- <sup>45</sup> Transient Heat Flow Apparatus for the Determination of Thermal Conductivity, by F. C. Hooper and F. R. Lepper (A.S.H.V.E. TRANSACTIONS, Vol. 56, 1950, p. 309).
- <sup>46</sup> Development of Thermal Conductivity Probe, by F. C. Hooper and S. C. Chang (A.S.H.V.E. TRANSACTIONS, Vol. 59, 1953, p. 463).
- <sup>47</sup> A Transient Heat Flow Method of Determining Thermal Conductivity: Application to Insulating Materials, by C. P. Lents (Canadian Journal of Technology, June 1952, Vol. 30, p. 153).
- <sup>48</sup> Tentative Method of Test for Thermal Conductance of and Transmittance of Built-up Sections by Means of Guarded Hot Box (American Society for Testing Materials, ASTM-C-236-49T).
- <sup>49</sup> A.S.H.V.E. RESEARCH REPORT No. 685—Measuring Heat Transmission in Building Structures and a Heat Transmission Meter, by P. Nicholls (A.S.H.V.E. TRANSACTIONS, Vol. 30, 1924, p. 65).
- <sup>50</sup> A Low-inertia Low-resistance Heat Flow Meter, by R. G. Huebscher, L. F. Schutrum, and G. V. Parmelee, (A.S.H.V.E. TRANSACTIONS, Vol. 58, 1952, p. 275).
- <sup>51</sup> Using the Heat Flow Meter to Study Heat Transfer, by J. T. Gier and R. V. Dunkle (Refrigerating Engineering, Vol. 62, No. 10, Oct. 1954, p. 63).
- <sup>52</sup> Instruments and Methods for Recording Thermal Factors Affecting Human Comfort, by C. P. Yaglou, A. P. Kratz and C.-E. A. Winslow (Year Book, American Journal Public Health, 36-37).
- <sup>53</sup> The Thermo-Integrator—A New Instrument for the Observation of Thermal Interchanges, by C.-E. A. Winslow and Leonard Greenburg (A.S.H.V.E. TRANSACTIONS, Vol. 41, 1935, p. 149).
- <sup>54</sup> I = B = R Testing and Rating Codes for Low Pressure Heating Boilers, 1947 (Institute of Boiler and Radiator Manufacturers).
- <sup>55</sup> Commercial Standard for Warm Air Furnaces Equipped with Vaporizing Pot-Type Oil Burners, C.S. 104-26 (National Bureau of Standards).
- <sup>56</sup> Rapid Determination of Small Amounts of Carbon Monoxide, by Martin Shepherd (Ind. Eng. Chem. Anal. Ed. 19, 77: 1947).
- <sup>57</sup> Determination of Small Amounts of Carbon Monoxide in Air by Various Reference Methods, by Martin Shepherd (National Bureau of Standards Journal of Research 38, 351-8; 1947 R. P. 1777).
- <sup>58</sup> A Carbon Monoxide Recorder, by S. H. Kratz, D. A. Reynolds, H. W. Frevert and J. J. Bloomfield (U. S. Bureau of Mines, Technical Paper No. 355, 1926).
- <sup>59</sup> Commercial Standard for Mechanical Draft Oil Burners Designed for Domestic Installations, C.S. 75-42 (National Bureau of Standards).
- <sup>60</sup> Industrial Dust, by Philip Drinker and Theodore Hatch (McGraw-Hill Book Company, New York).
- <sup>61</sup> Testing and Rating of Air Cleaning Devices Used for General Ventilation Work, by S. R. Lewis (A.S.H.V.E. TRANSACTIONS, Vol. 39, 1933, p. 277).
- <sup>62</sup> A.S.H.V.E. Code for Testing and Rating Air Cleaning Devices Used in General Ventilation Work, adopted January, 1934 (A.S.H.V.E. TRANSACTIONS, Vol. 39, 1933, p. 225).
- <sup>63</sup> A Test Method for Air Filters, by Richard S. Dill (A.S.H.V.E. TRANSACTIONS, Vol. 44, 1938, p. 379).
- <sup>64</sup> Analytical Chemistry of Industrial Poisons, Hazards and Solvents, by Morris B. Jacobs (Interscience Publishers, Inc., New York, 1941).
- <sup>65</sup> The Determination and Control of Industrial Dust, by J. J. Bloomfield and J. M. Dalla Valle (U. S. Public Health Bulletin No. 217, 1935).
- <sup>66</sup> Sampling and Analysis of Atmospheric Contaminants, by F. A. Patty (Industrial Hygiene and Toxicology, Vol. I, Interscience Publishers, Inc., New York, 1948).
- <sup>67</sup> Electrical Engineer's Handbook, by Harold Pender and Knox McIlvaine (John Wiley and Sons, New York).
- <sup>68</sup> Elements of Acoustical Engineering, by Harry F. Olson, (D. Van Nostrand Co., New York).
- <sup>69</sup> American Tentative Standards for Sound Level Meters for Measurement of Noise and Other Sounds, Z 24.3-1944 (American Standards Association).

## CHAPTER 53 CODES AND STANDARDS

THE Codes and Standards listed in Table 1 represent accepted practice, methods, or standards prepared and accepted by the organizations indicated. They are valuable guides for the practicing engineer in determining test methods, ratings, performance requirements, and limits applying to equipment used in heating, ventilating, and air conditioning. Copies can usually be obtained from the organization listed in the reference column.

TABLE 1. CODES AND STANDARDS PREPARED AND ACCEPTED BY VARIOUS SOCIETIES AND ASSOCIATIONS

| SUBJECT                                   | TITLE                                                                                                                        | SPONSOR                              | REFERENCE                           |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|-------------------------------------|
| Acoustics (Terminology)                   | American Standard Acoustical Terminology. (1951)                                                                             | AS of A                              | ASA Z24.1                           |
| Air Conditioning                          | Code of Minimum Requirements for Comfort Air Conditioning (1938).                                                            | ASHVE ASRE                           | ASHAE                               |
| Air Conditioning (120,000 Btu/Hr or less) | Code and Manual for the Design and Installation of Warm Air Winter Air Conditioning Systems (1953).                          | NWAH & ACA                           | NWAH & ACA Manual No. 7 4th Edition |
| Air Conditioning (Above 120,000 Btu/hr)   | Code and Manual for the Design and Installation of Mechanical Warm Air Heating Systems (1950).                               | NWAH & ACA                           | NWAH & ACA Manual No. 9 4th Edition |
| Air Conditioning                          | Standards for the Installation of Air Conditioning, Warm Air Heating, Air Cooling and Ventilating Systems.                   | NFPA                                 | NFPA or NBFU Pamphlet No. 90 1952   |
| Air Conditioning (Equipment)              | ASRE Standard Methods of Rating and Testing Air Conditioning Equipment (1942).                                               | ASRE<br>ASHVE<br>NEMA<br>RMA<br>ACMA | ASRE Circular No. 13-42             |
| Air Conditioners                          | ASRE Standard Methods of Rating and Testing Air Conditioners (1949). (Supersedes ASRE Circular 13-42)                        | ASRE                                 | ASRE Standard 16-53                 |
| Airplane                                  | Air Conditioning Equipment, Airplane—General Requirements for (1948).                                                        | SAE                                  | SAE ARP 83B                         |
| Airplane                                  | Heaters, Airplane, Internal Combustion Heat Exchanger Type (1949).                                                           | SAE                                  | SAE ARP 143B                        |
| Airplane                                  | Heaters, Airplane, Steam Type                                                                                                | SAE                                  | SAE ARP 87                          |
| Attic Ventilation                         | Residence Ventilation Guide (1950).                                                                                          | PFMA                                 | PFMA                                |
| Boilers                                   | I=B=R Testing and Rating Code for Low Pressure Heating Boilers (1950).                                                       | IBR                                  | IBR                                 |
| Boilers                                   | Net Load Recommendations for Heating Boilers. Publ. semi-annually.                                                           | HP & ACCNA                           | HP & ACCNA                          |
| Boilers                                   | Net Square Feet Radiation Loads in 70 Deg Fahr. Recommended for Low Pressure Heating Boilers (1948).                         | HP & ACCNA                           | HP & ACCNA                          |
| Boilers                                   | Standard and Short Form Heat Balance Codes for Testing Low Pressure Steam Heating Solid Fuel Boilers (Codes 1 and 2) (1929). | ASHVE                                | ASHAE                               |
| Boilers                                   | ASHVE Performance Test Code for Steam Heating Solid Fuel Boilers (Code No. 3) (1929).                                        | ASHVE                                | ASHAE                               |
| Boilers                                   | ASHVE Standard Code for Testing Steam Heating Boilers Burning Oil Fuel (1932).                                               | ASHVE                                | ASHAE                               |

TABLE 1. CODES AND STANDARDS—(Continued)

| SUBJECT                 | TITLE                                                                                                                                                      | SPONSOR      | REFERENCE            |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|----------------------|
| Boilers                 | ASHVE Standard Code for Testing Stoker-Fired Steam-Heating Boilers (1938).                                                                                 | ASHVE        | ASHAE                |
| Boilers                 | ASME Boiler Construction Code for Low Pressure Heating Boilers (1952 with 1954 Addenda).                                                                   | ASME         | ASME                 |
| Boilers                 | ASME Boiler and Pressure Vessel Code (1952, 8 Vol.).                                                                                                       | ASME         | ASME                 |
| Boilers (Gas)           | American Standard Approval Requirements for Central Heating Gas Appliances Vol. 1, Steam and Hot Water Boilers (1951 with Addenda, 1954).                  | A.G.A.       | ASA<br>Z21.13.1-1951 |
| Boilers (Miniature)     | ASME Miniature Boiler Code (1952).                                                                                                                         | ASME         | ASME                 |
| Boilers (Power)         | ASME Power Boiler Code (1952 with 1954 Addenda).                                                                                                           | ASME         | ASME                 |
| Boilers (Power)         | Suggested Rules for Care of Power Boiler. (1954).                                                                                                          | ASME         | ASME                 |
| Boilers (Steel)         | Steel Boiler Institute Rating Code for Steel Boilers (1954).                                                                                               | SBI          | SBI<br>6th Edition   |
| Boilers (Steel)         | Simplified Practice Recommendation for Steel Firebox Boilers and Steel Heating Boilers (Commercial and Residential Types) (1950).                          | BS<br>SBI    | BS<br>R157-50        |
| Building Code Standards | Building Code Standards of the NBFU for the Installation of Heat Producing Appliances, Heating, Ventilating, Air Conditioning, Blower and Exhaust Systems. | NBFU         | NBFU                 |
| Building Requirements   | American Standard Building Requirements (1946).                                                                                                            | NHA<br>USPHS | ASA<br>A53.1-1946    |
| Buildings               | Basic Building Code (Also published in Abridged form as Abridged Building Code) 1950.                                                                      | BOCA         | BOP                  |
| Burners (Anthracite)    | Commercial Standard for Domestic Burners for Pennsylvania Anthracite (Underfeed Type) (1940).                                                              | BS<br>AIL    | BS<br>CS48-40        |
| Burners (Gas)           | American Standard Requirements for Installation of Domestic Gas Conversion Burners (1948).                                                                 | A.G.A.       | ASA<br>Z21.8-1948    |
| Burners (Gas)           | American Standard Requirements for Installation of Gas Burning Equipment in Large Boilers (1950).                                                          | A.G.A.       | ASA<br>Z21.33-1950   |
| Burners (Gas)           | American Standard Listing Requirements for Domestic Gas Conversion Burners (1948).                                                                         | A.G.A.       | ASA<br>Z21.17-1948   |
| Burners (Oil)           | Commercial Standard for Mechanical-Draft Oil Burners Designed for Domestic Installations (1942).                                                           | BS<br>OBI    | BS<br>CS75-42        |
| Chimneys (Flue Linings) | American Standard Sizes of Clay Flue Linings (1947).                                                                                                       | AIA<br>PC    | ASA<br>A62.4-1947    |
| Cleaners (Air)          | Code for Testing Air Cleaning Devices Used in General Ventilation: Section I, Unit or Panel Type Air Filtering Devices (1953).                             | API          | API                  |
| Coal (For Stokers)      | Tentative Standard Procedure for Testing and Evaluating Bituminous Stoker Coals (1952).                                                                    | SMA<br>BCR   | SMA<br>BCR           |
| Coils                   | Proposed Commercial Standard for Rating and Testing Air Cooling Coils Using Non-Volatile Refrigerants (1945).                                              | BCMI<br>BS   | BS<br>TS 4044        |

TABLE 1. CODES AND STANDARDS—(Continued)

| SUBJECT                        | TITLE                                                                                                                       | SPONSOR                        | REFERENCE                                       |
|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------|--------------------------------|-------------------------------------------------|
| Coils                          | Standard Methods of Testing and Rating Forced-Circulation Air-Cooling and Air-Heating Coils (1955).                         | ARI<br>HCCMA                   | HCCMA<br>Bulletin No. 202                       |
| Color Scheme (Piping)          | Scheme for Identification of Piping Systems (1945).                                                                         | HP & ACCNA                     | HP & ACCNA<br>Engrg. Stds., Sec. 2,<br>Part V   |
| Color Scheme (Piping)          | Scheme for Identification of Piping Systems (1928).                                                                         | ASME                           | ASA<br>A13-1928                                 |
| Compressors                    | ASRE Standard Methods of Rating and Testing Refrigerant Compressors.                                                        | ASRE<br>ASHVE<br>ACRMA         | ASRE<br>Standard 23-R                           |
| Condensers                     | ASRE Standard Methods of Rating and Testing Evaporative Condensers.                                                         | ASRE<br>ASHVE<br>ACRMA         | ASRE<br>Standard 20                             |
| Condensers                     | ASRE Standard Methods of Rating and Testing Water-Cooled Refrigerant Condensers.                                            | ASRE<br>ASHVE<br>ACRMA         | ASRE<br>Standard 22                             |
| Condensing Units               | ASRE Standard Methods of Rating and Testing Mechanical Condensing Units (1940).                                             | ASRE<br>ASHVE<br>ACRMA         | ASRE<br>Standard 14-41                          |
| Conductance                    | Method of Test for Thermal Conductance and Transmittance of Built-Up Sections by Means of Guarded Hot Box (1949).           | ASTM                           | ASTM<br>C 230-49 T                              |
| Conductivity                   | Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate (1945).                     | ASHVE<br>ASRE<br>ASTM<br>NRC   | ASTM<br>C-177-45                                |
| Control Equipment (Industrial) | Underwriters' Laboratories, Inc., Standard for Industrial Control Equipment (July 1938).                                    | UL                             | UL<br>Subject 508                               |
| Controls                       | Underwriters' Laboratories, Inc., Standard for Temperature Indicating and Regulating Equipment (June 1953).                 | UL                             | UL<br>Subject 873                               |
| Controls Temperature           | NEMA Standards for Automatic Temperature Controls (1953).                                                                   | NEMA                           | NEMA<br>DCI-1953                                |
| Controls Temperature           | Temperature Control Equipment, Automatic, Airplane Cabin                                                                    | SAE                            | SAE<br>ARP 89A                                  |
| Convactor                      | ASHVE Standard Code for Testing and Rating Concealed Gravity Type Radiation (Hot Water Section) (1933).                     | ASHVE                          | ASHVE<br>TRANSACTIONS, Vol.<br>39, 1933, p. 237 |
| Convactor                      | ASHVE Standard Code for Testing and Rating Concealed Gravity Type Radiation (Steam Code) (1931).                            | ASHVE                          | ASHVE<br>TRANSACTIONS, Vol.<br>37, 1931, p. 387 |
| Convactor                      | Commercial Standard for Testing and Rating Convectors (1947).                                                               | BS<br>CMA<br>IBR               | BS<br>CS 140-47                                 |
| Coolers (Air)                  | ASRE Standard Methods of Rating and Testing Forced Circulation and Natural Convection Air Coolers for Refrigeration (1945). | ASRE<br>ASHVE<br>ACRMA<br>REMA | ASRE<br>Standard 25-44                          |
| Coolers                        | ASRE Standard Methods of Rating and Testing Water and Brine Coolers.                                                        | ASRE<br>ASHVE<br>ACRMA         | ASRE<br>Standard 24                             |
| Cooling Towers                 | Accepted Test Procedure for Water Cooling Towers, Mechanical Draft, Industrial Type (1955).                                 | CTI                            | CTI<br>Bulletin ATP-105                         |
| Ducts and Fittings             | Simplified Practice Recommendation for Pipes, Ducts and Fittings for Warm Air Heating and Air Conditioning (1945).          | Mfrs.<br>BS                    | BS<br>R207-49                                   |
| Exchangers (Heat)              | Standards of Tubular Exchanger Manufacturers Association (1941).                                                            | TEMA                           | TEMA                                            |

TABLE 1. CODES AND STANDARDS—(Continued)

| SUBJECT                           | TITLE                                                                                                                                                                                                                       | SPONSOR                         | REFERENCE                                 |
|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-------------------------------------------|
| Exhaust Systems                   | American Standard for Grinding, Polishing, and Buffing Equipment Sanitation (1941).                                                                                                                                         | AFA                             | ASA<br>Z43-1941                           |
| Exhaust Systems                   | Tentative Code of Recommended Practices for Testing and Measuring Air Flow in Exhaust Systems (1937).                                                                                                                       | AFA                             | AFA<br>Preprint 36-27                     |
| Exhaust Systems                   | Tentative Recommended Good Practice Code and Handbook on the Fundamentals of Design, Construction, Operation and Maintenance of Exhaust Systems.                                                                            | AFA                             | AFA                                       |
| Exhaust Systems                   | Standards for Blower and Exhaust Systems (1949).                                                                                                                                                                            | NFPA                            | NFPA or NBFU<br>No. 91                    |
| Exhaust Systems (Open Tanks)      | American Standard Safety Code for Ventilation and Operation of Open-Surface Tanks (1951).                                                                                                                                   | AIHA<br>A.S.H.V.E.<br>NAFM      | ASA<br>Z9.1-1951                          |
| Fans                              | Definitions and Terms in Use by the Blower Industry (1950) (Was NAFM Bulletin No. 105).                                                                                                                                     | NAFM                            | NAFM<br>Bulletin No. 110                  |
| Fans                              | Standard Test Code for Testing Centrifugal and Axial Fans (1950) (Was NAFM Bulletin No. 103).                                                                                                                               | NAFM*<br>ASHVE                  | NAFM<br>Bulletin No. 110                  |
| Fans                              | Standard Code for Testing Centrifugal, Axial, and Propeller Fans. (Having Wheels Less Than 12-in. Diam). 1953.                                                                                                              | NAFM                            | NAFM<br>Bulletin No. 116                  |
| Fans                              | Standards, Definitions, Terms and Test Codes for Centrifugal, Axial and Propeller Fans.                                                                                                                                     | NAFM*<br>ASHVE**                | NAFM<br>Bulletin 110<br>2nd Edition, 1952 |
| Fans                              | Standards for Fans (1947).                                                                                                                                                                                                  | NEMA                            | NEMA<br>Publ. 47-128                      |
| Fans                              | Test Code for Fans (1946).                                                                                                                                                                                                  | ASME                            | ASME<br>PTC 11-1946                       |
| Fans                              | Testing and Rating Ventilating Fans (Axial and Propeller Type).                                                                                                                                                             | CSD                             | CSD                                       |
| Fire Prevention                   | National Fire Codes (1954).                                                                                                                                                                                                 | NFPA                            | NFPA                                      |
|                                   | Vol. I—Flammable Liquids and Gases, Vol. II—Combustible Solids, Dusts, Chemicals, and Explosives, Vol. III—Building Construction and Equipment, Vol. IV—Extinguishing Equipment, Vol. V—Electrical, Vol. VI—Transportation. |                                 |                                           |
| Furnaces (Duct)                   | American Standard Approval Requirements for Gas-Fired Duct Furnaces (with 1954 Addenda).                                                                                                                                    | A.G.A.                          | ASA<br>Z21.34-1942                        |
| Furnaces (Gas)                    | American Standard Approval Requirements for Central Heating Gas Appliances Vol. II, Gravity and Forced Air Central Furnaces (1951 with 1952 and 1954 Addenda).                                                              | A.G.A.                          | ASA<br>Z21.13.2<br>1951                   |
| Furnaces (Forced Air, Solid-Fuel) | Commercial Standard for Solid-Fuel-Burning Forced Air Furnaces (1944).                                                                                                                                                      | FHA<br>N.W.A.H. & A.C.A.<br>AIL | BS<br>CS109-44                            |
| Furnaces (Heavy Duty)             | Code for Testing and Rating Heavy Duty Furnaces and Direct-Fired Unit Heaters (1955).                                                                                                                                       | ASHAE                           | ASHAE                                     |
| Furnaces (Oil-Fired)              | Commercial Standard for Warm Air Furnaces Equipped with Vaporizing Type Oil Burners (1949).                                                                                                                                 | Mfrs.<br>BS                     | BS<br>CS104-49                            |
| Furnaces (Oil-Fired)              | Recommended Commercial Standard for Warm Air Furnaces Equipped with Pressure Atomizing or Rotary Type Oil Burners.                                                                                                          | BS<br>NWAH & ACA                | BS<br>TS-5107                             |

\* Also endorsed by PFMA.

\*\* Refers to Test Code for Centrifugal and Axial Fans.

TABLE 1. CODES AND STANDARDS—(Continued)

| SUBJECT                       | TITLE                                                                                                                                                                                                                                                                                                                                                                                   | SPONSOR      | REFERENCE                                                                                                                                                                                                                                                            |
|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Furnaces (Oil)                | Commercial Standard for Oil Burning Floor Furnaces Equipped with Vaporizing Type Burners (1951).                                                                                                                                                                                                                                                                                        | BS<br>OPA    | BS<br>CS113-51                                                                                                                                                                                                                                                       |
| Furnaces (Oil)                | A Tentative Code for Testing Oil-Fired Furnaces.                                                                                                                                                                                                                                                                                                                                        | NWAH & ACA   | NWAH & ACA                                                                                                                                                                                                                                                           |
| Garage Ventilation            | Recommended Good Practice Requirements for the Construction and Protection of Garages (1932, Reprint 1952)                                                                                                                                                                                                                                                                              | NFPA<br>NBFU | NFPA or NBFU<br>Pamphlet No. 88                                                                                                                                                                                                                                      |
| Garages                       | Code of Minimum Requirements for Heating and Ventilating Garages (1935).                                                                                                                                                                                                                                                                                                                | ASHVE        | ASHAE                                                                                                                                                                                                                                                                |
| Gas Equipment (Large Boilers) | American Standard Requirements for Installation of Gas Equipment in Large Boilers.                                                                                                                                                                                                                                                                                                      | A.G.A.       | ASA<br>Z21.33-1950                                                                                                                                                                                                                                                   |
| Gases (Toxic) and Dust        | American Standard Allowable Concentration of Harmful Gases:<br>Carbon Monoxide<br>Hydrogen Sulfide<br>Carbon Di-sulfide<br>Benzene<br><br>Manganese<br>Chromic Acid and Chromates<br>Mercury<br><br>Xylene<br><br>Lead and Certain Inorganic Lead Compounds<br>Toluene<br>Oxides of Nitrogen<br>Methanol<br><br>Styrene-Monomer<br>Formaldehyde<br>Methyl Chloride<br>Trichloroethylene | ASA          | ASA<br><br>Z37.1-1941<br>Z37.2-1941<br>Z37.3-1941<br>Z37.4-1941<br><br>Z37.6-1948<br>Z37.7-1943<br>Z37.8-1943<br><br>Z37.10-1948<br><br>Z37.11-1943<br><br>Z37.12-1943<br>Z37.13-1944<br>Z37.14-1944<br><br>Z37.15-1944<br>Z37.16-1944<br>Z37.18-1949<br>Z37.19-1946 |
| Heat Transfer (Walls)         | Thermal Conductance and Transmittance of Built-up Sections by Means of Guarded Hot Box (1949).                                                                                                                                                                                                                                                                                          | ASTM         | ASTM<br>C-238-49 T                                                                                                                                                                                                                                                   |
| Heaters (Recessed Gas Fired)  | American Standard Approval Requirements for Central Heating Gas Appliances, Vol. IV Gravity and Fan Type Vented Recessed Heaters (1953 with 1954 Addenda).                                                                                                                                                                                                                              | A.G.A.       | ASA<br>Z21.13.4                                                                                                                                                                                                                                                      |
| Heaters (Room Gas Fired)      | American Standard Approval Requirements for Gas-Fired Room Heaters (formerly called Space Heaters) (1954).                                                                                                                                                                                                                                                                              | A.G.A.       | ASA<br>Z21.11-1954                                                                                                                                                                                                                                                   |
| Homes (Prefabricated)         | Commercial Standard for Prefabricated Homes.                                                                                                                                                                                                                                                                                                                                            | PHMI<br>BS   | BS<br>CS125-47                                                                                                                                                                                                                                                       |
| Mineral Wool                  | Commercial Standard for Mineral Wool Insulation for Heated Industrial Equipment (1949).                                                                                                                                                                                                                                                                                                 | BS<br>IMWI   | BS<br>CS117-49                                                                                                                                                                                                                                                       |
| Mineral Wool                  | Commercial Standard for Mineral Wool Insulation for Low Temperature Installations (1949).                                                                                                                                                                                                                                                                                               | BS<br>IMWI   | BS<br>CS105-48                                                                                                                                                                                                                                                       |
| Mineral Wool                  | Recommended Commercial Standard for Industrial Mineral Wool Products—All Types—Testing and Reporting (1946).                                                                                                                                                                                                                                                                            | IMWI<br>BS   | BS<br>CS131-46                                                                                                                                                                                                                                                       |
| Motors                        | Nema Motor and Generator Standards (June 1945).                                                                                                                                                                                                                                                                                                                                         | NEMA         | NEMA<br>45-102                                                                                                                                                                                                                                                       |
| Motors                        | Test Code for Single-Phase Motors (1941).                                                                                                                                                                                                                                                                                                                                               | AIEE         | AIEE<br>Report 502                                                                                                                                                                                                                                                   |
| Panel System (Warm Air)       | Code and Manual for the Design and Installation of Warm Air Ceiling Panel Systems.                                                                                                                                                                                                                                                                                                      | NWAH & ACA   | NWAH & ACA<br>Manual No. 7-A                                                                                                                                                                                                                                         |

TABLE 1. CODES AND STANDARDS—(Continued)

| SUBJECT                         | TITLE                                                                                                               | SPONSOR    | REFERENCE                            |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------|------------|--------------------------------------|
| Perimeter (Warm Air Small Pipe) | Small Pipe Warm Air Perimeter Heating.                                                                              | NWAH & ACA | NWAH & ACA Manual No. 10 (Tentative) |
| Perimeter (Warm Air)            | Warm Air Perimeter Heating (1953, 3rd Edition).                                                                     | NWAH & ACA | NWAH & ACA Manual No. 4              |
| Pipe & Tubing (Copper & Brass)  | Simplified Practice Recommendation for Copper Water Tubes and Brass Pipe.                                           | Mfrs. BS   | BS R217-49                           |
| Piping                          | American Standard Code for Pressure Piping (1955)                                                                   | ASME       | ASA B31.1-1955                       |
| Piping (Gas)                    | American Standard for Installation of Gas Piping and Gas Appliances in Buildings (1954).                            | A.G.A.     | ASA Z21.30-1954                      |
| Pumps                           | Hydraulic Institute Test Code for Centrifugal Pumps. Hydraulic Institute Test Code for Rotary Pumps (1943).         | HI         | HI Section F                         |
| Radiation (Baseboard)           | I=B=R Testing and Rating Code for Baseboard Type of Radiation (1950).                                               | IBR        | IBR                                  |
| Radiation (Finned-Type)         | I=B=R Testing and Rating Code for Finned-Type Radiation (First Edition 1951, with Addenda 1954).                    | IBR        | IBR                                  |
| Radiators                       | Code for Testing Radiators (1927).                                                                                  | ASHVE      | ASHAE                                |
| Radiators                       | Simplified Practice Recommendation for Cast Iron Radiators (1943).                                                  | IBR BS     | BS R174-47                           |
| Refrigeration (Equipment)       | Underwriters' Laboratories, Inc., Standard for Air Conditioning and Commercial Refrigerating Equipment (Feb. 1946). | UL         | UL Subject 207A                      |
| Refrigeration (Mechanical)      | American Standard Safety Code for Mechanical Refrigeration (1950).                                                  | ASRE       | ASA B9.1-1950                        |
| Refrigeration (Unit Systems)    | Underwriters' Laboratories, Inc., Standard for Unit Refrigerating Systems (Feb. 1946).                              | UL         | UL Subject 207C                      |
| Refrigerators (Gas-Fired)       | American Standard Approval Requirements for Refrigerators Using Gas Fuel (1942, Reaffirmed 1950).                   | A.G.A.     | ASA Z21.19-1941                      |
| Refrigerators (Household)       | American Standard Test Procedures for Household Electric Refrigerators (Mechanically Operated) (1944).              | ASRE USDA  | ASA B38.2-1944                       |
| Sound (Measurement)             | American Standard for Noise Measurement.                                                                            | AS of A    | ASA Z24.2-1941                       |
| Sound (Measurement)             | American Standard for Sound Level Meters for Measurement of Noise and Other Sounds.                                 | AS of A    | ASA Z24.3-1944                       |
| Sound (Measurement)             | American Standard Method for the Pressure Calibration of Laboratory Standard Pressure Microphones.                  | AS of A    | ASA Z24.4-1949                       |
| Sound (Measurement)             | Sound Measurement Test Code for Centrifugal and Axial Fans (1950) (Was NAFM Bulletin No. 104).                      | NAFM       | NAFM Bulletin No. 110 (1950)         |
| Sound (Measurement)             | Sound Measurement Test Code for Unit Heaters (1955).                                                                | IUHA       | IUHA Bulletin No. 13                 |
| Space Heaters                   | Commercial Standard for Flue-Connected Oil-Burning Space Heaters Equipped with Vaporizing Pot-Type Burners (1943).  | ICHAM      | BS CS101-43                          |

\*\*\* Also designated ASRE Circular No. 15.

TABLE 1. CODES AND STANDARDS (Concluded)

| SUBJECT                                   | TITLE                                                                                               | SPONSOR    | REFERENCE                           |
|-------------------------------------------|-----------------------------------------------------------------------------------------------------|------------|-------------------------------------|
| Stokers                                   | Code for Determination of Rated Capacities of Anthracite Underfeed Stokers (1944).                  | SMA        | SMA                                 |
| Stokers                                   | Code for Determination of Rated Capacities of Bituminous Underfeed Stokers (1944).                  | SMA        | SMA                                 |
| Stokers                                   | Recommended Minimum Firebox Dimensions and Base Heights (1944).                                     | SMA        | SMA                                 |
| Stokers                                   | Recommended Standards Governing Minimum Setting Heights (1944).                                     | SMA        | SMA                                 |
| Tubing (Seamless Copper and Copper Alloy) | Simplified Practice Recommendation for Copper and Copper-Alloy Round Seamless Tube (1948).          | Mfrs. BS   | BS R235-48                          |
| Tubing (Seamless Copper Water Tube)       | Standard Specifications for Seamless Copper Water Tube (1951).                                      | ASTM       | ASA H23.1-1951                      |
| Unfired Pressure Vessels                  | Unfired Pressure Vessel Code (1950).                                                                | ASME       | ASME                                |
| Unit Heaters                              | American Standard Approval Requirements for Gas Unit Heaters (1951 with 1953 Addenda).              | A.G.A.     | ASA Z21.16-1951                     |
| Unit Heaters                              | Standard Code for Testing and Rating Steam Unit Heaters (1950).                                     | ASHVE IUHA | IUHA Bulletin 10                    |
| Unit Heaters                              | Standard Code for Testing Hot Water Unit Heaters (1942).                                            | IUHA       | IUHA Bulletin 11                    |
| Unit Ventilators                          | A.S.H.V.E. Standard Code for Testing and Rating Steam Unit Ventilators (1934).                      | ASHVE      | ASHAE                               |
| Vacuum Pumps                              | A.S.H.V.E. Standard Code for Testing and Rating Return Line Low Vacuum Heating Pumps (1934).        | ASHVE      | ASHAE                               |
| Warm Air (Gravity)                        | Gravity Code and Manual for the Design and Installation of Gravity Warm Air Heating Systems (1947). | NWAH & ACA | NWAH & ACA Manual No. 5 5th Edition |
| Water Heaters                             | American Standard Household Automatic Electric Storage-type Water Heaters.                          | NEMA       | ASA C72.1-1949                      |
| Water Heaters                             | American Standard Approval Requirements for Gas Water Heaters (with 1954 Addenda).                  | A.G.A.     | ASA Z21.10-1953                     |
| Water Heaters                             | NEMA Standards for Electric Water Heaters (1945).                                                   | NEMA       | NEMA 45-104                         |
| Water Heaters                             | Testing and Rating Hand-Fired Hot Water Supply Boilers (1948).                                      | FHA        | BS CS145-47                         |
| Wiring                                    | Interior Wiring Design for Commercial Buildings.                                                    | AIEE       | AIEE                                |
| Wiring                                    | National Electrical Code, (1953).                                                                   | NFPA       | NFPA or NFBU Pamphlet No. 70.       |

## ABBREVIATIONS AND ADDRESSES

The Codes and Standards listed in preceding pages of this table can be obtained from the organizations listed in the *Reference Column*.

ACMA Air Conditioning Manufacturers Association, superseded 1940 by ACRMA.  
 ACRMA Air Conditioning and Refrigerating Machinery Association, Southern Bldg., Washington, D. C. superseded 1953 by ARI.  
 AFA American Foundrymen's Association, 616 S. Michigan Ave., Chicago, Ill.  
 AFI Air Filter Institute, 215 Central Ave., Louisville, Ky.  
 A.G.A. American Gas Association, 420 Lexington Ave., New York 17, N. Y.

## ABBREVIATIONS AND ADDRESSES (Concluded)

|            |                                                                                                                                                  |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| AGAEM      | Association of Gas Appliance and Equipment Manufacturers, superseded 1945 by GAMA.                                                               |
| AIA        | American Institute of Architects, 1741 New York Ave., Washington, D. C.                                                                          |
| AIEE       | American Institute of Electrical Engineers, 33 West 39th St., New York 18, N. Y.                                                                 |
| AIHA       | American Industrial Hygiene Association, 4400 Fifth Ave., Pittsburgh 13, Pa.                                                                     |
| AIL        | Anthracite Industries Laboratory, 237 Old River Rd., Wilkes Barre, Pa.                                                                           |
| ARI        | Air-Conditioning and Refrigeration Institute, 1345 Connecticut Ave., N. W. Washington, D. C.                                                     |
| ASA        | American Standards Association, 70 East 45th St., New York 17, N. Y.                                                                             |
| AS of A    | Acoustical Society of America, 205 West Monroe St., Chicago, Ill.                                                                                |
| ASHAE      | American Society of Heating and Air-Conditioning Engineers, 62 Worth St., New York 13, N. Y.                                                     |
| ASHVE      | American Society of Heating and Ventilating Engineers, name changed to American Society of Heating and Air-Conditioning Engineers, Dec. 8, 1954. |
| ASME       | American Society of Mechanical Engineers, 29 West 39th St., New York 18, N. Y.                                                                   |
| ASRE       | American Society of Refrigerating Engineers, 234 Fifth Ave., New York, N. Y.                                                                     |
| ASTM       | American Society for Testing Materials, 1916 Race St., Philadelphia, Pa.                                                                         |
| BCMI       | Blast Coil Manufacturers Institute, superseded by Heating and Cooling Coil Manufacturers Association, HCCMA.                                     |
| BCR*       | Bituminous Coal Research, Inc., 2609 First National Bank Bldg., Pittsburgh 22, Pa.                                                               |
| BOCA       | Building Officials Conference of America, 110 East 42nd St., New York 17, N. Y.                                                                  |
| BS         | National Bureau of Standards, Washington, D. C.                                                                                                  |
| CSD        | Commodity Standards Division, U. S. Dept. of Commerce, Washington, D. C.                                                                         |
| CMA        | Convactor Manufacturers Association, 2159 Guardian Bldg., Detroit, Mich.                                                                         |
| CTI        | Cooling Tower Institute, 444 Emerson St., Palo Alto, Calif.                                                                                      |
| FHA        | Federal Housing Administration, Washington, D. C.                                                                                                |
| GAMA       | Gas Appliance Manufacturers' Association, 60 East 42nd St., New York 17, N. Y.                                                                   |
| HCCMA      | Heating and Cooling Coil Manufacturers Association, 2159-Guardian Bldg., Detroit, Mich.                                                          |
| HI         | Hydraulic Institute, 122 East 42nd St., New York 17, N. Y.                                                                                       |
| HP & ACCNA | Heating, Piping and Air Conditioning Contractors National Association, Suite 1843, 30 Rockefeller Plaza, New York 20, N. Y.                      |
| IBR        | Institute of Boiler and Radiator Manufacturers, 608 5th Ave., New York, N. Y.                                                                    |
| ICHAM      | Institute of Cooking and Heating Appliance Manufacturers, Shoreham Hotel, Washington, D. C.                                                      |
| IMFI       | Industrial Mineral Fiber Institute, 441 Lexington Ave., New York 17, N. Y.                                                                       |
| IMWI       | Industrial Mineral Wool Institute, superseded 1953 by IMFI.                                                                                      |
| IUHA       | Industrial Unit Heater Association, 2159 Guardian Bldg., Detroit, Mich.                                                                          |
| NAPM       | National Association of Fan Manufacturers, 2159 Guardian Bldg., Detroit, Mich.                                                                   |
| NBFU       | National Board of Fire Underwriters, 85 John St., New York 8, N. Y.                                                                              |
| NEMA       | National Electrical Manufacturers Association, 155 East 44th St., New York 17, N. Y.                                                             |
| NFPA       | National Fire Protection Association, 60 Battery March St., Boston 10, Mass.                                                                     |
| NHA        | National Housing Agency, Washington, D. C.                                                                                                       |
| NRC        | National Research Council, 2101 Constitution Ave., Washington, D. C.                                                                             |
| NWAH & ACA | National Warm Air Heating and Air Conditioning Association, 640 Engineers Bldg., Cleveland, Ohio.                                                |
| OBI        | Oil Burner Institute, superseded 1942 by OHIA                                                                                                    |
| OHIA       | Oil Heat Institute of America, Room 1618 (Lower Level) 500 Fifth Ave., New York 36, N. Y.                                                        |
| OPA        | Office of Price Administration, Washington, D. C.                                                                                                |
| PC         | Producers Council, 1001-15th St., N.W., Washington, D. C.                                                                                        |
| PFMA       | Propeller Fan Manufacturers Association, 2159 Guardian Bldg., Detroit, Mich.                                                                     |
| PHMI       | Prefabricated Home Manufacturers Institute, 908 20th St., N.W., Washington 6, D. C.                                                              |
| REMA       | Refrigeration Equipment Manufacturers Association, superseded 1953 by ARI.                                                                       |
| RMA        | Refrigerating Machinery Association. See ACRMA.                                                                                                  |
| SAE        | Society of Automotive Engineers, 29 West 39th St., New York, N. Y.                                                                               |
| SBI        | Steel Boiler Institute, 1308 Land Title Bldg., Philadelphia 10, Pa.                                                                              |
| SMA        | Stoker Manufacturers Association, 307 N. Michigan Ave., Chicago 1, Ill.                                                                          |
| TEMA       | Tubular Exchanger Manufacturers Association, 53 Park Place, New York, N. Y.                                                                      |
| UL         | Underwriters' Laboratories, 207 East Ohio St., Chicago, Ill.                                                                                     |
| USDA       | United States Department of Agriculture, Washington, D. C.                                                                                       |
| USPHS      | United States Public Health Service, Washington, D. C.                                                                                           |

## SPECIFIC HEAT

TABLE 1. SPECIFIC HEAT OF SOLIDS\*

| MATERIALS           | TEMPERATURE F | SPECIFIC HEAT | AUTHORITY |
|---------------------|---------------|---------------|-----------|
| Alloys              |               |               |           |
| Brass, Red          | 32            | 0.0899        | S         |
| Brass, Yellow       | 32            | 0.0833        | S         |
| Bronze (80Cu, 20Sn) | 57-208        | 0.0862        | S         |
| Monel Metal         | 68-2370       | 0.127         | S         |
| Aluminum            | 80-212        | 0.212         | S         |
| Asbestos            | 68-208        | 0.195         | S         |
| Brickwork           |               | 0.195         | S         |
| Carbon (Graphite)   | 104-1637      | 0.314         | H         |
| Coal                |               | 0.278         | I         |
| Coke                |               | 0.201         | H         |
| Concrete            |               | 0.270         | H         |
| Copper              | 64-212        | 0.0928        | S         |
| Fire Clay Brick     | 77-1832       | 0.258         | I         |
| Glass               |               |               |           |
| Crown               | 50-122        | 0.161         | S         |
| Flint               | 50-122        | 0.117         | S         |
| Gold                | 64            | 0.0312        | S         |
| Gypsum              |               | 0.259         | H         |
| Ice                 | 32            | 0.487         | S         |
| Ice                 | -40           | 0.434         | S         |
| Iron, Pure          | 32            | 0.1043        | S         |
| Iron, Pure          | 32-600        | 0.127         | S         |
| Iron, Cast          | 68-212        | 0.1189        | M         |
| Iron, Wrought       | 59-212        | 0.1182        | H         |
| Lead                | 32            | 0.0297        | S         |
| Nickel              | 32            | 0.1032        | S         |
| Masonry             |               | 0.2159        | H         |
| Plaster             |               | 0.2           | H         |
| Platinum            | 58-212        | 0.0319        | S         |
| Rocks               |               |               |           |
| Gneiss              | 63-210        | 0.196         | S         |
| Granite             | 54-212        | 0.192         | S         |
| Limestone           | 59-212        | 0.216         | S         |
| Marble              | 32-212        | 0.21          | S         |
| Sandstone           |               | 0.22          | S         |
| Silver              | 32            | 0.0536        | S         |
| Steel               |               | 0.1175        | H         |
| Sulphur             | 240-320       | 0.220         | S         |
| Silica Brick        | 77-1832       | 0.263         | I         |
| Tin                 | 77            | 0.0548        | S         |
| Woods (Average)     | 68            | 0.327         | S         |
| Zinc                | 32            | 0.0913        | S         |

TABLE 2. SPECIFIC HEAT OF LIQUIDS

| LIQUID          | TEMPERATURE F | SPECIFIC HEAT | AUTHORITY |
|-----------------|---------------|---------------|-----------|
| Alcohol, Ethyl  | 32            | 0.548         | S         |
| Alcohol, Methyl | 59-68         | 0.601         | S         |
| Glycerine       | 59-122        | 0.576         | S         |
| Lead (Molten)   | 360           | 0.041         | H         |
| Mercury         | 68            | 0.03325       | S         |
| Petroleum       | 70-136        | 0.511         | S         |
| Sea Water       |               |               |           |
| Sp Gr 1.0043    | 64            | 0.980         | S         |
| Sp Gr 1.0463    | 64            | 0.903         | S         |
| Water           | 59            | 1.000         | S         |

TABLE 3. SPECIFIC HEAT OF GASES AND VAPORS

| SUBSTANCE       | TEMPERATURE F | SPECIFIC HEAT AT CONSTANT PRESSURE | RATIO OF SPECIFIC HEAT $C_p/C_v$ | SPECIFIC HEAT AT CONSTANT VOLUME (COMPUTED) | AUTHORITY |
|-----------------|---------------|------------------------------------|----------------------------------|---------------------------------------------|-----------|
| Air             | 32-392        | 0.2375                             | 1.405                            | 0.169                                       | S         |
| Ammonia         | 80-392        | 0.5356                             | 1.277                            | 0.419                                       | S         |
| Carbon Dioxide  | 32-417        | 0.2169                             | 1.3003                           | 0.1668                                      | S         |
| Carbon Monoxide | 79-388        | 0.2426                             | 1.395                            | 0.1736                                      | S         |
| Coal Gas        | 68-1900       | 0.3145                             |                                  |                                             | S         |
| Flue Gas        |               | 0.24 (Approx.)                     |                                  |                                             | H         |
| Hydrogen        | 70-212        | 3.41                               | 1.419                            | 2.402                                       | S         |
| Nitrogen        | 32-392        | 0.2438                             | 1.41                             | 0.1729                                      | S         |
| Oxygen          | 55-404        | 0.2175                             | 1.3977                           | 0.155                                       | S         |
| Water Vapor     | 212           | 0.421                              | 1.305                            | 0.322                                       | S         |
| Water Vapor     | 356           | 0.51                               |                                  |                                             | S         |

\* See also The Specific Heat of Thermal Insulating Materials, by Gordon B. Wilkes and Carl O. Wood (A.S.H.V.E. TRANSACTIONS, Vol. 48, 1942, p. 493).

NOTES: When one temperature is given the true specific heat is given, otherwise the value is the mean specific heat between the given limits.

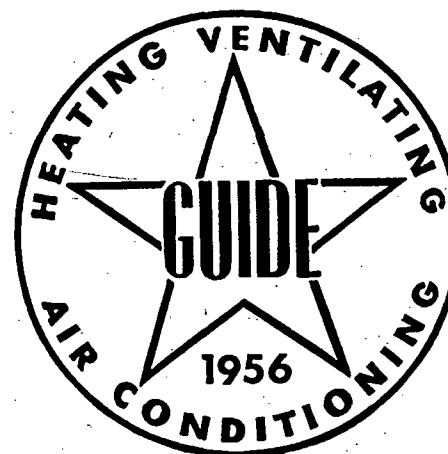
AUTHORITIES: S—Smithsonian Physical Tables, 1933; I—International Critical Tables; H—Heating, Ventilation and Air Conditioning, by L. A. Harding and A. C. Willard; M—Engineers' Handbook, by Lionel S. Marks.



TABLE 4. CIRCUMFERENCES AND AREAS OF CIRCLES

| DIAM-<br>ETER<br>IN<br>INCHES | AREA   |        | CIRCUMFERENCE |        | DIAMETER<br>IN<br>INCHES | AREA   |       | CIRCUMFERENCE |       |
|-------------------------------|--------|--------|---------------|--------|--------------------------|--------|-------|---------------|-------|
|                               | Sq In. | Sq Ft  | Inches        | Feet   |                          | Sq In. | Sq Ft | Inches        | Feet  |
| 1/4                           | 0.049  | 0.0003 | 0.785         | 0.0652 | 28                       | 615.8  | 4.276 | 87.97         | 7.330 |
| 1/2                           | 0.196  | 0.0014 | 1.571         | 0.1309 | 28 1/4                   | 637.9  | 4.430 | 89.54         | 7.462 |
| 3/4                           | 0.442  | 0.0031 | 2.356         | 0.1964 | 29                       | 660.52 | 4.587 | 91.11         | 7.592 |
| 1                             | 0.785  | 0.0054 | 3.142         | 0.2618 | 29 1/4                   | 683.5  | 4.747 | 92.63         | 7.725 |
| 1 1/4                         | 1.227  | 0.0085 | 3.927         | 0.3273 | 30                       | 706.8  | 4.909 | 94.25         | 7.854 |
| 1 1/2                         | 1.767  | 0.0123 | 4.712         | 0.3927 | 31                       | 754.8  | 5.241 | 97.39         | 8.116 |
| 1 3/4                         | 2.405  | 0.0167 | 5.498         | 0.4582 | 32                       | 804.3  | 5.585 | 100.5         | 8.378 |
| 2                             | 3.142  | 0.0218 | 6.283         | 0.5236 | 33                       | 855.3  | 5.940 | 103.7         | 8.639 |
| 2 1/4                         | 3.976  | 0.0276 | 7.069         | 0.5891 | 34                       | 907.9  | 6.305 | 106.8         | 8.901 |
| 2 1/2                         | 4.909  | 0.0341 | 7.854         | 0.6546 | 35                       | 962.1  | 6.681 | 109.9         | 9.163 |
| 2 3/4                         | 5.939  | 0.0412 | 8.639         | 0.7200 | 36                       | 1018.0 | 7.069 | 113.1         | 9.425 |
| 3                             | 7.069  | 0.0491 | 9.425         | 0.7854 | 37                       | 1075.0 | 7.467 | 116.2         | 9.688 |
| 3 1/4                         | 8.296  | 0.0576 | 10.21         | 0.8510 | 38                       | 1134.0 | 7.876 | 119.4         | 9.948 |
| 3 1/2                         | 9.621  | 0.0668 | 10.99         | 0.9160 | 39                       | 1195.0 | 8.296 | 122.5         | 10.21 |
| 3 3/4                         | 11.04  | 0.0767 | 11.78         | 0.9818 | 40                       | 1256.0 | 8.727 | 125.6         | 10.47 |
| 4                             | 12.57  | 0.0873 | 12.57         | 1.047  | 41                       | 1320.0 | 9.168 | 128.8         | 10.73 |
| 4 1/4                         | 14.19  | 0.0986 | 13.35         | 1.113  | 42                       | 1385.0 | 9.621 | 131.9         | 10.99 |
| 4 1/2                         | 15.90  | 0.1104 | 14.14         | 1.178  | 43                       | 1452.0 | 10.08 | 135.1         | 11.26 |
| 4 3/4                         | 17.72  | 0.1231 | 14.92         | 1.243  | 44                       | 1521.0 | 10.56 | 138.2         | 11.52 |
| 5                             | 19.64  | 0.1364 | 15.71         | 1.309  | 45                       | 1590.0 | 11.04 | 141.4         | 11.78 |
| 5 1/4                         | 21.65  | 0.1504 | 16.49         | 1.374  | 46                       | 1662.0 | 11.54 | 144.5         | 12.04 |
| 5 1/2                         | 23.76  | 0.1650 | 17.28         | 1.440  | 47                       | 1735.0 | 12.05 | 147.7         | 12.30 |
| 5 3/4                         | 25.97  | 0.1804 | 18.06         | 1.505  | 48                       | 1810.0 | 12.51 | 150.8         | 12.57 |
| 6                             | 28.27  | 0.1964 | 18.85         | 1.571  | 49                       | 1886.0 | 13.09 | 153.9         | 12.83 |
| 6 1/4                         | 30.68  | 0.2131 | 19.64         | 1.637  | 50                       | 1963.0 | 13.64 | 157.1         | 13.09 |
| 6 1/2                         | 33.18  | 0.2304 | 20.42         | 1.702  | 51                       | 2043.0 | 14.19 | 160.2         | 13.35 |
| 6 3/4                         | 35.79  | 0.2486 | 21.21         | 1.768  | 52                       | 2124.0 | 14.75 | 163.4         | 13.61 |
| 7                             | 38.49  | 0.2673 | 21.99         | 1.833  | 53                       | 2206.0 | 15.32 | 166.5         | 13.88 |
| 7 1/4                         | 41.28  | 0.2867 | 22.78         | 1.899  | 54                       | 2290.0 | 15.90 | 169.6         | 14.14 |
| 7 1/2                         | 44.18  | 0.3068 | 23.56         | 1.964  | 55                       | 2376.0 | 16.50 | 172.8         | 14.40 |
| 7 3/4                         | 47.17  | 0.3276 | 24.35         | 2.029  | 56                       | 2463.0 | 17.10 | 175.9         | 14.66 |
| 8                             | 50.27  | 0.3491 | 25.13         | 2.094  | 57                       | 2552.0 | 17.72 | 179.1         | 14.92 |
| 8 1/4                         | 53.46  | 0.3713 | 25.92         | 2.160  | 58                       | 2642.0 | 18.35 | 182.2         | 15.18 |
| 8 1/2                         | 56.75  | 0.3942 | 26.70         | 2.225  | 59                       | 2734.0 | 18.99 | 185.4         | 15.45 |
| 8 3/4                         | 60.13  | 0.4175 | 27.49         | 2.291  | 60                       | 2827.0 | 19.63 | 188.5         | 15.71 |
| 9                             | 63.62  | 0.4418 | 28.27         | 2.356  | 61                       | 2922.0 | 20.29 | 191.6         | 15.97 |
| 9 1/4                         | 67.20  | 0.4668 | 29.06         | 2.422  | 62                       | 3019.0 | 20.97 | 194.8         | 16.23 |
| 9 1/2                         | 70.88  | 0.4923 | 29.85         | 2.488  | 63                       | 3117.0 | 21.65 | 197.9         | 16.49 |
| 9 3/4                         | 74.66  | 0.5185 | 30.63         | 2.553  | 64                       | 3217.0 | 22.34 | 201.1         | 16.76 |
| 10                            | 78.54  | 0.5454 | 31.42         | 2.618  | 65                       | 3318.0 | 23.04 | 204.2         | 17.02 |
| 10 1/4                        | 82.59  | 0.6010 | 32.29         | 2.750  | 66                       | 3421.0 | 23.76 | 207.3         | 17.28 |
| 10 1/2                        | 85.03  | 0.6600 | 33.06         | 2.880  | 67                       | 3526.0 | 24.48 | 210.5         | 17.54 |
| 10 3/4                        | 103.9  | 0.7215 | 33.83         | 3.011  | 68                       | 3632.0 | 25.22 | 213.6         | 17.80 |
| 11                            | 113.1  | 0.7854 | 34.61         | 3.142  | 69                       | 3739.0 | 25.97 | 216.8         | 18.06 |
| 11 1/4                        | 122.7  | 0.8520 | 35.39         | 3.273  | 70                       | 3848.0 | 26.73 | 219.9         | 18.33 |
| 11 1/2                        | 132.7  | 0.9218 | 36.17         | 3.403  | 71                       | 3959.0 | 27.49 | 223.1         | 18.59 |
| 11 3/4                        | 143.1  | 0.9937 | 36.95         | 3.535  | 72                       | 4072.0 | 28.27 | 226.2         | 18.85 |
| 12                            | 153.9  | 1.069  | 37.73         | 3.665  | 73                       | 4185.0 | 29.07 | 229.3         | 19.11 |
| 12 1/4                        | 165.1  | 1.146  | 38.51         | 3.796  | 74                       | 4301.0 | 29.87 | 232.5         | 19.37 |
| 12 1/2                        | 176.7  | 1.227  | 39.29         | 3.927  | 75                       | 4418.0 | 30.68 | 235.6         | 19.63 |
| 12 3/4                        | 188.7  | 1.310  | 40.06         | 4.058  | 76                       | 4536.0 | 31.50 | 238.8         | 19.90 |
| 13                            | 201.1  | 1.396  | 40.83         | 4.189  | 77                       | 4657.0 | 32.34 | 241.9         | 20.16 |
| 13 1/4                        | 213.8  | 1.485  | 41.61         | 4.321  | 78                       | 4778.0 | 33.18 | 245.0         | 20.42 |
| 13 1/2                        | 226.9  | 1.576  | 42.39         | 4.451  | 79                       | 4902.0 | 34.04 | 248.2         | 20.68 |
| 13 3/4                        | 240.5  | 1.670  | 43.17         | 4.582  | 80                       | 5027.0 | 34.91 | 251.3         | 20.94 |
| 14                            | 254.5  | 1.767  | 43.95         | 4.712  | 81                       | 5153.0 | 35.78 | 254.5         | 21.21 |
| 14 1/4                        | 268.8  | 1.867  | 44.73         | 4.845  | 82                       | 5281.0 | 36.67 | 257.6         | 21.47 |
| 14 1/2                        | 283.5  | 1.969  | 45.51         | 4.974  | 83                       | 5411.0 | 37.57 | 260.8         | 21.73 |
| 14 3/4                        | 298.6  | 2.074  | 46.29         | 5.105  | 84                       | 5542.0 | 38.48 | 263.9         | 21.99 |
| 15                            | 314.2  | 2.182  | 47.07         | 5.236  | 85                       | 5675.0 | 39.41 | 267.0         | 22.25 |
| 15 1/4                        | 330.1  | 2.293  | 47.85         | 5.367  | 86                       | 5809.0 | 40.34 | 270.2         | 22.51 |
| 15 1/2                        | 346.4  | 2.405  | 48.63         | 5.498  | 87                       | 5945.0 | 41.28 | 273.3         | 22.78 |
| 15 3/4                        | 361.1  | 2.508  | 49.41         | 5.629  | 88                       | 6082.0 | 42.24 | 276.5         | 23.04 |
| 16                            | 380.1  | 2.640  | 50.19         | 5.760  | 89                       | 6221.0 | 43.20 | 279.6         | 23.30 |
| 16 1/4                        | 397.6  | 2.761  | 50.97         | 5.891  | 90                       | 6362.0 | 44.18 | 282.7         | 23.56 |
| 16 1/2                        | 415.5  | 2.885  | 51.75         | 6.021  | 91                       | 6504.0 | 45.17 | 285.9         | 23.82 |
| 16 3/4                        | 433.7  | 3.012  | 52.53         | 6.153  | 92                       | 6648.0 | 46.16 | 289.0         | 24.09 |
| 17                            | 452.4  | 3.142  | 53.31         | 6.283  | 93                       | 6793.0 | 47.17 | 292.2         | 24.35 |
| 17 1/4                        | 471.4  | 3.274  | 54.09         | 6.415  | 94                       | 6940.0 | 48.19 | 295.3         | 24.61 |
| 17 1/2                        | 490.9  | 3.409  | 54.87         | 6.545  | 95                       | 7088.0 | 49.22 | 298.4         | 24.87 |
| 17 3/4                        | 510.7  | 3.547  | 55.65         | 6.676  | 96                       | 7238.0 | 50.27 | 301.6         | 25.13 |
| 18                            | 530.9  | 3.687  | 56.43         | 6.807  | 97                       | 7390.0 | 51.32 | 304.7         | 25.39 |
| 18 1/4                        | 551.6  | 3.832  | 57.21         | 6.938  | 98                       | 7543.0 | 52.38 | 307.9         | 25.66 |
| 18 1/2                        | 572.6  | 3.976  | 58.00         | 7.069  | 99                       | 7698.0 | 53.46 | 311.0         | 25.92 |
| 18 3/4                        | 593.9  | 4.125  | 58.79         | 7.199  | 100                      | 7854.0 | 54.54 | 314.2         | 26.18 |

## CATALOG DATA SECTION



INDEX TO ADVERTISERS

PAGE 1179

INDEX TO MODERN  
EQUIPMENT

PAGE 1187

# CATALOG DATA SECTION

• • •

## INDEX TO ADVERTISERS

### HEATING VENTILATING AIR CONDITIONING GUIDE, 1956

#### A

|                                                                                                            |                     |
|------------------------------------------------------------------------------------------------------------|---------------------|
| A-J MFG. CO., 3601 E. 18 St., Kansas City 27, Mo.                                                          | 1426-1427           |
| ACME INDUSTRIES, INC., Jackson, Mich.                                                                      | 1358                |
| ADDISON PRODUCTS CO., Addison, Mich.                                                                       | 1243                |
| AERCO CORP., Paris Ave., P.O. Box 248, Northvale, N. J.                                                    | 1595                |
| AEROFIN CORP., 101 Greenway Ave., Syracuse 1, N. Y.                                                        | 1359-1360           |
| AEROQUIP CORP., Jackson, Mich.                                                                             | 1312                |
| AEROVENT FAN CO., INC., Ash & Blade Sts., Piqua, Ohio                                                      | 1374                |
| AIR & REFRIGERATION CORP., 439 Madison Ave., New York 22, N. Y.                                            | 1219                |
| AIR CONDITIONING, HEATING and VENTILATING (publication), 93<br>Worth St., New York 13, N. Y.               | 1689                |
| AIR CONTROL PRODUCTS, INC., Coopersville, Mich.                                                            | 1428-1429-1430-1431 |
| AIR DEVICES, INC., 185 Madison Ave., New York 16, N. Y.                                                    | 1316, 1432          |
| AIR-FACTORS, INC., 1624 S. Raymond Ave., Monrovia, Calif.                                                  | 1433                |
| AIR FAN ENGINEERING CO., 7401 Telegraph Rd., Los Angeles 22, Calif.                                        | 1343                |
| AIR FILTER CORP., 108G N. Water St., Milwaukee 2, Wis.                                                     | 1317                |
| AIR-MAZE CORP., 25000 Miles Rd., Cleveland 28, Ohio                                                        | 1318                |
| AIRTEMP DIV. OF CHRYSLER CORP., Dayton 1, Ohio                                                             | 1248-1249           |
| AIRTHERM MFG. CO., 728 S. Spring Ave., St. Louis 10, Mo.                                                   | 1522                |
| ALADDIN HEATING CORP., 1111 West Ave. 137, San Leandro, Calif.                                             | 1375                |
| ALCO VALVE CO., 851 Kingsland Ave., St. Louis 5, Mo.                                                       | 1472                |
| ALDRICH CO., 121 E. Williams St., Wyoming, Ill.                                                            | 1541                |
| ALLEN COOLER AND VENTILATOR, INC., 704 Woodward, Rochester, Mich.                                          | 1414                |
| AMERICAN AIR FILTER CO., INC., 673 Central Ave., Louisville 8, Ky.                                         | 1319-1320-1321      |
| AMERICAN ARTISAN (publication), 6 N. Michigan Ave., Chicago 2, Ill.                                        | 1694                |
| AMERICAN BLOWER CORP., P. O. Box 58, Roosevelt Park Annex, Detroit<br>32, Mich.                            | 1220-1221           |
| AMERICAN BRASS CO., THE, Waterbury 20, Conn.                                                               | 1310-1311           |
| AMERICAN DISTRICT STEAM DIV., ADSCO INDUSTRIES, INC., North<br>Tonawanda, N. Y.                            | 1505, 1594          |
| AMERICAN FLANGE & MFG. CO., INC., 30 Rockefeller Plaza, New York 20,<br>N. Y.                              | 1678                |
| AMERICAN FOUNDRY & FURNACE CO., P. O. Box 904, Bloomington, Ill.                                           | 1266-1267           |
| AMERICAN GILSONITE CO., Salt Lake City, Utah                                                               | 1646                |
| AMERICAN MOISTENING CO., Providence 1, R. I.                                                               | 1222                |
| AMERICAN RADIATOR & STANDARD SANITARY CORP., (Plumbing &<br>Heating Div.), New York 18, N. Y.              | 1523-1524-1525      |
| AMERICAN SOCIETY OF REFRIGERATING ENGINEERS, 40 West 40th<br>St., New York 18, N. Y.                       | 1690                |
| AMERICAN-STANDARD, Air Conditioning Div., Elyria, Ohio                                                     | 1244-1245           |
| AMERICAN 3 WAY-LUXFER PRISM CO., 431 S. Dearborn St., Chicago 5,<br>Ill.                                   | 1660                |
| C. L. AMMERMAN CO., 110 N. Second St., Minneapolis 1, Minn.                                                | 1415                |
| V. D. ANDERSON CO., THE, DIV. OF INTERNATIONAL BASIC ECONOMY<br>CORP., 1935 West 96th St., Cleveland, Ohio | 1612-1613           |
| ANEMOSTAT CORP. OF AMERICA, 10 East 39th St., New York 16, N. Y.                                           | 1434-1435           |
| APRIL SHOWERS CO., INC., 4126 Eighth St., N.W., Washington 11, D. C.                                       | 1644                |

|                                                                                           |           |
|-------------------------------------------------------------------------------------------|-----------|
| ARMSTRONG CORK CO., Lancaster, Pa.                                                        | 1665      |
| ARMSTRONG FURNACE CO., Columbus, Ohio                                                     | 1246-1247 |
| ARMSTRONG MACHINE WORKS, 851 Maple St., Three Rivers, Mich.                               | 1614-1615 |
| AUER REGISTER CO., THE, 6600 Clement Ave., Cleveland 5, Ohio                              | 1436      |
| AURORA PUMP DIV. THE NEW YORK AIR BRAKE CO., 40 Loucks St., Aurora (Chicago Suburb), Ill. | 1603      |

## B

|                                                                                                   |            |
|---------------------------------------------------------------------------------------------------|------------|
| BABCOCK & WILCOX CO., THE, 161 East 42nd St., New York 17, N. Y.                                  | 1542       |
| BADGER MFG. CO., 230 Bent St., Cambridge 41, Mass.                                                | 1506       |
| BAHNSON CO., THE, Winston-Salem, N. C.                                                            | 1223       |
| BALTIMORE AIRCOIL CO., INC., 2615 Mathews St., Baltimore 18, Md.                                  | 1346       |
| BARBER-COLMAN CO., 150 Loomis, Rockford, Ill.                                                     | 1437, 1473 |
| BARNEBEY-CHENEY CO., Cassidy & 8th Aves., Columbus 19, Ohio                                       | 1322-1323  |
| BARNES & JONES, INC., 34 Crafts St., Newtonville, Mass.                                           | 1616       |
| BAYLEY BLOWER CO., 1821 S. Sixty-Sixth St., Milwaukee 14, Wis.                                    | 1376       |
| BELL & GOSSETT CO., Morton Grove, Ill.                                                            | 1598-1599  |
| BINKS MFG. CO., 3130-36 Carroll Ave., Chicago 12, Ill.                                            | 1344-1345  |
| BISHOP & BABCOCK MFG. CO., THE, MASSACHUSETTS BLOWER DIV., 4901 Hamilton Ave., Cleveland 14, Ohio | 1377       |
| G. C. BREIDERT CO., THE, P.O. Box 1190, San Fernando, Calif.                                      | 1416       |
| BRONSON FAN MFG. CORP., 4560 Worth St., Los Angeles 63, Calif.                                    | 1378       |
| BROOKSIDE PRODUCTS CO., INC., McCordsville, Ind.                                                  | 1379       |
| BRUNDAGE CO., THE, 530 N. Park St., Kalamazoo, Mich.                                              | 1380-1381  |
| BRUNNER MFG. CO., Dept. M-56, Utica, N. Y.                                                        | 1368       |
| BRYAN STEAM CORP., Chili Pike, Peru, Ind.                                                         | 1543       |
| BUENSOD-STACEY, INC., 60 East 42nd St., New York 17, N. Y.                                        | 1224       |
| BUFFALO FORGE CO., 450 Broadway, Buffalo, N. Y.                                                   | 1382       |
| BUFFALO PUMPS, DIV. OF BUFFALO FORGE CO., 450 Broadway, Buffalo, N. Y.                            | 1604       |
| ALAN E. BURDEN CO., INC., 1940-50 Pontius Ave., Los Angeles 25, Calif.                            | 1383       |
| BURGESS-MANNING CO., 5970 Northwest Highway, Chicago 31, Ill.                                     | 1438       |
| BURNHAM CORP., Irvington-on-Hudson, N. Y.                                                         | 1526-1527  |

## C

|                                                                                            |                      |
|--------------------------------------------------------------------------------------------|----------------------|
| CAMBRIDGE FILTER CORP., 736 East Erie Blvd., Syracuse 3, N. Y.                             | 1324                 |
| E. K. CAMPBELL CO., 1809 Manchester, Kansas City 26, Mo.                                   | 1270                 |
| CAMPBELL HEATING CO., 3121 Dean, Des Moines 17, Iowa                                       | 1268-1269            |
| CAM-STAT, INC., DIV. OF THE PAUL HENRY CO., 11831 W. Olympic Blvd., Los Angeles 64, Calif. | 1474                 |
| CAREY ELECTRONIC ENGINEERING CO., Metal Wool Div., 1875 Clifton Ave., Springfield, Ohio    | 1325                 |
| PHILIP CAREY MFG. CO., THE, Lockland, Cincinnati 15, Ohio                                  | 1656-1657            |
| CARRIER CORP., Syracuse 1, N. Y.                                                           | 1226-1227            |
| A. W. CASH CO., P. O. Box 551, Decatur, Ill.                                               | 1617                 |
| CELOTEX CORP., THE, 120 S. LaSalle St., Chicago 3, Ill.                                    | 1666                 |
| CENTURY FAN & VENTILATOR CO., INC., 45 Cedar St., Stamford, Conn.                          | 1384                 |
| CHAMPION BLOWER & FORGE CO., Div. 9, Lancaster, Pa.                                        | 1385                 |
| CHICAGO BLOWER CORP., 9865 Pacific Ave., Franklin Park, Ill.                               | 1386                 |
| CHICAGO PUMP CO., 622 W. Diversey Parkway, Chicago 14, Ill.                                | 1606-1607            |
| CHICAGO STEEL FURNACE CO., 9326 S. Anthony Ave., Chicago 17, Ill.                          | 1271                 |
| CHRYSLER AIRTEMP, DIV. OF CHRYSLER CORP., Dayton 1, Ohio                                   | 1248-1249            |
| CLARAGE FAN CO., Kalamazoo, Mich.                                                          | 1225, 1387           |
| CLEAVER-BROOKS CO., 498 E. Keefe Ave., Milwaukee 12, Wis.                                  | 1544, 1580           |
| COAL-HEAT (publication), 20 W. Jackson Blvd., Chicago 4, Ill.                              | 1691                 |
| COLUMBIA BOILER CO., Pottstown, Pa.                                                        | 1546-1547            |
| COMBUSTION CONTROL DIV., ELECTRONICS CORP. OF AMERICA, 718 Beacon St., Boston 15, Mass.    | 1475                 |
| COMBUSTION ENGINEERING, INC., 200 Madison Ave., New York 16, N. Y.                         | 1548-1549            |
| COMBUSTION ENGINEERING, INC., Home Equipment Div., 911 W. Main St., Chattanooga, Tenn.     | 1250                 |
| CONNOR ENGINEERING CORP., Shelter Rock Lane, Danbury, Conn.                                | 1326-1327, 1441-1442 |
| CONTINENTAL AIR FILTERS, INC., P. O. Box 1647, Louisville 1, Ky.                           | 1328                 |
| COPELAND REFRIGERATION CORP., Sidney, Ohio                                                 | 1369                 |

|                                                                                    |           |
|------------------------------------------------------------------------------------|-----------|
| CRANE CO., 836 S. Michigan Ave., Chicago 5, Ill.                                   | 1528-1529 |
| CURTIS MANUFACTURING CO., Refrigeration Div., 1959 Kienlen Ave., St. Louis 20, Mo. | 1370      |
| CYCLOTHERM DIVISION, NATIONAL-U. S. RADIATOR CORP., Oswego, N. Y.                  | 1545      |

## D

|                                                                                                |                     |
|------------------------------------------------------------------------------------------------|---------------------|
| DE BOTHEZAT FANS DIV., AMERICAN MACHINE & METALS, INC., East Moline, Ill.                      | 1388-1389           |
| CHARLES DEMUTH & SONS, INC., 245 Elm Place, Mineola, N. Y.                                     | 1439                |
| DESOMATIC PRODUCTS, INC., 1109 W. Broad St., Falls Church, Va.                                 | 1228                |
| DETROIT STOKER CO., 5-125 General Motors Bldg., Detroit 2, Mich.                               | 1568                |
| DEVICES, INC., DIVISION MIRACLE ADHESIVES CORP., 214 East 53 St., New York 22, N. Y.           | 1654                |
| DEWEY-SHEPARD BOILER CO., THE, Sales Office, 1311 N. Capitol Ave., Indianapolis, Ind.          | 1550                |
| DOLE VALVE CO., THE, 1933 Carroll Ave., Chicago 12, Ill.                                       | 1640                |
| DOLLINGER CORP., 6 Centre Pk., Rochester 3, N. Y.                                              | 1330-1331           |
| DOMESTIC ENGINEERING PUBLICATIONS, 1801 Prairie Ave., Chicago 16, Ill.                         | 1692                |
| DOMESTIC PUMP & MFG. CORP., Shippensburg, Pa.                                                  | 1605                |
| DOW CHEMICAL CO., THE, Plastics Sales, Midland, Mich.                                          | 1667                |
| DRAVO CORP., Machinery Div., Dravo Bldg., Fifth & Liberty Aves., Pittsburgh 22, Pa.            | 1272-1273           |
| DRAYER-HANSON, DIV. OF NATIONAL-U. S. RADIATOR CORP., 3301 Medford St., Los Angeles 63, Calif. | 1229                |
| C. A. DUNHAM CO., 400 West Madison St., Chicago 6, Ill.                                        | 1618-1619-1620-1621 |
| DURANT INSULATED PIPE CO., Demeter St. off Bay Road, Palo Alto, Calif.                         | 1647                |
| DURO-DYNE CORP., 800 Third Ave., New Hyde Park, L. I., N. Y.                                   | 1466-1467           |
| DUTTON BOILERS, DIVISION HAPMAN-DUTTON CO., 639 Gibson St., Kalamazoo, Mich.                   | 1551                |

## E

|                                                                                                                          |      |
|--------------------------------------------------------------------------------------------------------------------------|------|
| EDDINGTON METAL SPECIALTY CO., Eddington, Pa.                                                                            | 1591 |
| ELECTRIC AUTO-LITE CO., THE, Instrument & Gauge Div., Dept. HV, Toledo 1, Ohio                                           | 1476 |
| ELECTRO-AIR CLEANER CO., 1285 Reedsdale St., Pittsburgh 33, Pa.                                                          | 1329 |
| ELECTROMODE CORP., 45 Crouch St., Rochester 3, N. Y.                                                                     | 1305 |
| ELGEN MFG. CORP., 41-34 39th St., Long Island City 4, N. Y.                                                              | 1468 |
| ENTERPRISE ENGINE & MACHINERY CO., A SUBSIDIARY OF GENERAL METALS CORP., 18th and Florida Sts., San Francisco 10, Calif. | 1581 |

## F

|                                                                                                 |           |
|-------------------------------------------------------------------------------------------------|-----------|
| FAIRBANKS CO., THE, 393 Lafayette St., New York 3, N. Y.                                        | 1641      |
| FARR COMPANY, P. O. Box 45187, Airport Sta., Los Angeles 45, Calif.                             | 1332-1333 |
| FARRAR & TREFTS DIV., ADSCO INDUSTRIES, INC., 20 Milburn St., Buffalo 12, N. Y.                 | 1554      |
| FEDDERS-QUIGAN CORP., Hancock & Lator Sts., Trenton 7, N. J.                                    | 1286      |
| FIELD CONTROL DIVISION OF H. D. CONKEY & CO., Press Bldg., Mendota, Ill.                        | 1477      |
| T. R. FINN & CO., INC., Industrial Div., 200 Central Ave., Hawthorne, N. J.                     | 1686      |
| FITZGIBBONS BOILER CO., INC., 101 Park Ave., New York 17, N. Y.                                 | 1552-1553 |
| FLEXONICS CORPORATION, Expansion Joint Division, Maywood, Ill.                                  | 1507      |
| FLUOR PRODUCTS CO., A DIV. OF THE FLUOR CORP., LTD., 1200 E. Washington Blvd., Whittier, Calif. | 1347      |
| FRICK CO., Waynesboro, Pa.                                                                      | 1371      |
| FULTON-SYLPHON DIVISION, ROBERTSHAW-FULTON CONTROLS CO., Knoxville 1, Tenn.                     | 1478-1479 |

## G

|                                                                       |      |
|-----------------------------------------------------------------------|------|
| G & O MANUFACTURING CO., THE, 138 Winchester Ave., New Haven 8, Conn. | 1362 |
| GALLAHER CO., THE, 4108 Dodge St., Omaha 3, Nebr.                     | 1417 |
| GARDEN CITY FAN CO., 332 S. Michigan Ave., Chicago 4, Ill.            | 1390 |

|                                                                                                       |           |
|-------------------------------------------------------------------------------------------------------|-----------|
| GENERAL AUTOMATIC PRODUCTS CORP., 2300 Sinclair Lane, Baltimore 13, Md.                               | 1513      |
| GENERAL BLOWER CO., 8602 Ferris Ave., Morton Grove, Ill.                                              | 1391      |
| GENERAL CONTROLS, 801 Allen Ave., Glendale 1, Calif.                                                  | 1480-1481 |
| GENERAL ELECTRIC, Home Heating and Cooling Dept., 5 Lawrence St., Bloomfield, N. J.                   | 1230      |
| GENERAL ELECTRIC, Commercial and Industrial Air Conditioning Dept., 5 Lawrence St., Bloomfield, N. J. | 1231      |
| GENERAL FITTINGS CO., Box 151K, East Greenwich, R. I.                                                 | 1596      |
| GENERAL REGISTER CORP., 14 Factory St., Cedar Grove, N. J.                                            | 1442-1443 |
| GENIE-AIR, INC., 4273 S. Broadway, Los Angeles 37, Calif.                                             | 1418-1419 |
| E. D. GOODFELLOW CO., INC., 496 E. Bodley Ave., Memphis, Tenn.                                        | 1348      |
| B. F. GOODRICH, Sponge Products Div., 274 Derby Place, Shelton, Conn.                                 | 1683      |
| GOODYEAR TIRE & RUBBER CO., INC., THE, Akron 16, Ohio                                                 | 1334      |
| GORDON-PIATT, INC., P. O. Box 914, Winfield, Kans.                                                    | 1576      |
| GOVERNAIR CORP., 513 N. Blackwelder, Oklahoma City 4, Okla.                                           | 1232      |

## H

|                                                                                                                      |                     |
|----------------------------------------------------------------------------------------------------------------------|---------------------|
| HALSTEAD & MITCHELL, Bessemer Bldg., Pittsburgh 22, Pa.                                                              | 1350-1351           |
| HAMMOND BRASS WORKS, Summer Blvd., Hammond, Ind.                                                                     | 1642                |
| ARTHUR HARRIS & CO., 210-218 N. Aberdeen St., Chicago 7, Ill.                                                        | 1512                |
| HART & COOLEY MFG. CO., Holland, Mich.                                                                               | 1444-1445           |
| HARTZELL PROPELLER FAN CO., DIV. of CASTLE HILLS CORP., Piqua, Ohio                                                  | 1392                |
| HASTINGS AIR CONDITIONING CO., INC., Hastings, Nebr.                                                                 | 1233                |
| HAVENS STRUCTURAL STEEL CO., 1713 Crystal Ave., Kansas City, Mo.                                                     | 1349                |
| HAYES FURNACE MFG. & SUPPLY CO., 2929 S. Fairfax Ave., Los Angeles 16, Calif.                                        | 1252-1253           |
| HEATING & AIR CONDITIONING CONTRACTOR, (publication, formerly SHEET METAL WORKER) 92 Martling Ave., Tarrytown, N. Y. | 1693                |
| HEATING & PLUMBING EQUIPMENT NEWS (publication), 93 Worth St., New York 13, N. Y.                                    | 1689                |
| HEATING, PIPING and AIR CONDITIONING (publication), 6 N. Michigan Ave., Chicago 2, Ill.                              | 1694                |
| HELLER LABORATORIES, INC., 124 Fort Lee Road, Leonia, N. J.                                                          | 1352                |
| HENDRICK MFG. CO., 48 Dundaff St., Carbondale, Pa.                                                                   | 1446-1447           |
| HENRY VALVE CO., Melrose Park, Ill.                                                                                  | 1482                |
| HIRSCHMAN-POHLE CO., INC., 200 Lent Ave., Le Roy, N. Y.                                                              | 1420                |
| HOFFMAN SPECIALTY MFG. CORP., 1001 York St., Indianapolis 7, Ind.                                                    | 1622-1623-1624-1625 |
| HUBBELL CORP., P. O. Box 700, Hawley Road, Mundelein, Ill.                                                           | 1483                |
| HYDRALINE PRODUCTS, DIV. BORG-WARNER CORP., 18538 Mack Ave., Detroit 36, Mich.                                       | 1251                |
| HYDROTHERM, INC., Northvale, N. J.                                                                                   | 1555                |

## I

|                                                                                                       |            |
|-------------------------------------------------------------------------------------------------------|------------|
| ILG ELECTRIC VENTILATING CO., 2880 N. Crawford Ave., Chicago 41, Ill.                                 | 1287, 1393 |
| ILLINOIS ENGINEERING CO., DIV. of AMERICAN AIR FILTER CO., INC., 2059 S. Racine Ave., Chicago 8, Ill. | 1626-1627  |
| ILLINOIS TESTING LABORATORIES, INC., Room 516, 420 N. LaSalle St., Chicago 10, Ill.                   | 1486       |
| INDEPENDENT REGISTER CO., THE, 3747 East 93rd St., Cleveland 5, Ohio                                  | 1448       |
| INDUSTRIAL ENGINEERING & EQUIPMENT CO., 711 S. Teresa Ave., St. Louis 3, Mo.                          | 1306       |
| INFRA INSULATION, INC., 525 Broadway, New York, N. Y.                                                 | 1679       |
| INSULITE DIVISION, MINNESOTA and ONTARIO PAPER CO., Investors Bldg., Minneapolis 2, Minn.             | 1668-1669  |
| INTERNATIONAL BOILER WORKS CO., THE, 500 Birch St., East Stroudsburg, Pa.                             | 1556       |
| INTERNATIONAL EXPOSITION CO., 480 Lexington Ave., New York 17, N. Y.                                  | 1636       |

## J

|                                                                                                        |           |
|--------------------------------------------------------------------------------------------------------|-----------|
| JACKSON & CHURCH, Furnace Div., Saginaw, Mich.                                                         | 1276      |
| JENKINS BROS., 100 Park Ave., New York 17, N. Y.                                                       | 1643      |
| JOHNS-MANVILLE, 22 East 40th St., New York 16, N. Y.                                                   | 1670-1671 |
| S. T. JOHNSON CO., 940 Arlington Ave., Oakland 8, Calif.                                               | 1582-1583 |
| JOHNSON HEATER CORP., 1 Winnisimmet St., Chelsea, Mass.                                                | 1274-1275 |
| JOHNSON SERVICE CO., Milwaukee, Wis.                                                                   | 1484-1485 |
| JOHNSTON BROS., INC., Ferrysburg, Mich.                                                                | 1557      |
| JOURNAL of PLUMBING, HEATING & AIR CONDITIONING, THE, (publication) 92 Martling Ave., Tarrytown, N. Y. | 1693      |
| JOY MFG. CO., General Offices, Henry W. Oliver Bldg., Pittsburgh 22, Pa.                               | 1394-1395 |

## K

|                                                                           |                     |
|---------------------------------------------------------------------------|---------------------|
| KAISER ALUMINUM & CHEMICAL SALES, INC., Palmolive Bldg., Chicago 11, Ill. | 1684-1685           |
| E. B. KAISER CO., P. O. Box 276, 2114 W. Lake Ave., Glenview, Ill.        | 1648-1649           |
| KENNARD CORP., 1819 S. Hanley Rd., St. Louis 17, Mo.                      | 1234                |
| KEWANEE BOILER DIV. of AMERICAN-STANDARD, Kewanee, Ill.                   | 1558-1559-1560-1561 |
| KEWAUNEE MFG. CO., 5119 S. Center St., Adrian, Mich.                      | 1411                |
| KILLEBREW ENGINEERING CORP., 8640 Pardee Lane, St. Louis 23, Mo.          | 1597                |
| KIMBERLY-CLARK CORP., Neenah, Wis.                                        | 1672-1673           |
| KNOWLES MUSHROOM VENTILATOR CO., Upper Montclair, N. J.                   | 1449                |
| KORFUND CO., INC., THE, 48-01R 32nd Pl., Long Island City 1, N. Y.        | 1687                |
| KRAISSL CO., INC., 297 Williams Ave., Hackensack, N. J.                   | 1610                |
| KRITZER RADIANT COILS, INC., 2909A Lawrence Ave., Chicago 25, Ill.        | 1514                |

## L

|                                                                                  |           |
|----------------------------------------------------------------------------------|-----------|
| L.O.F. GLASS FIBERS CO., 1810 Madison Ave., Toledo 2, Ohio                       | 1655      |
| LADISH CO., Cudahy, Wis.                                                         | 1508      |
| LAMNECK DIVISION, CLAYTON & LAMBERT MFG. CO., 1026 Lamneck St., Middletown, Ohio | 1256      |
| LAU BLOWER CO., THE, 2007 Home Ave., Dept. J, Dayton 7, Ohio                     | 1396-1397 |
| LEE CORP., Foot of Madison St., Wilmington, Del.                                 | 1277      |
| LESLIE CO., 266 Grant Ave., Lyndhurst, N. J.                                     | 1487      |
| LILIE-HOFFMANN COOLING TOWERS, INC., 1450 S. Vandeventer Ave., St. Louis 10, Mo. | 1353      |
| LIMA REGISTER CO., Lima, Ohio                                                    | 1450-1451 |
| LOCKPORT MILLS INC., Dept. C, Lockport, N. Y.                                    | 1674      |
| LOUVRA MANUFACTURING & SALES CO., 1010 Jeanette Ave., Union, N. J.               | 1452      |

## M

|                                                                                  |                     |
|----------------------------------------------------------------------------------|---------------------|
| MAID-O'-MIST, INC., 3217 N. Pulaski Rd., Chicago 41, Ill.                        | 1630-1631-1632      |
| MAMMOTH FURNACE CO., THE, 509 Vandalia St., St. Paul 4, Minn.                    | 1278                |
| CHARLES E. MANNING CO., 90 Clairton Blvd., Pittsburgh 36, Pa.                    | 1335                |
| MARLEY CO., THE, 222 W. Gregory, Kansas City 14, Mo.                             | 1354                |
| MARLO COIL CO., 6135 Manchester Ave., St. Louis 10, Mo.                          | 1355                |
| JAS. P. MARSH CORP., Dept. 5, Skokie, Ill.                                       | 1628-1629           |
| MAXITROL CO., 12200 Beech Rd., Detroit 39, Mich.                                 | 1488                |
| McDONNELL & MILLER, INC., 3500 N. Spaulding Ave., Chicago 18, Ill.               | 1570-1571-1572-1573 |
| McQUAY, INC., 1602 Broadway, N.E., Minneapolis 13, Minn.                         | 1288-1289           |
| MERCOID CORP., THE, 4201 Belmont Ave., Chicago 41, Ill.                          | 1489                |
| METALBESTOS DIV., WILLIAM WALLACE CO., Belmont, Calif.                           | 1592-1593           |
| MILWAUKEE GAS SPECIALTY CO., 730 N. Jackson St., Milwaukee 2, Wis.               | 1492                |
| MINNEAPOLIS-HONEYWELL REGULATOR CO., 2644 Fourth Ave., So., Minneapolis 8, Minn. | 1490-1491           |
| MIRACLE ADHESIVES CORP., 214 East 53 St., New York 22, N. Y.                     | 1654                |
| MODINE MFG. CO., 1515 Dekoven Ave., Racine, Wis.                                 | 1290-1291           |
| MOELLER INSTRUMENT CO., 132nd St. and 89th Ave., Richmond Hill 18, N. Y.         | 1493                |
| MONARCH MFG. WORKS, INC., 2509 E. Ontario St., Philadelphia 34, Pa.              | 1357                |
| MORRISON PRODUCTS, INC., East 168th St. and Waterloo Rd., Cleveland 10, Ohio     | 1398                |

|                                                                   |           |
|-------------------------------------------------------------------|-----------|
| MUCKLE MFG. CO., 666 Belford Road, Owatonna, Minn.                | 1421      |
| MUELLER CLIMATROL, DIV. of WORTHINGTON CORP., Milwaukee 15, Wis.  | 1254-1255 |
| MUELLERMIST IRRIGATION CO., 2612-22 So. Ninth Ave., Maywood, Ill. | 1645      |
| D. J. MURRAY MFG. CO., Wausau, Wis.                               | 1292      |

## N

|                                                                              |                               |
|------------------------------------------------------------------------------|-------------------------------|
| NASH ENGINEERING CO., THE, 234 Wilson Rd., South Norwalk, Conn.              | 1608-1609                     |
| NATIONAL CLAY PIPE MANUFACTURERS, INC., 1820 N St. N.W., Washington 6, D. C. | 1516-1517-1518-1519-1520-1521 |
| NATIONAL HEATER CO., 2180 Cleora Ave., St. Paul 4, Minn.                     | 1280-1281                     |
| NATIONAL-U. S. RADIATOR CORP., Johnstown, Pa.                                | 1530-1531-1532-1533           |
| HERMAN NELSON, AMERICAN AIR FILTER CO., INC., Louisville, Ky.                | 1296-1297                     |
| JOHN J. NESBITT, INC., Philadelphia 36, Pa.                                  | 1293-1294-1295                |
| NEW YORK BLOWER CO., THE, 3145 S. Shields Ave., Chicago 16, Ill.             | 1399                          |
| NIAGARA BLOWER CO., 405 Lexington Ave., New York 17, N. Y.                   | 1235                          |
| NORMAN PRODUCTS CO., 1150 Chesapeake Ave., Columbus 12, Ohio                 | 1257                          |

## O

|                                                             |            |
|-------------------------------------------------------------|------------|
| ARTHUR A. OLSON & CO., Broad and Court Sts., Canfield, Ohio | 1279       |
| ORR & SEMBOWER, INC., Morgantown Rd., Reading, Pa.          | 1562       |
| OWENS-CORNING FIBERGLAS CORP., Toledo 1, Ohio               | 1336, 1658 |
| OWENS-ILLINOIS, General Offices, Toledo 1, Ohio             | 1661       |

## P

|                                                                                                |                |
|------------------------------------------------------------------------------------------------|----------------|
| PACIFIC LUMBER CO., THE, 100 Bush St., San Francisco 4, Calif.                                 | 1675           |
| PACIFIC STEEL BOILER DIV., NATIONAL-U. S. RADIATOR CORP., Johnstown, Pa.                       | 1534-1535      |
| PACKARD WATER CONDITIONER DIVISION, INC., PACKARD MFG. CO. P. O. Box 719, Jacksonville 1, Fla. | 1575           |
| PARKS-CRAMER CO., Fitchburg, Mass.                                                             | 1236-1237      |
| PATTERSON-KELLEY CO., INC., THE, 101 Burson St., East Stroudsburg, Pa.                         | 1363           |
| PEERLESS ELECTRIC CO., THE, Fan and Blower Div., Warren, Ohio                                  | 1400           |
| PENN CONTROLS, INC., Goshen, Ind.                                                              | 1494           |
| PENN VENTILATOR CO., Goodman above Allegheny Ave., Philadelphia 40, Pa.                        | 1422           |
| PENNSYLVANIA FURNACE & IRON CO., 316 N. Pine St., Warren, Pa.                                  | 1258           |
| PENNSYLVANIA SEPARATOR CO., Box 348-H, Brookville, Pa.                                         | 1574           |
| PHILLIPS COOLING TOWER CO., INC., 220 Dupont St., Brooklyn 22, N. Y.                           | 1356           |
| PITTSBURGH CORNING CORP., One Gateway Center, Pittsburgh 22, Pa.                               | 1662-1663      |
| PITTSBURGH LECTRODRYER CORP., Foot of 32nd St., P. O. Box 1766, Pittsburgh 30, Pa.             | 1238           |
| PITTSBURGH PLATE GLASS CO., Fiber Glass Div., 1 Gateway Center, Pittsburgh 22, Pa.             | 1337, 1664     |
| H. W. PORTER & CO., INC., 817-G Frelinghuysen Ave., Newark 5, N. J.                            | 1650           |
| POTTER & BRUMFIELD MFG. CO., INC., Princeton, Ind.                                             | 1495           |
| POWERS REGULATOR CO., THE, General Office and Factory, 3400 Oakton St., Skokie, Ill.           | 1496-1497-1498 |
| PREFERRED UTILITIES MFG. CORP., 1860A Broadway, New York 23, N. Y.                             | 1566           |
| PROPELLAIR DIVISION, ROBBINS & MYERS, INC., 1947 Clark Blvd., Springfield, Ohio                | 1401           |
| FRANK PROX CO., INC., 1201 S. First St., Terre Haute, Ind.                                     | 1536           |
| PUR AIR DIV., BARNEBEY-CHENEY CO., Cassady & 8th Aves., Columbus 3, Ohio                       | 1322-1323      |
| PYLE-NATIONAL CO., THE, Multi-Vent Div., 1363-78 N. Kostner Ave., Chicago 51, Ill.             | 1454-1455      |

## R

|                                                                      |           |
|----------------------------------------------------------------------|-----------|
| RAY OIL BURNER CO., 1301 San Jose Ave., San Francisco 12, Calif.     | 1584-1585 |
| RAYFIELD-STAFFCO BURNER CO., 2066 S. Canalport Ave., Chicago 8, Ill. | 1586      |
| RAYPAK CO., INC., 2416 Chico Ave., El Monte, Calif.                  | 1563      |
| READY-POWER CO., THE, 11231 Freud Ave., Detroit 14, Mich.            | 1372      |

|                                                                                     |           |
|-------------------------------------------------------------------------------------|-----------|
| REED UNIT-FANS, INC., 1001 St. Charles Ave., New Orleans, La.                       | 1402      |
| REFLECTAL CORP., A SUB. OF BORG-WARNER CORP., 310 S. Michigan Ave., Chicago 4, Ill. | 1682      |
| REFRIGERATION APPLIANCES, INC., 923 West Lake St., Chicago 7, Ill.                  | 1259      |
| REFRIGERATION ENGINEERING, INC., 7250 E. Slauson Ave., Los Angeles 22, Calif.       | 1373      |
| REGISTER & GRILLE MFG. CO., INC., 70 Berry St., Brooklyn 11, N. Y.                  | 1453      |
| RESEARCH PRODUCTS CORP., Madison 10, Wis.                                           | 1338      |
| REVCOR, Dept. R, 249 Edward St., Carpentersville, Ill.                              | 1403      |
| REVERE COPPER AND BRASS INCORPORATED, 230 Park Ave., New York 17, N. Y.             | 1313      |
| REZMOR MFG. CO., 66 Union St., Mercer, Pa.                                          | 1282-1283 |
| RHEEM MFG. CO., 7600 S. Kedzie Ave., Chicago 29, Ill.                               | 1260-1261 |
| RIC-WIL INCORPORATED, 24 Brown St., Barberton, Ohio                                 | 1651      |
| RITTLING CORP., THE, 103 Kentucky St., Buffalo 4, N. Y.                             | 1364      |
| ROBERTS-GORDON APPLIANCE CO., Dept. HVG, Buffalo 6, N. Y.                           | 1577      |
| ROBSON BACKING RING CO., THE, 675 Garden St., Elizabeth 2, N. J.                    | 1509      |
| ROME-TURNEY RADIATOR CO., THE, Erie Blvd., East, Rome, N. Y.                        | 1365      |

## S

|                                                                                         |           |
|-----------------------------------------------------------------------------------------|-----------|
| SARCO CO., INC., Empire State Bldg., New York 1, N. Y.                                  | 1634-1635 |
| SARCOTHERM CONTROLS, INC., Empire State Bldg., New York 1, N. Y.                        | 1633      |
| SCULLY SIGNAL CO., 174 Green St., Melrose 76, Mass.                                     | 1499      |
| SERVEL AIR CONDITIONING DIV., SERVEL, INC., Evansville 20, Ind.                         | 1262-1263 |
| SHAW-PERKINS MFG. CO., 201 E. Carson St., Pittsburgh 19, Pa.                            | 1515      |
| E. H. SHELDON EQUIPMENT CO., Muskegon, Mich.                                            | 1412-1413 |
| SHELDONS ENGINEERING LIMITED, Galt, Ontario, Canada                                     | 1404      |
| SIEMON MFG. CO., Grandview, Mo. (Suburb of Kansas City, Mo.)                            | 1587      |
| SILVERCOTE PRODUCTS, INC., 161 E. Erie St., Chicago 11, Ill.                            | 1680-1681 |
| SIMPLEX MFG. CO., 198-206 N. Main St., Fond du Lac, Wis.                                | 1500      |
| SKIDMORE CORP., St. Joseph, Mich.                                                       | 1611      |
| SLANT-FIN RADIATOR CORP., 87-67-130th St., Richmond Hill 18, N. Y.                      | 1366      |
| H. B. SMITH CO., INC., THE, Westfield, Mass.                                            | 1537      |
| SNIPS MAGAZINE (publication), 5707 W. Lake St., Chicago 44, Ill.                        | 1695      |
| SOMERS CORP., 6063 Wabash Ave., Detroit 8, Mich.                                        | 1339      |
| SONNER-BURNER CO., THE, 412-420 East 6th Ave., Winfield, Kansas                         | 1578      |
| SONOCO PRODUCTS CO., Construction Products Div., Hartsville, S. C.                      | 1659      |
| SPENCE ENGINEERING CO., INC., 28 Grant St., Walden, N. Y.                               | 1501      |
| SPENCER HEATER, LYCOMING DIVISION-AVCO MFG. CORP., Williamsport, Pa.                    | 1538-1539 |
| STANDARD STAMPING & PERFORATING CO., 3111 West 49th Place, Chicago 32, Ill.             | 1456      |
| STERLING, INC., 3738 N. Holton St., Milwaukee 12, Wis.                                  | 1502      |
| STEWART MFG. CO., INC., Cedar Grove, Essex County, N. J.                                | 1457      |
| STILLWATER CLAY PRODUCTS CO., THE, Conduit Div., 3334 Prospect Ave., Cleveland 15, Ohio | 1652      |
| STRONG, CARLISLE & HAMMOND CO., 1392 W. Third St., Cleveland 13, Ohio                   | 1637      |
| SWARTWOUT CO., THE, 18511 Euclid Ave., Cleveland 12, Ohio                               | 1423      |

## T

|                                                                                |           |
|--------------------------------------------------------------------------------|-----------|
| TACO HEATERS, INC., 1160 Cranston St., Cranston 9, R. I.                       | 1602      |
| TAYLOR FORGE & PIPE WORKS, P. O. Box 485, Chicago 90, Ill.                     | 1510      |
| TAYLOR INSTRUMENT COMPANIES, Rochester 1, N. Y.                                | 1503      |
| TECTUM DIVISION, PEOPLES RESEARCH & MFG. CO., 105 S. Sixth St., Newark, Ohio   | 1676      |
| THERMOBLOC DIV., PRAT-DANIEL CORP., Meadow St., South Norwalk, Conn.           | 1284      |
| H. A. THRUSH & CO., Peru, Ind.                                                 | 1600-1601 |
| TITUS MFG. CORP., 113 East 8th St., Waterloo, Iowa                             | 1458-1459 |
| TITUSVILLE IRON WORKS CO., THE, DIV. OF STRUTHERS WELLS CORP., Titusville, Pa. | 1564-1565 |
| TJERNLUND MFG. CO., 2140 Kasota Ave., St. Paul 14, Minn.                       | 1285      |
| TORRINGTON MFG. CO., THE, 50 Franklin St., Torrington, Conn.                   | 1406-1407 |
| TRADE-WIND MOTORFANS, INC., 7755 Paramount Blvd., Rivera, Calif.               | 1405      |

TRANE CO., THE, 2021 Cameron Ave., LaCrosse, Wis. .... 1298-1299-1300-1301  
 TRION, INC., 1000 Island Ave., McKees Rocks, Pa. .... 1340  
 TUBE TURNS, A DIV. of NATIONAL CYLINDER GAS CO., Louisville 1, Ky. .... 1511  
 TUTTLE & BAILEY, INC., New Britain, Conn. .... 1460-1461

## U

UNION ASBESTOS & RUBBER CO., 332 S. Michigan Ave., Chicago 4, Ill. .... 1265  
 UNITED STATES REGISTER CO., Battle Creek, Mich. .... 1462-1463  
 UNITED STATES STEEL, Pittsburgh, Pa. .... 1425  
 UNIVERSAL DIFFUSER CORP., 1360 Garrison Ave., New York 59, N. Y. .... 1464  
 UTILITY FAN CORP., A DIV. of UTILITY APPLIANCE CORP., 911 East 59 St., Los Angeles 1, Calif. .... 1264

## V

VAPOR HEATING CORP., 80 E. Jackson Blvd., Chicago 4, Ill. .... 1567  
 VIBRATION MOUNTINGS, INC., 98-01 50th Ave., Corona 68, N. Y. .... 1688  
 VIKING AIR PRODUCTS, DIV. of NATIONAL-U. S. RADIATOR CORP., 5601 Walworth Ave., Cleveland 2, Ohio .... 1408  
 VORTOX CO., Claremont, Calif. .... 1341  
 VULCAN RADIATOR CO., THE, 26 Francis Ave., Hartford 6, Conn. .... 1367

## W

WALTON LABORATORIES, Irvington 11, N. J. .... 1239  
 WATERLOO REGISTER CO., INC., P. O. Box 72, Waterloo, Iowa .... 1465  
 WARREN WEBSTER & CO., 1731 Federal St., Camden 5, N. J. .... 1638-1639  
 WEBSTER ENGINEERING CO., THE, DIV. of SURFACE COMBUSTION CORP., 115 S. Frisco St., P. O. Box 2168, Tulsa, Okla. .... 1579  
 WEIL-McLAIN CO., General Sales Office, Michigan City, Ind. .... 1540  
 WESIX ELECTRIC HEATER CO., 390 First St., San Francisco 5, Calif. .... 1307  
 WESTERN BLOWER CO., 1800 Airport Way, Seattle 4, Wash. .... 1409  
 WESTERN ENGINEERING & MFG. CO., 4112 Glencoe Ave., Venice, Calif. .... 1424  
 WESTINGHOUSE ELECTRIC CORP., Air Conditioning Div., Staunton, Virginia .... 1240  
 WESTINGHOUSE ELECTRIC CORP., STURTEVANT DIV., Hyde Park, Boston 36, Mass. .... 1342, 1410  
 WHITE-RODGERS ELECTRIC CO., 1209 Cass Ave., St. Louis 6, Mo. .... 1504  
 EDWIN L. WIEGAND CO., 7672 Thomas Blvd., Pittsburgh 8, Pa. .... 1308-1309  
 WILL-BURT CO., THE, Orrville, Ohio .... 1569  
 L. J. WING MFG. CO., 59 Vreeland Mills Road, Linden, N. J. .... 1302-1303  
 WIREMOLD CO., THE, Hartford 10, Conn. .... 1469  
 WOLVERINE TUBE, 1463 Central Ave., Detroit 9, Mich. .... 1314-1315  
 WOOD CONVERSION CO., Dept. 220-6, First National Bank Bldg., St. Paul 1, Minn. .... 1677  
 WORTHINGTON CORP., Air Conditioning & Refrigeration Div., Harrison, N. J. .... 1241

## Y

YORK CORP., York, Pa. .... 1242  
 YORK-SHIPLEY, INC., York 16, Pa. .... 1590  
 YOUNG RADIATOR CO., Dept. 546, Racine, Wis. .... 1304  
 YOUNG REGULATOR CO., 5209 Euclid Ave., Cleveland 3, Ohio .... 1470-1471

## Z

Z-CRETE DIVISION, ZONOLITE CO., 135 S. LaSalle St., Chicago 3, Ill. .... 1653  
 JOHN ZINK CO., 4401 S. Peoria, Tulsa, Okla. .... 1588-1589

## INDEX TO MODERN EQUIPMENT

### OF ADVERTISERS APPEARING IN HEATING VENTILATING AIR CONDITIONING GUIDE, 1956

- ACCUMULATORS**  
 Domestic Pump & Mfg. Corp., 1605 Hoffman Specialty Mfg. Corp., 1622-1625  
 McQuay, Inc., 1288-1289  
 Worthington Corp., 1241
- ACOUSTICAL CONTROL**  
 Burgess-Manning Co., 1438  
 Korlund Co., Inc., The, 1687  
 Tectum Div., Peoples Research & Mfg. Co., 1676
- ADHESIVES**  
 Armstrong Cork Co., 1665  
 Goodyear Tire & Rubber Co., Inc., The, 1334  
 Miracle Adhesives Corp., 1654
- ADSORBERS, Odor**  
 Barnebey-Cheney Co., 1322-1323  
 Connor Engineering Corp., 1326-1327  
 Charles E. Manning Co., 1335
- ADSORPTION SYSTEMS**  
 Barnebey-Cheney Co., 1322-1323  
 Connor Engineering Corp., 1326-1327  
 Desomatie Products, Inc., 1228  
 Charles E. Manning Co., 1335  
 Pittsburgh Lectrodryer Corp., 1238  
 Pur Air Div., Barnebey-Cheney Co., 1322-1323
- AFTER COOLERS**  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Niagara Blower Co., 1235  
 Parks-Cramer Co., 1236-1237
- AIR CLEANING EQUIPMENT**  
 (See also *Filters, Air*)  
 Air & Refrigeration Corp., 1219  
 Air Devices, Inc., 1316, 1432  
 Air Filter Corp., 1317  
 Air-Maze Corp., The, 1318  
 American Air Filter Co., Inc., 1319-1321  
 American Moistening Co., 1222  
 V. D. Anderson Co., The, 1612-1613  
 Bahnsen Co., The, 1223  
 Barnebey-Cheney Co., 1322-1323  
 Buffalo Forge Co., 1382  
 Cambridge Filter Corp., 1324  
 Carey Electronic Engineering Co., 1325  
 Continental Air Filters, Inc., 1328  
 Dollinger Corp., 1330-1331  
 Electro-Air Cleaner Co., 1329  
 Farr Co., 1332-1333  
 Goodyear Tire & Rubber Co., 1334  
 Charles E. Manning Co., 1335  
 Owens-Corning Fiberglass Corp., 1336, 1658  
 Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664  
 Research Products Corp., 1338  
 E. H. Sheldon Equipment Co., 1412-1413  
 Somers Corp., 1339  
 Trion, Inc., 1340  
 Vortox Co., 1341  
 Westinghouse Electric Corp., Sturtevant Div., 1342
- AIR COMPRESSORS** (See *Compressors, Air*)
- AIR CONDITIONING COILS**  
 Acme Industries, Inc., 1358  
 Aeroform Corp., 1359-1361  
 Airtemp Div., Chrysler Corp., 1248-1249  
 American Blower Corp., 1220-1221  
 Bell & Gossett Co., 1598-1599  
 Carrier Corp., 1226-1227  
 Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
 Governair Corp., 1232  
 Hastings Air Conditioning Co., Inc., 1233  
 Kennard Corp., 1234  
 Marlo Coil Co., 1355  
 McQuay, Inc., 1288-1289  
 Modine Mfg. Co., 1290-1291  
 John J. Nesbitt, Inc., 1293-1295  
 Niagara Blower Co., 1295  
 Patterson-Kelley Co., Inc., The, 1293
- AIR CONDITIONING SCREEN** (See *Screening*)
- AIR CONDITIONING UNITS**  
 Acme Industries, Inc., 1358  
 Addison Products Co., 1243  
 Air & Refrigeration Corp., 1219  
 Airtemp Div., Chrysler Corp., 1248-1249  
 American Blower Corp., 1220-1221  
 American Moistening Co., 1222  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
 American-Standard, Air Conditioning Div., 1244-1245  
 Armstrong Furnace Co., 1246-1247  
 Bell & Gossett Co., 1598-1599  
 Bishop & Babcock Mfg. Co., The, (Massachusetts Blower Div.), 1377  
 Brunner Mfg. Co., 1368  
 Buensod-Stacey, Inc., 1224  
 Buffalo Forge Co., 1382  
 Burnham Corp., 1526-1527  
 Carrier Corp., 1226-1227  
 Clarage Fan Co., 1225, 1387  
 Curtis Mfg. Co., Refrigeration Div., 1370  
 Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
 Electromode Corp., 1305  
 Farr Co., 1332-1333  
 Pedders-Quigan Corp., 1286  
 Frick Co., 1371  
 General Automatic Products Co., 1513  
 General Electric Co., 1231  
 Governair Corp., 1232  
 Hastings Air Conditioning Co., Inc., 1233  
 Hydraline Products, Div. Borg-Warner Corp., 1251  
 S. T. Johnson Co., 1582-1583  
 Kennard Corp., 1234  
 Marlo Coil Co., 1355  
 McQuay, Inc., 1288-1289  
 Modine Mfg. Co., 1290-1291  
 Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
 National-U. S. Radiator Corp., 1530-1533  
 Herman Nelson, American Air Filter Co., Inc., 1296-1297  
 John J. Nesbitt, Inc., 1293-1295  
 Niagara Blower Co., 1235  
 Norman Products Co., 1257  
 Parks-Cramer Co., 1236-1237  
 Patterson-Kelley Co., Inc., The, 1353  
 Pennsylvania Furnace & Iron Co., 1258  
 Ready-Power Co., The, 1372  
 Refrigeration Appliances, Inc., 1259  
 Refrigeration Engineering, Inc., 1373  
 Rheem Mfg. Co., 1260-1261  
 Rittinger Corp., The, 1364  
 Roberts-Gordon Appliance Corp., 1577  
 Servel, Inc., 1262-1263  
 Sheldons Engineering Ltd., 1404  
 Trane Co., The, 1298-1301  
 Union Asbestos & Rubber Co., 1265  
 Vulcan Radiator Co., The, 1367



Western Blower Co., 1409  
Worthington Corp., 1241  
York Corp., 1242  
York-Shipley, Inc., 1590  
Young Radiator Co., 1304

#### AIR COOLING EQUIPMENT (See Cooling Equipment, Air)

#### AIR COOLING, HUMIDIFYING AND DEHUMIDIFYING AP- PARATUS

Addison Products Co., 1243  
Aerofin Corp., 1359-1361  
Air & Refrigeration Corp., 1219  
Airtemp Div., Chrysler Corp., 1248-  
1249  
American Blower Corp., 1220-1221  
American Moistening Co., 1222  
American-Standard, Air Condition-  
ing Div., 1244-1245  
Armstrong Machine Works, 1614-1615  
Bahnsen Co., The, 1223  
Bayley Blower Co., 1376  
Buensod-Stacey, Inc., 1224  
Buffalo Forge Co., 1382  
Carrier Corp., 1226-1227  
Clarage Fan Co., 1225, 1387  
Curtis Mfg. Co., Refrigeration Div.,  
1370  
Desomatic Products, Inc., 1228  
Drayer-Hanson, Inc., Div. of Na-  
tional-U. S. Radiator Corp., 1229  
Farr Co., 1332-1333  
Frick Co., 1371  
General Electric Co., 1231  
Governair Corp., 1232  
Hydraline Products, Div. Borg-  
Warner Corp., 1251  
Kannard Corp., 1234  
Marlo Coil Co., 1355  
McQuay, Inc., 1288-1289  
Modine Mfg. Co., 1290-1291  
John J. Nesbitt, Inc., 1293-1295  
Niagara Blower Co., 1235  
Parks-Cramer Co., 1236-1237  
Pittsburgh Electrodyer Corp., 1238  
Refrigeration Appliances, Inc., 1259  
Refrigeration Engineering Inc., 1373  
Serval, Inc., 1262-1263  
Trade-Wind Motors, Inc., 1405  
Trane Co., The, 1298-1301  
Westinghouse Electric Corp., Air  
Conditioning Div., 1240  
Worthington Corp., 1241  
York Corp., 1242

#### AIR DIFFUSER UNITS, High Pressure

Anemostat Corp. of America, 1434-  
1435  
Auer Register Co., 1436  
Connor Engineering Corp., 1326-  
1327, 1440-1441  
Lima Register Co., 1450-1451  
Standard Stamping & Perforating  
Co., 1456  
Tuttle & Bailey, Inc., 1460-1461

#### AIR DIFFUSERS AND VENTI- LATORS, CEILING, FLOOR AND WALL

A-J Mfg. Co., 1428-1427  
Air Control Products, Inc., 1428-1431  
Air Devices, Inc., 1316, 1432  
Air-Factors, Inc., 1433  
Airfan Engineering Co., 1343  
Anemostat Corp. of America, 1434-  
1435  
Auer Register Co., The, 1436  
Barber-Colman Co., 1437, 1473  
Connor Engineering Corp., 1326-  
1327, 1440-1441  
Charles Demuth & Sons, Inc., 1439

Hart & Cooley Mfg. Co., 1444-1445  
Hendrick Mfg. Co., 1446-1447  
Independent Register Co., The, 1448  
Knowles Mushroom Ventilator Co.,  
1449

Lima Register Co., 1450-1451  
Louvra Mfg. & Sales Co., 1452  
Pyle-National Co., The, Multi-Vent  
Div., 1454-1455  
Register & Grille Mfg. Co., Inc., 1453  
Standard Stamping & Perforating  
Co., 1456  
Titus Mfg. Corp., 1458-1459  
Tuttle & Bailey, Inc., 1460-1461  
United States Register Co., 1462-  
1463  
Universal Diffuser Corp., 1464  
Vulcan Radiator Co., The, 1367  
Waterloo Register Co., 1465

#### AIR DUCTS (See Ducts)

#### AIR ELIMINATORS

V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-  
1615  
Dole Valve Co., The, 1640  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-  
1625  
Illinois Engineering Co., 1630-1632  
Maid-O'-Mist, Inc., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Sarco Co., Inc., 1634-1635  
Taco Heaters, Inc., 1602  
H. A. Thrush & Co., 1600-1601

#### AIR FILTER GAGE

Air Devices, Inc., 1316, 1432  
Cambridge Filter Corp., 1324  
Owens-Corning Fiberglas Corp.,  
1336, 1658  
Research Products Corp., 1338

#### AIR FILTERS (See Filters, Air; Air Cleaning Equipment)

#### AIR MEASURING INDICAT- ING AND RECORDING IN- STRUMENTS

Anemostat Corp. of America, 1434-  
1435  
Illinois Testing Laboratories, Inc.,  
1488  
Minneapolis-Honeywell Regulator  
Co., 1490-1491  
Parks-Cramer Co., 1236-1237  
Taylor Instrument Co's., 1503  
Trion, Inc., 1340

#### AIR MIXING UNITS (See Dual Duct Systems)

#### AIR MOISTENING APPARA- TUS (See Humidifiers)

#### AIR PURIFYING APPARATUS

Air & Refrigeration Corp., 1219  
Air Filter Corp., 1317  
V. D. Anderson Co., The, 1612-1613  
Barnebey-Cheney Co., 1322-1323  
Connor Engineering Corp., 1326-1327,  
1440-1441  
Dollinger Corp., 1330-1331  
Electro-Air Cleaner Co., 1329  
Charles E. Manning Co., 1335  
Somers Corp., 1339  
Trion, Inc., 1340  
Universal Diffuser Corp., 1464

#### AIR RECEIVERS (See Receivers, Air)

#### AIR RECOVERY, Method of

Barnebey-Cheney Co., 1322-1323

Connor Engineering Corp., 1326-  
1327, 1440-1441  
Charles E. Manning Co., 1335

#### AIR TRAPS (See Traps, Air)

#### AIR TUBING, Flexible Metal (See Tubing, Flexible Metallic)

#### AIR TURNING VANES (See Vaness, Air Turning)

#### AIR VELOCITY METERS (See Meters)

#### AIR WASHERS

Air & Refrigeration Corp., 1219  
Airfan Engineering Co., 1343  
American Blower Corp., 1220-1221  
Bahnsen Co., The, 1223  
Bayley Blower Co., 1376  
Bishop & Babcock Mfg. Co., The,  
(Massachusetts Blower Div.), 1377  
Buensod-Stacey, Inc., 1224  
Buffalo Forge Co., 1382  
Carrier Corp., 1226-1227  
Clarage Fan Co., 1225, 1387  
Continental Air Filters, Inc., 1328  
Dollinger Corp., 1330-1331  
Marlo Coil Co., 1355  
D. J. Murray Mfg. Co., 1292  
Niagara Blower Co., 1235  
Parks-Cramer Co., 1236-1237  
Sheldons Engineering Ltd., 1404  
Trane Co., The, 1298-1301  
Western Blower Co., 1409  
Westinghouse Electric Corp., Stur-  
tevant Div., 1410  
York Corp., 1242

#### ALARMS, Water Level

McDonnell & Miller, Inc., 1570-1573

#### ALUMINUM DUCTS (See Ducts, Aluminum)

#### ALUMINUM FOIL, Insulation

Infra Insulation, Inc., 1679  
Reflectal Corp., 1682  
Silvercote Products, Inc., 1680-1681

#### ALUMINUM FOIL VAPOR BAR- RIER (See Aluminum Foil)

#### ALUMINUM SHEETS (See Sheets, Aluminum)

#### AMMONIA COILS (See Coils, Am- monia)

#### ANCHORS, for Insulation

Devices, Inc., 1654  
Miracle Adhesives Corp., 1654  
H. W. Porter & Co., Inc., 1650

#### ANEMOMETERS

Illinois Testing Laboratories, Inc.,  
1488

#### ANGLES AND ELBOWS

Lamneck Div., Clayton & Lambert  
Mfg. Co., 1256

#### ASBESTOS PRODUCTS (See In- sulation)

Philip Carey Mfg. Co., The, 1656-  
1657  
Infra Insulation, Inc., 1679  
Johns-Manville, 1670-1671  
H. W. Porter & Co., Inc., 1650  
Reflectal Corp., 1682  
Reid Hayden Inc., 1650

## Index to Modern Equipment

#### ATMOSPHERIC COOLING TOWERS (See Cooling Towers, Atmospheric)

#### ATOMIZING SPRAY NOZZLES (See Spray Nozzles)

#### ATTIC FAN COOLERS (See Fans, Attic; Ventilators, Attic)

#### AUTOMATIC FUEL BURNING EQUIPMENT (See Burners, Au- tomatic; Gas Burners; Oil Burners; Stokers)

#### AUTOMATIC SHUTTERS (See Shutters, Automatic)

#### AXIAL FLOW FANS (See Fans, Axial Flow)

#### BACKING RINGS (See Rings, Backing)

#### BASEBOARD HEATING

A-J Mfg. Co., 1428-1427  
Air Control Products, Inc., 1428-1431  
Air-Factors, Inc., 1433  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Auer Register Co., 1436  
Burnham Corp., 1526-1527  
Campbell Heating Co., 1268-1269  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
Dole Vale Co., The, 1640  
C. A. Dunham Co., 1618-1621  
Electromode Corp., 1306  
Feddars-Quigan Corp., 1286  
General Automatic Products Corp.,  
1513  
Hart & Cooley Mfg. Co., 1444-1445  
Hoffman Specialty Mfg. Corp.,  
1622-1625  
Kritzer Radiant Coils, Inc., 1514  
Lima Register Co., 1450-1451  
National Clay Pipe Mfgs., The,  
1516-1521  
National-U. S. Radiator Corp., 1530-  
1533  
Herman Nelson, American Air Filter  
Co., Inc., 1296-1297  
John J. Nesbitt, Inc., 1293-1295  
Rivapak Co., Inc., 1563  
Rittinger Corp., The, 1364  
Rome-Turney Radiator Co., The,  
1385  
Sarco-Sarcotherm, 1633-1635  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1366  
Standard Stamping & Perforating  
Co., 1456  
Trane Co., The, 1298-1301  
Tuttle & Bailey, Inc., 1460-1461  
Union Asbestos & Rubber Co., 1265  
Vulcan Radiator Co., The, 1367  
Warren Webster & Co., 1638-1639  
Well-McLain Co., 1640  
Westair Electric Heater Co., 1307  
Edwin L. Wiegand Co., 1308-1309

#### BASES, Fan and Motor Vibra- tion

T. R. Finn & Co., Inc., 1686  
Korfund Co., Inc., The, 1687  
Vibration Mountings, Inc., 1688

#### BELLOWS

Bishop & Babcock Mfg. Co., The,  
1377  
Flexonics Corp., 1507  
Fulton Sylphon Div., The, Robert-  
shaw-Fulton Controls Co., 1478-  
1479

#### BENDS, Pipe, Ferrous and Non- Ferrous

Arthur Harris & Co., 1512  
Parks-Cramer Co., 1236-1237

#### BENDS (See Pipe, Returns)

#### BLOCKS, Asbestos

Philip Carey Mfg. Co., The, 1656-  
1657  
Johns-Manville, 1670-1671

#### BLOCKS, Glass

Owens-Illinois, 1661  
Pittsburgh Corning Corp., 1662

#### BLOWER HOUSINGS

Airfan Engineering Co., 1343  
Bishop & Babcock Mfg. Co., The  
(Massachusetts Blower Div.),  
1377  
Brundage Co., The, 1380-1381  
Champion Blower & Forge Co., 1385  
Clarage Fan Co., 1225, 1387  
Lau Blower Co., The, 1396-1397  
Morrison Products, Inc., 1398  
Revor, 1403  
Utility Fan Corp., 1264

#### BLOWER MOTORS (See Motors, Electric)

#### BLOWERS, Centrifugal (See Fans)

#### BLOWERS, Fan (See Fans, Supply and Exhaust)

#### BLOWERS, Forced Draft

Aerovent Fan Co., Inc., 1374  
Aladdin Heating Corp., 1375  
American Blower Corp., 1220-1221  
Bayley Blower Co., 1376  
Bishop & Babcock Mfg. Co., The,  
(Massachusetts Blower Div.), 1377  
Buffalo Forge Co., 1382  
Century Fan & Ventilator Co., 1384  
Champion Blower & Forge Co., 1385  
Chicago Blower Corp., 1386  
Clarage Fan Co., 1225, 1387  
Garden City Fan Co., 1390  
General Blower Co., 1391  
Ilg Electric Ventilating Co., 1287,  
1393  
Joy Mfg. Co., 1394-1395  
Lau Blower Co., The, 1396-1397  
Herman Nelson, American Air Filter  
Co., Inc., 1296-1297  
New York Blower Co., The, 1399  
Sheldons Engineering Ltd., 1404  
Tjernlund Mfg. Co., 1285  
Westinghouse Electric Corp., Stur-  
tevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

#### BLOWERS, Heating and Venti- lating

Aerovent Fan Co., Inc., 1374  
Airfan Engineering Co., 1343  
Aladdin Heating Corp., 1375  
American Blower Corp., 1220-1221  
American Foundry & Furnace Co.,  
1268-1267  
American-Standard, Air Condition-  
ing Div., 1244-1245  
Bayley Blower Co., 1376  
Bishop & Babcock Mfg. Co., The  
(Massachusetts Blower Div.),  
1377  
Brookside Products Co., Inc., 1379  
Brundage Co., The, 1380-1381  
Buffalo Forge Co., 1382  
Campbell Heating Co., 1268-1269  
E. K. Campbell Co., 1270

Century Fan & Ventilator Co., 1384  
Champion Blower & Forge Co., 1385  
Chicago Blower Corp., 1386  
Clarage Fan Co., 1225, 1387  
C. A. Dunham Co., 1618-1621  
Garden City Fan Co., 1390  
General Blower Co., 1391  
Hartzell Propeller Fan Co., Div. of  
Castle Hills Corp., 1392  
Hastings Air Conditioning Co., Inc.,  
1233  
Ilg Electric Ventilating Co., 1287  
1393  
Joy Mfg. Co., 1394-1395  
Lau Blower Co., The, 1396-1397  
McQuay, Inc., 1288-1289  
Morrison Products, Inc., 1398  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
Herman Nelson, American Air Filter  
Co., Inc., 1296-1297  
John J. Nesbitt, Inc., 1293-1295  
New York Blower Co., The, 1399  
Niagara Blower Co., 1235  
Peerless Electric Co., The, 1400  
Refrigeration Engineering, Inc., 1373  
Revor, 1403  
Sheldons Engineering Ltd., 1404  
Torrington Mfg. Co., The, 1406-1407  
Trane Co., The, 1298-1301  
Utility Fan Corp., 1264  
Viking Air Conditioning Div., of  
The National-U. S. Radiator  
Corp., 1408  
Western Blower Co., 1409  
Westinghouse Electric Corp., Stur-  
tevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

#### BLOWERS, Pressure

Aerovent Fan Co., Inc., 1374  
Air Fan Engineering Co., 1343  
American Blower Corp., 1220-1221  
Bayley Blower Co., 1376  
Brookside Products Co., Inc., 1379  
Buffalo Forge Co., 1382  
Century Fan & Ventilator Co., 1384  
Champion Blower & Forge Co., 1385  
Chicago Blower Corp., 1386  
Clarage Fan Co., 1225, 1387  
Desomatic Products, Inc., 1228  
General Blower Co., 1391  
Hartzell Propeller Fan Co., Div. of  
Castle Hills Corp., 1392  
Ilg Electric Ventilating Co., 1287,  
1393  
Lau Blower Co., The, 1396-1397  
Peerless Electric Co., The, 1400  
Sheldons Engineering Ltd., 1404  
Westinghouse Electric Corp., Stur-  
tevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

#### BLOWERS, Turbine

C. L. Ammerman Co., 1415  
General Blower Co., 1391  
Western Blower Co., 1409  
L. J. Wing Mfg. Co., 1302-1303

#### BLOWERS, Warm Air Furnace

Aladdin Heating Corp., 1375  
American Blower Corp., 1220-1221  
American Standard, Air Condition-  
ing Div., 1244-1245  
Brookside Products Co., Inc., 1379  
Brundage Co., The, 1380-1381  
Chicago Blower Corp., 1386  
Clarage Fan Co., 1225, 1387  
General Blower Co., 1391  
Lau Blower Co., The, 1396-1397  
Morrison Products, Inc., 1398  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
Peerless Electric Co., The, 1400

Please mention THE GUIDE 1956 when writing to Advertisers

Numerals following Manufacturers' Names refer to pages in the Catalog Data Section



Please mention THE GUIDE 1956 when writing to Advertisers

**CIRCULATORS, Hot Water Heating**

Bell & Gossett Co., 1598-1599  
Chicago Pump Co., 1606-1607  
Crane Co., 1529-1529  
Domestic Pump & Mfg. Corp., 1605  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Kraissl Co., Inc., The, 1610  
Jas. P. Marsh Corp., 1628-1629  
Minneapolis-Honeywell Regulator Co., 1490-1491  
H. A. Thrush & Co., 1600-1601  
Trane Co., The, 1298-1301

**CLEANERS, Air (See Air Cleaning Equipment)****CLEANERS, Flue (See Flue Cleaners)****COAL BURNERS (See Burners, Automatic)**

**COATINGS**  
Armstrong Cork Co., 1665  
Miracle Adhesives Corp., 1654

**COATINGS, Protective**  
Philip Carey Mfg. Co., The, 1656-1657  
Miracle Adhesives Corp., 1654

**COILS, Aluminum**

Aerofin Corp., 1359-1361  
Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
John J. Nesbitt, Inc., 1293-1295  
Niagara Blower Co., 1235  
Patterson-Kelley Co., Inc., The, 1363  
Rome-Turney Radiator Co., The, 1365  
Trane Co., The, 1298-1301  
Westinghouse Electric Corp., Sturtevant Div., 1410  
Worthington Corp., 1241

**COILS, Ammonia**

Acme Industries, Inc., 1358  
Aerofin Corp., 1359-1361  
Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
Marlo Coil Co., 1355  
McQuay, Inc., 1288-1289  
Modine Mfg. Co., 1290-1291  
Niagara Blower Co., 1235  
Patterson-Kelley Co., Inc., The, 1363  
Refrigeration Appliances, Inc., 1259  
Refrigeration Engineering, Inc., 1373  
Trane Co., The, 1298-1301  
Worthington Corp., 1241  
York Corp., 1242

**COILS, Blast**

Aerofin Corp., 1359-1361  
American Blower Corp., 1220-1221  
Bayley Blower Co., 1376  
G & O Mfg. Co., The, 1362  
Governair Corp., 1232  
Halstead & Mitchell, 1350-1351  
Hastings Air Conditioning Co., Inc., 1233  
Industrial Engineering & Equipment Co., 1306  
Kennard Corp., 1234  
Marlo Coil Co., 1355  
McQuay, Inc., 1288-1289  
Modine Mfg. Co., 1290-1291

D. J. Murray Mfg. Co., 1292  
John J. Nesbitt, Inc., 1293-1295  
New York Blower Co., The, 1399  
Niagara Blower Co., 1235  
Rome-Turney Radiator Co., The, 1365  
Trane Co., The, 1298-1301  
Westinghouse Electric Corp., Sturtevant Div., 1410  
Young Radiator Co., 1304

**COILS, Brass**

Arthur Harris & Co., 1512  
Marlo Coil Co., 1355  
McQuay, Inc., 1288-1289  
Trane Co., The, 1298-1301

**COILS, Cooling**

Aerofin Corp., 1359-1361  
Airtemp Div., Chrysler Corp., 1248-1249  
American Blower Corp., 1220-1221  
Burgess-Manning Co., 1438  
Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
Fluor Corp., Ltd., The, 1347  
Frick Co., 1371  
G & O Mfg. Co., The, 1362  
Governair Corp., 1232  
Halstead & Mitchell, 1350-1351  
Arthur Harris & Co., 1512  
Hastings Air Conditioning Co., Inc., 1233  
Kennard Corp., 1234  
Marlo Coil Co., 1355  
McQuay, Inc., 1288-1289  
Modine Mfg. Co., 1290-1291  
John J. Nesbitt, Inc., 1293-1295  
New York Blower Co., The, 1399  
Niagara Blower Co., 1235  
Patterson-Kelley Co., Inc., The, 1363  
Refrigeration Appliances, Inc., 1259  
Refrigeration Engineering, Inc., 1373  
Rome-Turney Radiator Co., The, 1365  
Trane Co., The, 1298-1301  
Westinghouse Electric Corp., Sturtevant Div., 1410  
Worthington Corp., 1241  
York Corp., 1242  
Young Radiator Co., 1304

**COILS, Pipe, Copper**

Arthur Harris & Co., 1512  
Kritzer Radiant Coils, Inc., 1514  
Niagara Blower Co., 1235  
Refrigeration Engineering, Inc., 1373  
York Corp., 1242

**COILS, Pipe, Iron**

Acme Industries, Inc., 1358  
Bayley Blower Co., 1376  
Kritzer Radiant Coils, Inc., 1514  
Niagara Blower Co., 1235  
Refrigeration Engineering, Inc., 1373  
York Corp., 1242

**COILS, Pipe, Copper**

Arthur Harris & Co., 1512  
Kritzer Radiant Coils, Inc., 1514  
Niagara Blower Co., 1235  
Refrigeration Engineering, Inc., 1373  
York Corp., 1242

**COILS, Pipe, Iron**

Acme Industries, Inc., 1358  
Bayley Blower Co., 1376  
Kritzer Radiant Coils, Inc., 1514  
Niagara Blower Co., 1235  
Refrigeration Engineering, Inc., 1373  
York Corp., 1242

**COILS, Pipe and Tube, Non-Ferrous**

Killebrew Engineering Corp., 1597  
McQuay, Inc., 1288-1289  
Niagara Blower Co., 1235  
Patterson-Kelley Co., Inc., The, 1363  
Refrigeration Engineering, Inc., 1373  
Rome-Turney Radiator Co., The, 1365

**COILS, Stainless Steel**

Arthur Harris & Co., 1512  
Niagara Blower Co., 1235

Patterson-Kelley Co., Inc., The, 1363  
Trane Co., The, 1298-1301

**COILS, Tank**

General Fittings Co., 1596  
Patterson-Kelley Co., Inc., The, 1363  
Western Blower Co., 1409

**COLLECTORS, Fly Ash**

American Air Filter Co., Inc., 1319-1321  
American Blower Corp., 1220-1221  
V. D. Anderson Co., The, 1612-1613  
Detroit Stoker Co., 1568  
Pratt-Daniel Corp., 1284

**COMPENSATORS, Expansion**

Flexonics Corp., 1507

**COMPOUNDS, Boiler**

Heller Laboratories, Inc., 1352  
Packard Water Conditioner Div., Packard Mfg. Co., 1575

**COMPRESSOR MOTORS (See Motors, Electric)****COMPRESSOR TUBING, Flexible (See Tubing, Flexible Metallic)****COMPRESSORS, Air**

American Blower Corp., 1220-1221  
Binks Mfg. Co., 1344-1345  
Brunner Mfg. Co., 1368  
Curtis Mfg. Co., Refrigeration Div., 1370  
Johnson Service Co., 1484-1485  
Joy Mfg. Co., 1394-1395  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Nash Engineering Co., 1608-1609  
Worthington Corp., 1241

**COMPRESSORS, Refrigeration**

Airtemp Div., Chrysler Corp., 1248-1249  
Brunner Mfg. Corp., 1368  
Carrier Corp., 1226-1227  
Copeland Refrigeration Corp., 1369  
Curtis Mfg. Co., Refrigeration Div., 1370  
Frick Co., 1371  
Trane Co., The, 1298-1301  
Worthington Corp., 1241  
York Corp., 1242

**CONCRETE INSERTS (See Inserts, Concrete)****CONCRETE SLAB HEATING (See Slab, Heating Concrete)****CONDENSERS and EVAPORATORS**

Acme Industries, Inc., 1358  
Addison Products Co., 1243  
American Blower Corp., 1220-1221  
American District Steam Div., Adco Industries, Inc., 1505, 1504  
Baltimore Aircraft Co., Inc., 1346  
Bell & Gossett Co., 1598-1599  
Buffalo Forge Co., 1382  
Carrier Corp., 1226-1227  
Curtis Mfg. Co., Refrigeration Div., 1370  
Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
Feddars-Quigan Corp., 1288  
Frick Co., 1371  
G & O Mfg. Co., The, 1362  
Governair Corp., 1232  
Halstead & Mitchell, 1350-1351

Kennard Corp., 1234  
Killebrew Engineering Corp., 1597  
Marlo Coil Co., 1355  
McQuay, Inc., 1288-1289  
Niagara Blower Co., 1235  
Patterson-Kelley Co., Inc., The, 1363  
Refrigeration Appliances, Inc., 1259  
Refrigeration Engineering, Inc., 1373  
Rittling Corp., The, 1384  
Rome-Turney Radiator Co., The, 1365  
Trane Co., The, 1298-1301  
Worthington Corp., 1241  
York Corp., 1242

**CONDUIT, Non-Ferrous Metal**

American Brass Co., The, 1310-1311

**CONDUIT, Refrigeration (See Hose, Flexible Metal, and Liquid Gas, Vapor)****CONDUITS, Underground Fittings**

Durant Insulated Pipe Co., 1647  
Durant International Corp., 1647  
E. B. Kaiser Co., 1648-1649  
National Clay Pipe Mfgs., The, 1516-1521  
H. W. Porter & Co., Inc., 1650  
Reid Hayden Inc., 1650  
Rie-wil, Inc., 1651  
Stillwater Clay Products Co., The, 1652

**CONDUITS, Underground Pipe**

Durant Insulated Pipe, 1647  
Durant International Corp., 1647  
E. B. Kaiser Co., 1648-1649  
National Clay Pipe Mfgs., The, 1516-1521  
H. W. Porter & Co., Inc., 1650  
Reid Hayden Inc., 1650  
Rie-wil, Inc., 1651  
Stillwater Clay Products Co., The, 1652  
Z-Crete Div., Zonolite Co., 1653

**CONNECTORS, FLEXIBLE**

Wiremold Co., The, 1469

**CONTROL, ACOUSTICAL (See Acoustical Control)****CONTROL, Air Volume Damper**

A-J Mfg. Co., 1426-1427  
Air & Refrigeration Corp., 1219  
Air Control Products, Inc., 1428-1431  
Air Devices, Inc., 1316, 1432  
Air-Factors, Inc., 1436  
Anemostat Corp. of America, 1434-1435

**CONTROL, Combustion, Automatic Air for Stokers**

Will-Burt Co., The, 1569

**CONTROLS, Liquid Level (See Liquid Level Controls)****CONTROLS, Motor (See Motor Controls)****CONTROLS, Water Level**

Heller Laboratories, Inc., 1352  
Leslie Co., 1487  
Maid-O'-Mist, Inc., 1630-1632  
McDonnell & Miller, Inc., 1570-1573  
Mercoid Corp., The, 1489  
Titus Mfg. Co., 1458-1459  
Waterloo Register Co., 1465  
Young Regulator Co., 1470-1471

**CONTROL, Boiler Water Level**

Leslie Co., 1487  
Maid-O'-Mist, Inc., 1630-1632

McDonnell & Miller, Inc., 1570-1573  
Mercoid Corp., The, 1489  
Warren Webster & Co., 1638-1639

**CONTROL EQUIPMENT, Air Conditioning, Electric, Combustion**

Barber-Colman Co., 1437, 1473  
Combustion Control Div., Electronics Corp. of America, 1475  
General Controls, 1480-1481  
Maxitrol Co., 1488  
Mercoid Corp., The, 1489  
Milwaukee Gas Specialty Co., 1492  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
Simplex Mfg. Co., 1500  
Webster Engineering Co., The, 1579  
White-Rodgers Electric Co., 1504

**CONTROL EQUIPMENT, Time**

April Showers, Inc., 1644  
Barber-Colman Co., 1437, 1473  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494

**CONTROLLERS AND CONTROL EQUIPMENT, ELECTRIC (See Humidity and Temperature Control)**

Alco Valve Co., 1472  
American Moistening Co., 1222  
Barber-Colman Co., 1437, 1473  
Heller Laboratories, Inc., 1352  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494

**CONTROLLERS, Pump**

A. W. Cash Co., 1617  
C. A. Dunham Co., 1618-1621  
Hoffman-Specialty Mfg. Corp., 1622-1625  
Hubbell Corp., 1483  
Illinois Engineering Co., 1226-1227  
Leslie Co., 1487  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Mercoid Corp., The, 1489  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498  
Sarootherm Controls, Inc., 1633  
Simplex Mfg. Co., 1500  
Sterling, Inc., 1502  
Taylor Instrument Cos., 1503  
Weiss Electric Heater Co., 1307  
White-Rodgers Electric Co., 1504

**CONTROLS, Combustion, Automatic Air for Stokers**

Will-Burt Co., The, 1569

**CONTROLS, Liquid Level (See Liquid Level Controls)****CONTROLS, Motor (See Motor Controls)****CONTROLS, Water Level**

Heller Laboratories, Inc., 1352  
Leslie Co., 1487  
Maid-O'-Mist, Inc., 1630-1632  
McDonnell & Miller, Inc., 1570-1573  
Mercoid Corp., The, 1489  
Titus Mfg. Co., 1458-1459  
Waterloo Register Co., 1465  
Young Regulator Co., 1470-1471

**CONVECTION HEATERS**

Airtherm Mfg. Co., 1522  
American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
C. A. Dunham Co., 1618-1621

Electromode Corp., 1305  
Industrial Engineering & Equipment Co., 1306  
Kritzer Radiant Coils, Inc., 1514  
Modine Mfg. Co., 1290-1291  
National-U. S. Radiator Corp., 1530-1533

**CONVECTORS AND CONVECTOR ENCLOSURES**

Acme Industries, Inc., 1358  
Airtherm Mfg. Co., 1522  
American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Feddars-Quigan Corp., 1288  
G & O Mfg. Co., The, 1362  
Kritzer Radiant Coils, Inc., 1514  
Louvra Mfg. & Sales Co., 1452  
Modine Mfg. Co., 1290-1291  
National-U. S. Radiator Corp., 1530-1533  
Herman Nelson, American Air Filter Co., Inc., 1296-1297  
Pacific Steel Boiler Div., National-U. S. Radiator Corp., 1534-1535  
Rittling Corp., The, 1384  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1386  
Somers Corp., 1339  
Standard Stamping & Perforating Co., 1456  
Trane Co., The, 1298-1301  
Tuttle & Bailey, Inc., 1460-1461  
Union Asbestos & Rubber Co., 1265  
Vulcan Radiator Co., The, 1367  
Warren Webster & Co., 1638-1639

**COOLERS EVAPORATIVE (See Evaporative Coolers)****COOLING EQUIPMENT, Air**

Addison Products Co., 1243  
Aerofin Corp., 1359-1361  
Airtemp Div., Chrysler Corp., 1248-1249  
American Blower Corp., 1220-1221  
American Moistening Co., 1222  
American-Standard, Air Conditioning Div., 1244-1245  
April Showers, Inc., 1644  
Armstrong Furnace Co., 1246-1247  
Bell & Gossett Co., 1598-1599  
Brunner Mfg. Co., 1368  
Buensod-Stacey, Inc., 1224  
Buffalo Forge Co., 1382  
Carrier Corp., 1226-1227  
Clavage Fan Co., 1225, 1387  
Copeland Refrigeration Corp., 1369  
Curtis Mfg. Co., 1370  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
Farr Co., 1332-1333  
General Automatic Products Co., 1513  
General Electric Co., 1230  
Halstead & Mitchell, 1350-1351  
Hydraline Products, Div. Borg-Warner Corp., 1251

Joy Mfg. Co., 1394-1395  
 Kennard Corp., 1234  
 Marlo Coil Co., 1235  
 McQuay, Inc., 1288-1289  
 Mueller Climatic Div. of Worthington Corp., 1254-1255  
 D. J. Murray Mfg. Co., 1292  
 Niagara Blower Co., 1235  
 Parks-Cramer Co., 1236-1237  
 Pennsylvania Furnace & Iron Co., 1258  
 Ready-Power Co., The, 1372  
 Refrigeration Appliances, Inc., 1259  
 Refrigeration Engineering, Inc., 1373  
 Rhein Mfg. Co., 1260-1261  
 Rittling Corp., 1364  
 Servel, Inc., 1262-1263  
 Trane Co., The, 1298-1301  
 Westinghouse Electric Corp., Air Conditioning Div., 1240  
 Westinghouse Electric Corp., Sturtevant Div., 1410  
 Worthington Corp., 1241  
 York Corp., 1242

**COOLING EQUIPMENT, Oil**  
 Acme Industries, Inc., 1358  
 Aeroform Corp., 1359-1361  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Bell & Gossett Co., 1598-1599  
 Binks Mfg. Co., 1344-1345  
 Brunner Mfg. Co., 1368  
 Marley Co., The, 1354  
 Niagara Blower Co., 1235  
 Patterson-Kelley Co., Inc., The, 1363  
 Refrigeration Engineering, Inc., 1373  
 Sterling, Inc., 1502  
 Taco Heaters, Inc., 1602  
 Trane Co., The, 1298-1301  
 Worthington Corp., 1241  
 Young Radiator Co., 1304

**COOLING EQUIPMENT, Water**  
 (See also Water Cooling)  
 Acme Industries, Inc., 1358  
 Addison Products Co., 1243  
 Aeroform Corp., 1359-1361  
 Airtemp Div., Chrysler Corp., 1248-1249  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1522-1525  
 Bell & Gossett Co., 1598-1599  
 Binks Mfg. Co., 1344-1345  
 Brunner Mfg. Co., 1368  
 Carrier Corp., 1226-1227  
 Copeland Refrigeration Corp., 1369  
 Curtis Mfg. Co., Refrigeration Div., 1370  
 Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
 C. A. Dunham Co., 1618-1621  
 Fluor Corp., Ltd., The, 1347  
 Frick Co., 1371  
 General Electric Co., 1230  
 E. D. Goodfellow Co., Inc., 1348  
 Governor Corp., 1232  
 Halstead & Mitchell, 1350-1351  
 Hastings Air Conditioning Co., Inc., 1233  
 Havens Structural Steel Co., 1349  
 Heller Laboratories, Inc., 1352  
 Kennard Corp., 1234  
 Killebrew Engineering Corp., 1597  
 Lilie-Hoffmann Cooling Towers, Inc., 1353  
 Marley Co., The, 1354

McQuay, Inc., 1288-1289  
 Modine Mfg. Co., 1290-1291  
 Niagara Blower Co., 1235  
 Packard Water Conditioner Div., Packard Mfg. Co., 1575  
 Patterson-Kelley Co., Inc., The, 1363  
 Pennsylvania Furnace & Iron Co., 1258  
 Phillips Cooling Tower Co., Inc., 1356  
 Ready-Power Co., The, 1372  
 Refrigeration Appliances, Inc., 1259  
 Refrigeration Engineering, Inc., 1373  
 Rome-Turney Radiator Co., 1365  
 Servel, Inc., 1262-1263  
 Taco Heaters, Inc., 1602  
 Trane Co., The, 1298-1301  
 Worthington Corp., 1241  
 York Corp., 1242  
 Young Radiator Co., 1304

**COOLING TOWER FANS**  
 Aerovent Fan Co., Inc., 1374  
 Binks Mfg. Co., 1344-1345  
 Clamage Fan Co., 1225, 1387  
 Fluor Corp., Ltd., The, 1347  
 Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
 Joy Mfg. Co., 1394-1395  
 Lau Blower Co., The, 1396-1397  
 Lilie-Hoffmann Cooling Towers, Inc., 1353  
 Marley Co., The, 1354  
 Morrison Products, Inc., 1398  
 Utility Fan Corp., 1264  
 L. J. Wing Mfg. Co., 1302-1303

**COOLING TOWERS, Atmospheric, Mechanical Draft, Forced Draft, Induced Draft**  
 (See also Cooling Equipment, Water)  
 Acme Industries, Inc., 1358  
 Air & Refrigeration Corp., 1219  
 Airtemp Div., Chrysler Corp., 1248-1249  
 American Blower Corp., 1220-1221  
 Baltimore Aircraft Co., Inc., 1346  
 Binks Mfg. Co., 1344-1345  
 Buensod-Stacey, Inc., 1224  
 Carrier Corp., 1226-1227  
 Curtis Mfg. Co., Refrigeration Div., 1370  
 Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
 Fluor Corp., Ltd., The, 1347  
 E. D. Goodfellow Co., Inc., 1348  
 Governor Corp., 1232  
 Halstead & Mitchell, 1350-1351  
 Havens Structural Steel Co., 1349  
 Kennard Corp., 1234  
 Lilie-Hoffmann Cooling Towers, Inc., 1353  
 Marley Co., The, 1354  
 Marlo Coil Co., 1235  
 McQuay, Inc., 1288-1289  
 D. J. Murray Mfg. Co., 1292  
 Phillips Cooling Tower Co., Inc., 1356  
 Refrigeration Appliances, Inc., 1259  
 Refrigeration Engineering, Inc., 1373  
 Servel, Inc., 1262-1263

**CORK PRODUCTS** (See Insulation)  
 Armstrong Cork Co., 1665  
 Korfund Co., Inc., The, 1687  
 Vibration Mountings, Inc., 1688

**CORROSION, Treatment of**  
 American Gilsonite Co., 1646  
 Durant Insulated Pipe Co., 1647  
 Durant International Corp., 1647  
 Heller Laboratories, Inc., 1352  
 E. B. Kaiser Co., 1648-1649  
 Owens-Corning Fiberglass Corp., 1658  
 Packard Water Conditioner Div., Packard Mfg. Co., 1575  
 Ric-wil, Inc., 1651

**COUPLINGS**  
 Aeroquip Corp., 1312

**COVERING, Pipe and Surface**  
 American Gilsonite Co., 1646  
 Philip Carey Mfg. Co., The, 1656-1657  
 Durant Insulated Pipe Co., 1647  
 Durant International Corp., 1647  
 Infra Insulation, Inc., 1679  
 Johns-Manville, 1670-1671  
 E. B. Kaiser Co., 1648-1649  
 Kimberly Clark Corp., 1672-1673  
 Lockport Mills, Inc., 1674  
 Miracle Adhesives, Inc., 1654  
 Owens-Corning Fiberglass Corp., 1658  
 Owens-Illinois, 1661  
 Pittsburgh Corning Corp., 1662  
 H. W. Porter & Co., Inc., 1650  
 Reflectal Corp., 1682  
 Reid Hayden, Inc., 1650  
 Ric-wil, Inc., 1651  
 Z-Crete Div., Zonolite Co., 1653

**CUT-OFFS, Low Water**  
 Barber-Colman Co., 1437, 1473  
 General Controls, 1480-1481  
 Maid-O'-Mist, Inc., 1630-1632  
 McDonnell & Miller, Inc., 1570-1573  
 Mercoind Corp., The, 1489  
 Minneapolis-Honeywell Regulator Co., 1490-1491  
 National-U. S. Radiator Corp., 1530-1533  
 Warren Webster & Co., 1638-1639

**DAMPER QUADRANTS** (See Quadrants, Damper)

**DAMPER REGULATOR SETS**  
 Barber-Colman Co., 1437, 1473  
 Duro-Dyne Corp., 1466-1467  
 Elgen Mfg. Corp., 1468  
 Field Control Div. of H. D. Conkey & Co., 1477  
 Hart & Cooley Mfg. Co., 1444-1445  
 Mercoind Corp., The, 1489  
 Minneapolis-Honeywell Regulator Co., 1490-1491  
 National-U. S. Radiator Corp., 1530-1533  
 Penn Controls, Inc., 1494  
 Standard Stamping & Perforating Co., 1456  
 Tuttle & Bailey, Inc., 1460-1461  
 Young Regulator Co., 1470-1471

**DAMPER REGULATORS**  
 Boiler (See Regulators)  
 Penn Controls, Inc., 1494  
 Preferred Utilities Mfg. Corp., 1566  
 Simplex Mfg. Co., 1500  
 Spence Engineering Co., Inc., 1501

**DAMPER REGULATORS, Furnace**  
 A. W. Cash Co., 1617  
 Duro-Dyne Corp., 1466-1467  
 Field Control Div. of H. D. Conkey & Co., 1477  
 Hart & Cooley Mfg. Co., 1444-1445

Mercoind Corp., The, 1489  
 Minneapolis-Honeywell Regulator Co., 1490-1491  
 Penn Controls, Inc., 1494  
 Simplex Mfg. Co., 1500  
 United States Register Co., 1462-1463  
 Young Regulator Co., 1470-1471

**DAMPERS, Air Volume Control**  
 Air Control Products, Inc., 1428-1431  
 Air Devices, Inc., 1316, 1432  
 Air-Factors, Inc., 1433  
 American Foundry & Furnace Co., 1266-1267  
 Anemostat Corp. of America, 1434-1435  
 Auer Register Co., 1436  
 Barber-Colman Co., 1437, 1473  
 Duro-Dyne Corp., 1466-1467  
 General Register Corp., 1442-1443  
 Hart & Cooley Mfg. Co., 1444-1445  
 Johnson Service Co., 1484-1485  
 Lima Register Co., 1450-1451  
 Minneapolis-Honeywell Regulator Co., 1490-1491  
 Parks-Cramer Co., 1236-1237  
 Powers Regulator Co., The, 1496-1498  
 Register & Grille Mfg. Co., 1453-1454  
 Rittling Corp., The, 1364  
 Titus Mfg. Corp., 1458-1459  
 Tuttle & Bailey, Inc., 1460-1461  
 United States Register Co., 1462-1463  
 Vulcan Radiator Co., The, 1367  
 Waterloo Register Co., Inc., 1465  
 Young Regulator Co., 1470-1471

**DAMPERS, Back Draft** (See Dampers, Air Volume Control)

**DAMPERS, Mechanical**  
 Barber-Colman Co., 1437, 1473  
 Buensod-Stacey, Inc., 1224  
 Carrier Corp., 1226-1227  
 Duro-Dyne Corp., 1466-1467  
 Elgen Mfg. Corp., 1468  
 Minneapolis-Honeywell Regulator Co., 1490-1491  
 Powers Regulator Co., The, 1496-1498  
 Young Regulator Co., 1470-1471

**DAMPERS, Multi-Blade, Hard-ware**  
 Duro-Dyne Corp., 1466-1467  
 Elgen Mfg. Corp., 1468

**DEFLECTION GRILLE** (See Grilles, Registers and Ornamental Metal Work, also Louvers, Registers)  
 A-J Mfg. Co., 1426-1427  
 Air Control Products, Inc., 1428-1431  
 Air-Factors, Inc., 1433  
 Auer Register Co., The, 1436  
 Barber-Colman Co., 1437, 1473  
 General Register Corp., 1442-1443  
 Hart & Cooley Mfg. Co., 1444-1445  
 Hendrick Mfg. Co., 1446-1447  
 Lima Register Co., 1450-1451  
 Louva Mfg. & Sales Co., 1452  
 Register & Grille Mfg. Co., 1453  
 Standard Stamping & Perforating Co., 1456  
 Titus Mfg. Corp., 1458-1459  
 Tuttle & Bailey, Inc., 1460-1461  
 United States Register Co., 1462-1463  
 Waterloo Register Co., 1465  
 Young Regulator Co., 1470-1471

**DEHUMIDIFIERS**  
 Addison Products Co., 1243  
 Air & Refrigeration Corp., 1219  
 Airtemp Div., Chrysler Corp., 1248-1249  
 American Blower Corp., 1220-1221  
 Bahnsen Co., The, 1223  
 Bayley Blower Co., 1376  
 Buensod-Stacey, Inc., 1224  
 Buffalo Forge Co., 1382  
 Carrier Corp., 1226-1227  
 Clamage Fan Co., 1225, 1387  
 Desomatic Products, Inc., 1228  
 Marlo Coil Co., 1355  
 New York Blower Co., The, 1390  
 Niagara Blower Co., 1235  
 Parks-Cramer Co., 1236-1237  
 Pittsburgh Electrodryer Corp., 1238  
 Refrigeration Engineering, Inc., 1373  
 Trane Co., The, 1298-1301  
 Walton Laboratories, Inc., 1239  
 Westinghouse Electric Corp., Sturtevant Div., 1410  
 York Corp., 1242

**DESTROYERS, Soot** (See Soot Destroyers)

**DETECTORS, Smoke** (See Smoke Detectors and Indicators, for Flues and Ducts)

**DIFFUSERS, Air** (See Air Diffusers, and Ventilators, Ceiling, Floor and Wall)

**DIFFUSERS, Ceiling** (See Ceiling, Diffusers)

**DISCS, Removable Composition**  
 Fairbanks Co., The, 1641  
 Jenkins Bros., 1643

**DISTRICT HEATING** (See Corrosion, Treatment of—Expansion Joints—Insulation, Underground—Meters, Pipe)

**DISTRICT HEATING, High-temperature Fluid Systems**  
 American Gilsonite Co., 1646  
 Durant Insulated Pipe Co., 1647  
 Durant International Corp., 1647  
 E. B. Kaiser Co., 1648-1649  
 Z-Crete Div., Zonolite Co., 1653  
 Field Control Div. of H. D. Conkey & Co., 1477  
 General Controls, 1480-1481  
 National-U. S. Radiator Corp., 1530-1533  
 Simplex Mfg. Co., 1500  
 Webster Engineering Co., 1579

**DRIERS, Refrigerant**  
 Henry Valve Co., 1452

**DRYING EQUIPMENT**  
 Aerovent Fan Co., Inc., 1374  
 Air Devices, Inc., 1316, 1432  
 Buffalo Forge Co., 1382  
 Campbell Heating Co., 1268-1269  
 Dravo Corp., 1272-1273  
 Lau Blower Co., The, 1396-1397  
 Lee Corp., 1277  
 Modine Mfg. Co., 1290-1291  
 National Heater Co., 1280-1281  
 Niagara Blower Co., 1235  
 Arthur A. Olson & Co., 1279

Trane Co., The, 1298-1301  
 Edwin L. Wiegand Co., 1308-1309

**DUAL DUCT SYSTEMS**  
 Buensod-Stacey, Inc., 1224

**DUCT AND FITTINGS**  
 Lamneck Div., Clayton & Lambert Mfg. Co., 1256

**DUCT CONNECTORS, Prefabricated**  
 Duro-Dyne Corp., 1466-1467  
 Elgen Mfg. Corp., 1468

**DUCT FABRIC**  
 Duro-Dyne Corp., 1466-1467

**DUCT FURNACES** (See Heaters, Duct)

**DUCT INSULATION** (See Insulation, Ducts, Ventilating, Air Conditioning)

**DUCTS, AIR CONDITIONING, HEATING AND VENTILATING, Under Concrete Floor Slabs**  
 National Clay Pipe Mfgs., The, 1516-1521  
 Sonoco Products Co., 1659  
 Stillwater Clay Products Co., The, 1652

**DUCTS, FLEXIBLE**  
 Wiremold Co., The, 1469

**DUCTS, Prefabricated**  
 Duro-Dyne Corp., 1466-1467  
 Johns-Manville, 1670-1671  
 Mueller Climatic Div. of Worthington Corp., 1254-1255  
 National Clay Pipe Mfgs., The, 1516-1521  
 Sonoco Products Co., 1659  
 United States Register Co., 1462-1463

**DUCTS, Ventilating**  
 National Clay Pipe Mfgs., The, 1516-1521  
 Sonoco Products Co., 1659

**DUST COLLECTING EQUIPMENT**

Air Filter Corp., 1317  
 American Air Filter Co., Inc., 1319-1321  
 American Blower Corp., 1220-1221  
 V. D. Anderson Co., The, 1612-1613  
 Buffalo Forge Co., 1382  
 Clamage Fan Co., 1225, 1387  
 Farr Co., 1332-1333  
 General Blower Co., 1391  
 Thermobloc Div., Prat-Daniel Corp., 1284  
 Trion, Inc., 1340

**DUST COLLECTORS, Cloth Type**  
 American Air Filter Co., Inc., 1319-1321

**EJECTORS, Sewage**  
 Buffalo Pumps, Inc., 1604  
 Chicago Pump Co., 1606-1607

**ELECTRICAL RELAYS** (See Relays, Electrical and Pneumatic)

**ELECTROSTATIC AIR CLEANERS**  
 Air-Maze Corp., 1318

American Air-Filter Co., Inc., 1319-1321  
American-Standard, Air Conditioning Div., 1244-1245  
Dollinger Corp., 1330-1331  
Electro-Air Cleaner Co., 1329  
Trion, Inc., 1340  
Westinghouse Electric Corp., Sturtevant Div., 1342

**ELECTROSTATIC FILTERS,**  
Gas  
Electro-Air Cleaner Co., 1329  
Trion, Inc., 1340

**ELIMINATORS, Air** (See Air Eliminators)

**EVAPORATIVE CONDENSERS**  
(See Condensers and Evaporators)

**EVAPORATIVE COOLERS**  
Airfan Engineering Co., 1343  
Baltimore Aircoil Co., Inc., 1346  
Trade-Wind Motorfans, Inc., 1405

**EVAPORATIVE ROOF COOLING SYSTEMS**  
April Showers Co., Inc., 1644  
Muellermist Irrigation Co., 1645

**EVAPORATORS**  
American District Steam Div., Adco Industries, Inc., 1505, 1594  
Bell & Gossett Co., 1598-1599  
Buffalo Forge Co., 1382  
Drayer-Hanson Div. of National U. S. Radiator Corp., 1229  
Marlo Coil Co., 1355  
McQuay, Inc., 1288-1289  
Refrigeration Appliances, Inc., 1259  
Refrigeration Engineering, Inc., 1373  
Rome-Turney Radiator Co., The, 1365  
Trane Co., The, 1298-1301  
Young Radiator Co., 1304

**EXHAUST HEADS** (See Heads, Exhaust)

**EXHAUST TUBING, Flexible** (See Tubing, Flexible, Metallic)

**EXHAUSTERS**  
Aerovent Fan Co., Inc., 1374  
Air Devices, Inc., 1316, 1432  
Airfan Engineering Co., 1343  
Aladdin Heating Corp., 1375  
Allen Cooler & Ventilator, Inc., 1414  
American Air Filter Co., Inc., 1319-1321  
American Blower Corp., 1220-1221  
C. L. Ammerman Co., 1415  
Bayler-Blower Co., 1376  
G. C. Breidert Co., 1416  
Brookside Products Co., Inc., 1379  
Brundage Co., The, 1380-1381  
Buffalo Forge Co., 1382  
Century Fan & Ventilator Co., 1384  
Champion Blower & Forge Co., 1385  
Chicago Blower Corp., 1386  
Clara Fan Co., 1225, 1387  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
Gallagher Co., The, 1417  
Garden City Fan Co., 1390  
General Blower Co., 1391  
Genie-Air, Inc., 1418-1419  
Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Hirschmann-Pohle Co., Inc., 1420  
Ilg Electric Ventilating Co., 1287, 1393

Joy Mfg. Co., 1394-1395  
Kewanee Mfg. Co., 1411  
Lau Blower Co., The, 1396-1397  
Muckle Mfg. Co., 1421  
John J. Nesbitt, Inc., 1293-1295  
New York Blower Co., The, 1399  
Peerless Electric Co., The, 1400  
Penn Ventilator Co., 1422  
Propellair Div., Robbins & Myers, Inc., 1401  
Reed Unit-Fans, Inc., 1402  
Sheldons Engineering Ltd., 1404  
Swartwout Co., The, 1423  
Trade Wind Motorfans, Inc., 1405  
Trane Co., The, 1298-1301  
Westinghouse Electric Corp., Sturtevant Div., 1342, 1410  
L. J. Wing Mfg. Co., 1302-1303

**EXHAUSTERS, Laboratory**  
C. L. Ammerman Co., 1415  
Gallagher Co., The, 1417  
Genie-Air, Inc., 1418-1419  
Muckle Mfg. Co., 1421  
E. H. Sheldon Equipment Co., 1412-1413

**EXPANSION JOINTS**  
American District Steam Div., Adco Industries, Inc., 1505, 1594  
Badger Mfg. Co., 1508  
Philip Carey Mfg. Co., The, 1656-1657  
Celotex Corp., The, 1666  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
T. R. Finn & Co., Inc., 1686  
Flexonics Corp., 1507  
Fulton-Syphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Owens-Corning Fiberglas Corp., 1336, 1658  
Vibration Mountings, Inc., 1688  
Warren Webster & Co., 1639-1639

**EXPANSION LOOPS**  
Durant Insulated Pipe Co., 1647  
Durant International Corp., 1647  
E. B. Kaiser Co., 1648-1649  
Z-Crete Div., Zonolite Co., 1653

**EXPOSITIONS**  
International Exposition Co., 1636

**FABRIC, Duct** (See Duct Fabric)

**FAN BLADE HUBS**  
Alan E. Burden Co., Inc., 1383

**FAN BLADES**  
Bronson Fan Mfg. Corp., 1378  
Brookside Products Co., Inc., 1379  
Alan E. Burden Co., Inc., 1383  
Century Fan & Ventilator Co., 1384  
Torrington Mfg. Co., The, 1406-1407

**FAN MOTORS** (See Motors, Electric)

**FAN STACKS**  
Dutton Boilers, Division Hapman-Dutton Co., 1551

**FANS, Attic**  
Allen Cooler & Ventilator Inc., 1414  
American Blower Corp., 1220-1221  
Buffalo Forge Co., 1382

Philip Carey Mfg. Co., The, 1656-1657  
Champion Blower & Forge Co., 1385  
General Blower Co., 1391  
Genie-Air, Inc., 1418-1419  
Ilg Electric Ventilating Co., 1287, 1393  
Lau Blower Co., The, 1396-1397  
Muckle Mfg. Co., 1421  
Peerless Electric Co., The, 1400  
Reed Unit-Fans, Inc., 1402  
Somers Corp., 1339  
Trade-Wind Motorfans, Inc., 1405  
Viking Air Conditioning Div. of The National-U. S. Radiator Corp., 1408  
John Zink Co., 1588-1589

**FANS, Axial Flow**  
Aerovent Fan Co., Inc., 1374  
Allen Cooler & Ventilator Inc., 1414  
American Blower Corp., 1220-1221  
C. L. Ammerman Co., 1415  
Bronson Fan Mfg. Corp., 1378  
Brookside Products Co., Inc., 1379  
Buffalo Forge Co., 1382  
Century Fan & Ventilator Co., Inc., 1384  
Chicago Blower Corp., 1386  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
Gallagher Co., The, 1417  
Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Ilg Electric Ventilating Co., 1287, 1393  
Joy Mfg. Co., 1394-1395  
Lau Blower Co., The, 1396-1397  
New York Blower Co., The, 1399  
Peerless Electric Co., The, 1400  
Penn Ventilator Co., 1422  
Propellair Div., Robbins & Myers, Inc., 1401  
Reed Unit-Fans, Inc., 1402  
Sheldons Engineering Ltd., 1404  
Torrington Mfg. Co., The, 1406-1407  
Trade-Wind Motorfans, Inc., 1405  
Westinghouse Electric Corp., Sturtevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

**FANS, Centrifugal**  
Aerovent Fan Co., Inc., 1374  
Air Fan Engineering Co., 1343  
Aladdin Heating Corp., 1375  
American Blower Corp., 1220-1221  
Bayler-Blower Co., 1376  
Bishop & Babcock Mfg. Co., The, (Massachusetts Blower Div.), 1377  
Brookside Products Co., Inc., 1379  
Brundage Co., The, 1380-1381  
Buffalo Forge Co., 1382  
E. K. Campbell Co., 1270  
Campbell Heating Co., 1268-1269  
Carrier Corp., 1226-1227  
Century Fan & Ventilator Co., Inc., 1384  
Champion Blower & Forge Co., 1385  
Chicago Blower Corp., 1386  
Clara Fan Co., 1225, 1387  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
Gallagher Co., The, 1417  
Garden City Fan Co., 1390  
General Blower Co., 1391  
Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Hirschmann-Pohle Co., Inc., 1420  
Ilg Electric Ventilating Co., 1287, 1393  
Morrison Products, Inc., 1398  
Muckle Mfg. Co., 1421  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255

## Index to Modern Equipment

Herman Nelson, American Air Filter Co., Inc., 1296-1297  
New York Blower Co., The, 1399  
Niagara Blower Co., 1235  
Peerless Electric Co., The, 1400  
Peap Ventilator Co., 1422  
Revcor, 1403  
Sheldons Engineering Ltd., 1404  
Torrington Mfg. Co., The, 1406-1407  
Trade-Wind Motorfans, Inc., 1405  
Trane Co., The, 1298-1301  
Utility Fan Corp., 1264  
Western Blower Co., 1409  
Westinghouse Electric Corp., Sturtevant Div., 1410

**FANS, Electric**  
Allen Cooler & Ventilator Inc., 1414  
Philip Carey Mfg. Co., The, 1656-1657  
Century Fan & Ventilator Co., 1384  
Champion Blower & Forge Co., 1385  
General Blower Co., 1391  
Hirschmann-Pohle Co., Inc., 1420  
Ilg Electric Ventilating Co., 1287, 1393  
Joy Mfg. Co., 1394-1395  
Lau Blower Co., The, 1396-1397  
Propellair Div., Robbins & Myers, Inc., 1401  
Trade-Wind Motorfans, Inc., 1405  
Utility Fan Corp., 1264  
Viking Air Conditioning Div. of The National-U. S. Radiator Corp., 1408  
Western Engineering & Mfg. Co., 1424  
Westinghouse Electric Corp., Sturtevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

**FANS Furnace**  
Aladdin Heating Corp., 1375  
American Blower Corp., 1220-1221  
Bishop & Babcock Mfg. Co., The, (Massachusetts Blower Div.), 1377  
Brundage Co., The, 1380-1381  
Champion Blower & Forge Co., 1385  
Clara Fan Co., 1225, 1387  
Joy Mfg. Co., 1394-1395  
Morrison Products, Inc., 1398  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
Utility Fan Corp., 1264  
L. J. Wing Mfg. Co., 1302-1303

**FANS Induced Draft**  
American Blower Corp., 1220-1221  
C. L. Ammerman Co., 1415  
Bayler-Blower Co., 1376  
Buffalo Forge Co., 1382  
Century Fan & Ventilator Co., 1384  
Champion Blower & Forge Co., 1385  
Chicago Blower Corp., 1386  
Clara Fan Co., 1225, 1387  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
Gallagher Co., The, 1417  
Garden City Fan Co., 1390  
General Blower Co., 1391  
Muckle Mfg. Co., 1421  
Pacific Steel Boiler Div., National-U. S. Radiator Corp., 1534-1535  
Sheldons Engineering Ltd., 1404  
Westinghouse Electric Corp., Sturtevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

**FANS, Portable**  
Aerovent Fan Co., Inc., 1374  
Champion Blower & Forge Co., 1385  
General Blower Co., 1391

Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Ilg Electric Ventilating Co., 1287, 1393  
Joy Mfg. Co., 1394-1395  
Lau Blower Co., The, 1396-1397  
Propellair Div., Robbins & Myers, Inc., 1401  
Reed Unit-Fans, Inc., 1402  
Torrington Mfg. Co., The, 1406-1407  
L. J. Wing Mfg. Co., 1302-1303

**FANS, Propeller**  
Aerovent Fan Co., Inc., 1374  
Allen Cooler & Ventilator Inc., 1414  
American Blower Corp., 1220-1221  
C. L. Ammerman Co., 1415  
Bishop & Babcock Mfg. Co., The, (Massachusetts Blower Div.), 1377  
Bronson Fan Mfg. Corp., 1378  
Brookside Products Co., Inc., 1379  
Buffalo Forge Co., 1382  
Alan E. Burden Co., Inc., 1383  
Century Fan & Ventilator Co., 1384  
Chicago Blower Corp., 1386  
Clara Fan Co., 1225, 1387  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
Gallagher Co., The, 1417  
General Blower Co., 1391  
Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Hirschmann-Pohle Co., Inc., 1420  
Ilg Electric Ventilating Co., 1287, 1393  
Lau Blower Co., The, 1396-1397  
Muckle Mfg. Co., 1421  
Herman Nelson, American Air Filter Co., Inc., 1296-1297  
New York Blower Co., The, 1399  
Peerless Electric Co., The, 1400  
Penn Ventilator Co., 1422  
Propellair Div., Robbins & Myers, Inc., 1401  
Reed Unit-Fans, Inc., 1402  
Trane Co., The, 1298-1301  
Utility Fan Corp., 1264  
Viking Air Conditioning Div. of The National-U. S. Radiator Corp., 1408  
Westinghouse Electric Corp., Sturtevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

**FANS, Supply and Exhaust**  
Aerovent Fan Co., Inc., 1374  
Air Fan Engineering Co., 1343  
Aladdin Heating Corp., 1375  
Allen Cooler & Ventilator Inc., 1414  
American Blower Corp., 1220-1221  
C. L. Ammerman Co., 1415  
Bayler-Blower Co., 1376  
Binks Mfg. Co., 1344-1345  
Bishop & Babcock Mfg. Co., The, (Massachusetts Blower Div.), 1377  
Brundage Co., The, 1380-1381  
Buffalo Forge Co., 1382  
Philip Carey Mfg. Co., The, 1656-1657  
Century Fan & Ventilator Co., Inc., 1384  
Champion Blower & Forge Co., 1385  
Chicago Blower Corp., 1386  
Clara Fan Co., 1225, 1387  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
Gallagher Co., The, 1417  
Garden City Fan Co., 1390  
General Blower Co., 1391  
Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Hirschmann-Pohle Co., Inc., 1420  
Ilg Electric Ventilating Co., 1287, 1393  
Morrison Products, Inc., 1398  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
Utility Fan Corp., 1264  
L. J. Wing Mfg. Co., 1302-1303

**FELT, Insulating** (See Insulation, Felt)  
**FELT, Sound Deadening**  
Armstrong Cork Co., 1665  
Kimberly-Clark Corp., 1672-1673  
Lockport Mills, Inc., 1674  
Owens-Corning Fiberglas Corp., 1658  
Wood Conversion Co., 1677  
**FIBER INSULATION** (See Insulation)  
**FILTERS, Air** (See Air Cleaning Equipment)  
Air & Refrigeration Corp., 1219  
Air Devices, Inc., 1316, 1432  
Air Filter Corp., 1317  
Air-Maze Corp., 1318  
American Air Filter Co., Inc., 1319-1321  
American Moistening Co., 1222  
American-Standard, Air Conditioning Div., 1244-1245  
V. D. Anderson Co., The, 1612-1613  
Cambridge Filter Corp., 1324  
Carey Electronic Engineering Co., 1325  
Continental Air Filters, Inc., 1323  
Dollinger Corp., 1330-1331  
Electro-Air Cleaner Co., 1329  
Farr Co., 1332-1333  
Goodyear Tire & Rubber Co., 1334

Muckle Mfg. Co., 1491  
Owens-Corning Fiberglas Corp., 1336  
Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664  
Research Products Corp., 1338  
Somers Corp., 1339  
Trion, Inc., 1340  
Vortex Co., 1341

**FILTERS, Air, Continuous, Automatic.**  
Air-Maze Corp., 1318  
American Air Filter Co., Inc., 1319-1321  
V. D. Anderson Co., The, 1612-1613  
Bahnsen Co., The, 1223  
Continental Air Filters, Inc., 1328  
Dollinger Corp., 1330-1331  
Electro-Air Cleaner Co., 1329  
Farr Co., 1332-1333  
Charles E. Manning Co., 1335  
Trion, Inc., 1340

**FILTERS, Electrostatic Precipitators**  
Air-Maze Corp., 1318  
American Air Filter Co., Inc., 1319-1321  
American-Standard, Air Conditioning Div., 1244-1245  
Dollinger Corp., 1330-1331  
Electro-Air Cleaner Co., 1329  
Trion, Inc., 1340  
Westinghouse Electric Corp., Sturtevant Div., 1342

**FILTERS, Gas**  
Air-Maze Corp., 1318  
American Air Filter Co., Inc., 1319-1321  
V. D. Anderson Co., The, 1612-1613  
Barnebey-Cheney Co., 1322-1323  
Cambridge Filter Co., 1324  
Connor Engineering Corp., 1326-1327, 1440-1441  
Dollinger Corp., 1330-1331  
Electro-Air Cleaner Co., 1329  
Pur Air Div., Barnebey-Cheney Co., 1322-1323  
Trion, Inc., 1340

**FILTERS, Grease**  
Air Devices, Inc., 1316, 1432  
Air Filter Corp., 1317  
Air-Maze Corp., 1318  
American Air Filter Co., Inc., 1319-1321  
Continental Air Filters, Inc., 1328  
Dollinger Corp., 1330-1331  
Farr Co., 1332-1333  
Research Products Corp., 1338  
Trion, Inc., 1340

**FILTERS, Liquid**  
Air-Maze Corp., The, 1318  
Dollinger Corp., 1330-1331  
Eddington Metal Specialty Co., 1501  
Knaiss Co., Inc., The, 1610

**FILTERS, Odors**  
Barnebey-Cheney Co., 1322-1323  
Connor Engineering Corp., 1326-1327, 1440-1441  
Charles E. Manning Co., 1335  
Pur Air Div., Barnebey-Cheney Co., 1322-1323  
Research Products Corp., 1338

**FIREBRICK, Insulating**  
Babcock & Wilcox Co., The, 1542  
Johns-Manville, 1670-1671

**FITTINGS, Air Conditioning and Warm Air Furnace (See Furnace Pipe and Fittings)**  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
United States Register Co., 1462-1463

**FITTINGS, Hot Water Heating Systems**  
Bell & Gossett Co., 1598-1599  
C. A. Dunham Co., 1618-1621  
Flexonics Corp., 1507  
General Fittings Co., 1596  
Hammond Brass Works, 1642  
Hoffman Specialty Mfg. Corp., 1622-1625  
Maid-O'-Mist, Inc., 1630-1632  
Jas. P. Marsh Corp., 1628-1629  
National-U. S. Radiator Corp., 1530-1533  
Packard Water Conditioner Div., Packard Mfg. Co., 1575  
Sarco Co., Inc., 1634-1635  
Sarcotherm Controls, Inc., 1633  
Taco Heaters, Inc., 1602  
H. A. Thrush & Co., 1600-1601  
Trane Co., The, 1298-1301  
Warren Webster & Co., 1638-1639

**FITTINGS, Jacketed, Steam and Oil**  
E. B. Kaiser Co., 1648-1649  
Parks-Cramer Co., 1236-1237

**FITTINGS, Pipe, Acid Resisting**  
Ladish Co., 1508  
National Clay Pipe Mfgs., The, 1516-1521  
Stillwater Clay Products Co., The, 1652  
Taylor Forge & Pipe Works, Inc., 1510

**FITTINGS, Pipe, Alloy and Stainless, Non-Ferrous**  
Ladish Co., 1508  
Robvon Backing Ring Co., The, 1509  
Taylor Forge & Pipe Works, 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FITTINGS, Pipe, Flanged**  
York Corp., 1242

**FITTINGS, Pipe for Underground Conduit**  
Durant Insulated Pipe Co., 1647  
Durant International Corp., 1647  
E. B. Kaiser Co., 1648-1649  
National Clay Pipe Mfgs., The, 1516-1521  
H. W. Porter & Co., Inc., 1650  
Reid Hayden, Inc., 1650  
Ric-wil, Inc., 1651  
Robvon Backing Ring Co., The, 1509  
Stillwater Clay Products Co., The, 1652

**FITTINGS, Pipe, Galvanized**  
E. B. Kaiser Co., 1648-1649  
Ladish Co., 1508

**FITTINGS, Pipe, Screwed**  
Ladish Co., 1508

**FITTINGS, Pipe, Seamless Welding**  
Ladish Co., 1508  
Robvon Backing Ring Co., The, 1509

Taylor Forge & Pipe Works, Inc., 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FITTINGS, Pipe, Socket-Welding**  
Ladish Co., 1508

**FITTINGS, Pipe, Solder**  
American Brass Co., The, 1310-1311  
General Fittings Co., 1596

**FITTINGS, Pipe, Steel**  
Henry Valve Co., 1482  
Ladish Co., 1508  
Robvon Backing Ring Co., The, 1509  
Taylor Forge & Pipe Works, Inc., 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FITTINGS, Welding**  
Ladish Co., 1508  
Robvon Backing Ring Co., The, 1509  
Taylor Forge & Pipe Works, Inc., 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FLANGES, Galvanized or Non-Ferrous**  
Ladish Co., 1508  
Simplex Mfg. Co., 1500

**FLANGES, Lead, Roof**  
Simplex Mfg. Co., 1500

**FLANGES, Pipe, Alloy, Stainless, Non-Ferrous**  
Ladish Co., 1508  
Taylor Forge & Pipe Works, Inc., 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FLANGES, Pipe Blind**  
Ladish Co., 1508  
Taylor Forge & Pipe Works, Inc., 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FLANGES, Pipe, Reducing**  
Ladish Co., 1508  
Taylor Forge & Pipe Works, Inc., 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FLANGES, Pipe, Steel**  
Ladish Co., 1508  
Taylor Forge & Pipe Works, Inc., 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FLANGES, Welding**  
Ladish Co., 1508  
Taylor Forge & Pipe Works, Inc., 1510  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**FLOATS, Ferrous and Non-Ferrous (Seamless)**  
Arthur Harris & Co., 1512

**FLOATS, Welded-Stainless, Monel, Plated Steel**  
Arthur Harris & Co., 1512

**FLOOR PLATES**  
United States Steel, 1425

**FLUES**  
Metalbestos Div., William Wallace Co., 1592-1593

**FOOD SAVERS**  
Barnebey-Cheney Co., 1322-1323  
Connor Engineering Corp., 1326-1327, 1440-1441  
Pur Air Div., Barnebey-Cheney Co., 1332-1333

**FORCED-AIR DUCTS and FITTINGS (See Ducts; Fittings)**

**FORCED DRAFT COOLING TOWERS (See Cooling Towers, Induced Draft, Mechanical Draft)**  
Acme Industries, Inc., 1358  
Air & Refrigeration Corp., 1219  
Airtemp Div., Chrysler Corp., 1248-1249  
Baltimore Aircorl Co., Inc., 1347  
Carrier Corp., 1226-1227  
Fluor Corp., Ltd., The, 1347  
E. D. Goodfellow Co., Inc., 1348  
Kennard Corp., 1234  
Lillie-Hoffmann Cooling Towers, Inc., 1353  
Marley Co., The, 1354  
Marlo Coil Co., 1355  
McQuay, Inc., 1288-1289  
Phillips Cooling Tower Co., Inc., 1356  
Refrigeration Engineering, Inc., 1373  
Servel, Inc., 1262-1263

**FUEL BURNING EQUIPMENT, Automatic (See Burners, Automatic; Gas Burners; Oil Burners; Stokers)**

**FUEL OIL, Heating, Pumping and Straining Units**  
S. T. Johnson Co., 1532-1533  
Edwin L. Wiegand Co., 1308-1309

**FUME DISPOSAL DUCTS, Vitriified Clay**  
National Clay Pipe Mfgs., The, 1516-1521

**FUME DISPOSAL UNITS (Hoods) Laboratory**  
Kewaunee Mfg. Co., 1411  
E. H. Sheldon Equipment Co., 1412-1413

**FURNACE PIPE AND FITTINGS**  
Lamneck Div., Clayton & Lambert Mfg. Co., 1256  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
United States Register Co., 1462-1463

**FURNACES, Duct (See Heaters, Duct)**

**FURNACES, Electric**  
Electromode Corp., 1305  
West Electric Heater Co., 1307

**FURNACES, Gas-Fired, Floor**  
Chicago Steel Furnace Co., 1271  
Dravo Corp., 1272-1273  
Jackson & Church Co., 1276  
Johnson Heater Corp., 1274-1275  
Mammoth Furnace Co., The, 1278

National Heater Co., 1280-1281  
Rheem Mfg. Co., 1260-1261  
John Zink Co., 1588-1589

**FURNACES, Oil Burnings, Floor**  
Airtherm Mfg. Co., 1522  
American Foundry & Furnace Co., 1266-1267  
Chicago Steel Furnace Co., 1271  
Dravo Corp., 1272-1273  
General Automatic Products Co., 1513  
Jackson & Church Co., 1276  
Johnson Heater Corp., 1274-1275  
Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
National Heater Co., 1280-1281  
Arthur A. Olson & Co., 1279  
Vapor Heating Corp., 1567

**FURNACES, Suspended**  
Airtemp Div., Chrysler Corp., 1248-1249  
American-Standard, Air Conditioning Div., 1244-1245  
Armstrong Furnace Co., 1246-1247  
Chicago Steel Furnace Co., 1271  
Dravo Corp., 1272-1273  
General Automatic Products Co., 1513  
Hayes Furnace Mfg. & Supply Co., 1252-1253  
Jackson & Church Co., 1276  
Johnson Heater Corp., 1274-1275  
Mammoth Furnace Co., The, 1278  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
National Heater Co., 1280-1281  
Norman Products Co., 1257  
Resnor Mfg. Co., 1282-1283  
Rheem Mfg. Co., 1260-1261  
Vapor Heating Corp., 1567  
West Electric Heater Co., 1307  
York-Shipleigh, Inc., 1590

**FURNACES, Wall**  
Rheem Mfg. Co., 1260-1261  
West Electric Heater Co., 1307  
John Zink Co., 1588-1589

**FURNACES, Warm Air, Heavy Duty**  
Air Devices, Inc., 1316, 1432  
Airtherm Mfg. Co., 1522  
Aladdin Heating Corp., 1375  
American Foundry & Furnace Co., 1266-1267  
Armstrong Furnace Co., 1246-1247  
E. K. Campbell Co., 1270  
Campbell Heating Co., 1268-1269  
Carrier Corp., 1226-1227  
Chicago Steel Furnace Co., 1271  
Dravo Corp., 1272-1273  
Hayes Furnace Mfg. & Supply Co., 1252-1253  
Jackson & Church Co., 1276  
Johnson Heater Corp., 1274-1275  
Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
National Heater Co., 1280-1281  
Arthur A. Olson & Co., 1279  
Ray Oil Burner Co., 1584-1585  
Rheem Mfg. Co., 1260-1261

**FURNACES, Warm Air, Resilience**  
Airtemp Div., Chrysler Corp., 1248-1249  
Aladdin Heating Corp., 1375  
American-Standard, Air Conditioning Div., 1244-1245  
Armstrong Furnace Co., 1246-1247  
Babcock & Wilcox Co., The, 1542  
Cleaver-Brooks Co., 1544-1545  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
Dewey-Shepard Boiler Co., 1550  
Gordon-Platt, Inc., 1576  
Hastings Air Conditioning Co., Inc., 1233  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
National-U. S. Radiator Corp., 1530-1533  
Norman Products Co., 1257

Eddington Metal Specialty Co., 1501  
General Automatic Products Corp., 1513  
Hayes Furnace Mfg. & Supply Co., 1252-1253  
Jackson & Church Co., 1276  
S. T. Johnson Co., 1582-1583  
Johnson Heater Corp., 1274-1275  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
National-U. S. Radiator Corp., 1530-1533  
Norman Products Co., 1257  
Pennsylvania Furnace & Iron Co., 1258  
Ray Oil Burner Co., 1584-1585  
Rheem Mfg. Co., 1260-1261  
Roberts-Gordon Appliance Corp., 1577  
Servel, Inc., 1262-1263  
York-Shipleigh, Inc., 1590  
John Zink Co., 1588-1589

**GAGES, Altitude**  
Jas. P. Marsh Corp., 1628-1629

**GAGES, Compound**  
C. A. Dunham Co., 1618-1621  
Jas. P. Marsh Corp., 1628-1629

**GAGES, Liquid Level**  
Scully Signal Co., 1499

**GAGES, Pressure**  
C. A. Dunham Co., 1618-1621  
General Controls, 1480-1481  
Jas. P. Marsh Corp., 1628-1629  
Mercoind Corp., The, 1489  
Taylor Instrument Cos., 1503

**GAGES, Steam**  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Jas. P. Marsh Corp., 1628-1629

**GAGES, Tank**  
Scully Signal Co., 1499

**GAGES, Vacuum**  
C. A. Dunham Co., 1618-1621  
Electric Auto-Lite Co., The Instrument & Gauge Div., 1476  
Hoffman Specialty Mfg. Corp., 1622-1625  
Jas. P. Marsh Corp., 1628-1629  
Moeller Instrument Co., 1493  
Taylor Instrument Cos., 1503

**GAGES, Vapor**  
C. A. Dunham Co., 1618-1621

**GAS BURNERS**  
Airtemp Div., Chrysler Corp., 1248-1249  
American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
American-Standard, Air Conditioning Div., 1244-1245  
Armstrong Furnace Co., 1246-1247  
Babcock & Wilcox Co., The, 1542  
Cleaver-Brooks Co., 1544-1545  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
Dewey-Shepard Boiler Co., 1550  
Gordon-Platt, Inc., 1576  
Hastings Air Conditioning Co., Inc., 1233  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
National-U. S. Radiator Corp., 1530-1533  
Norman Products Co., 1257



Orr & Sembower, Inc., 1562  
 Pennsylvania Furnace & Iron Co., 1258  
 Preferred Utilities Mfg. Corp., 1506  
 Ray Oil Burner Co., 1584-1585  
 Rayfield-Staffco Burner Co., Inc., 1586  
 Roberts-Gordon Appliance Corp., 1577  
 Siemon Mfg. Co., 1587  
 Sonner Burner Co., 1578  
 Webster Engineering Co., The, 1579  
 John Zink Co., 1588-1589

#### GAS FILTERS (See Filters, Gas)

#### GAS SAFETY PILOTS (See Pilots)

#### GAS VENT PIPE or GAS VENTS (See Pipe, Gas Vent)

#### GASKETS, Cork Armstrong Cork Co., (Industrial Div.), 1665

#### GLASS BLOCK ROOFLIGHTS (See Skylights Insulated)

#### GLASS BLOCKS

Owens-Illinois, 1661  
 Pittsburgh Corning Corp., 1662

#### GLASS, Cellular

Pittsburgh Corning Corp., 1662

#### GOVERNORS, Pump

Leslie Co., 1487  
 McDonnell & Miller, Inc., 1570-1573  
 Spence Engineering Co., Inc., 1501  
 Warren Webster & Co., 1638-1639

#### GREASE FILTERS (See Filters, Grease)

#### GRIDS, Panel

American Brass Co., The, 1310-1311

#### GRILLES, REGISTERS AND ORNAMENTAL METAL WORK (See also Louvers, Registers)

A-J Mfg. Co., 1428-1427  
 Air Control Products Inc., 1428-1431  
 Air-Factors, Inc., 1433  
 Auer Register Co., The, 1436  
 Barber-Colman Co., 1437-1473  
 Dole Valve Co., The, 1440  
 General Register Corp., 1442-1443  
 Hart & Cooley Mfg. Co., 1444-1445  
 Hendrick Mfg. Co., 1446-1447  
 Independent Register Co., The, 1448  
 Lima Register Co., 1450-1451  
 Louvrs Mfg. & Sales Co., 1452  
 Pyle-National Co., The Multivent Div., 1454-1455  
 Register & Grille Mfg. Co., Inc., 1453  
 Standard Stamping & Perforating Co., 1458  
 Stewart Mfg. Co., Inc., 1457  
 Titus Mfg. Corp., 1458-1459  
 Tuttle & Bailey, Inc., 1460-1461  
 United States Register Co., 1462-1463  
 Vulcan Radiator Co., The, 1367  
 Waterloo Register Co., Inc., 1465  
 Young Regulator Co., 1470-1471

#### HANGERS, Pipe

T. R. Finn & Co., Inc., 1686  
 Korfund Co., Inc., The, 1687  
 Vibration Mountings, Inc., 1688

#### HANGERS, Radiator

American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
 T. R. Finn & Co., Inc., 1686  
 National-U. S. Radiator Corp., 1530-1533

#### HEADS, Exhaust

V. D. Anderson Co., The, 1612-1613  
 Muckle Mfg. Co., 1421

#### HEAT EXCHANGERS

Acme Industries, Inc., 1358  
 Aero Corp., 1595  
 Aerofin Corp., 1359-1361  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Bell & Gossett Co., 1598-1599  
 Binks Mfg. Co., 1344-1345  
 Fluor Corp., Ltd., The, 1347  
 General Fittings Co., 1596  
 Hayes Furnace Mfg. & Supply Co., 1252-1253  
 Illinois Engineering Co., 1626-1627  
 International Boiler Works Co., The, 1556  
 E. B. Kaiser Co., 1648-1649  
 Killebrew Engineering Corp., 1597  
 Marley Co., The, 1354  
 Mario Coil Co., 1355  
 McQuay, Inc., 1288-1289  
 Modine Mfg. Co., 1290-1291  
 National Heater Co., 1280-1281  
 National-U. S. Radiator Corp., 1530-1533

John J. Nesbitt, Inc., 1293-1295

Niagara Blower Co., 1235  
 Patterson-Kelley Co., Inc., The, 1363  
 Taco Heaters, Inc., 1602  
 H. A. Thrush & Co., 1600-1601  
 Trane Co., The, 1289-1301  
 Western Blower Co., 1409  
 Westinghouse Electric Corp., Sturtevant Div., 1410  
 Worthington Corp., 1241  
 York Corp., 1242  
 York Shipley, Inc., 1590  
 Young Radiator Co., 1304

John J. Nesbitt, Inc., 1293-1295  
 Patterson-Kelley Co., Inc., The, 1363  
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 Young Radiator Co., 1304

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 Western Blower Co., 1409  
 Westinghouse Electric Corp., Sturtevant Div., 1410  
 Worthington Corp., 1241  
 York Corp., 1242  
 York Shipley, Inc., 1590  
 Young Radiator Co., 1304

#### Combustion Engineering, Inc., 1548-1549

Dravo Corp., 1272-1273  
 Electromode Corp., 1305  
 Industrial Engineering & Equipment Co., 1306  
 Lee Corp., 1277  
 Mammoth Furnace Co., The, 1278  
 McQuay, Inc., 1288-1289  
 Mario Coil Co., 1355  
 Modine Mfg. Co., 1290-1291  
 Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
 National Heater Co., 1280-1281  
 National-U. S. Radiator Corp., 1530-1533  
 Herman Nelson, American Air Filter Co., Inc., 1296-1297  
 John J. Nesbitt, Inc., 1293-1295  
 Arthur A. Olson & Co., 1279  
 Resnor Mfg. Co., 1282-1283  
 Thermobloc Div., Prat-Daniel Corp., 1284  
 Trane Co., The, 1298-1301  
 Vapor Heating Corp., 1567  
 Westinghouse Electric Corp., Sturtevant Div., 1410  
 Edwin L. Wiegand Co., 1308-1309  
 L. J. Wing Mfg. Co., 1302-1303  
 John Zink Co., 1588-1589

#### HEATERS, Automatic Hot Water, Domestic

Airtemp Div., Chrysler Corp., 1248-1249  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1524  
 Bryan Steam Corp., 1543  
 Combustion Engineering, Inc., (Chattanooga Div.), 1250  
 Crane Co., 1528-1529  
 Dewey-Shepard Boiler Co., 1550  
 Hydrotherm, Inc., 1555  
 S. T. Johnson Co., 1582-1583  
 National-U. S. Radiator Corp., 1530-1533  
 Ray Oil Burner Co., 1584-1585  
 Rheem Mfg. Co., 1260-1261  
 Wesix Electric Heater Co., 1307

#### HEATERS, Blast

Aerofin Corp., 1359-1361  
 Airtherm Mfg. Co., 1532  
 Bayley Blower Co., 1376  
 Carrier Corp., 1226-1227  
 Drayer-Hanson, Inc., Div. of National-U. S. Radiator Corp., 1229  
 Electromode Corp., 1305  
 G & O Mfg. Co., The, 1362  
 Hastings Air Conditioning Co., Inc., 1233  
 Industrial Engineering & Equipment Co., 1306  
 Mario Coil Co., 1355  
 McQuay, Inc., 1288-1289  
 Modine Mfg. Co., 1290-1291  
 D. J. Murray Mfg. Co., 1292  
 Herman Nelson, American Air Filter Co., Inc., 1296-1297  
 John J. Nesbitt, Inc., 1293-1295  
 Niagara Blower Co., 1235  
 Rome-Turney Radiator Co., The, 1365  
 Trane Co., The, 1298-1301  
 Westinghouse Electric Corp., Sturtevant Div., 1410  
 Edwin L. Wiegand Co., 1308-1309  
 Young Radiator Co., 1304

#### HEATERS, Cabinet

American Blower Corp., 1220-1221

Carrier Corp., 1226-1227

C. A. Dunham Co., 1618-1621  
 Electromode Corp., 1305  
 Modine Mfg. Co., 1290-1291  
 Herman Nelson, American Air Filter Co., Inc., 1296-1297  
 John J. Nesbitt, Inc., 1293-1295  
 Trane Co., The, 1298-1301  
 Wesix Electric Heater Co., 1307  
 Young Radiator Co., 1304

#### HEATERS, Convection (See Baseboard Heating, Convection Heaters)

#### HEATERS, Duct

Campbell Heating Co., 1268-1269  
 Carrier Corp., 1226-1227  
 Chicago Steel Furnace Co., 1271  
 Dravo Corp., 1272-1273  
 Electromode Corp., 1305  
 Hastings Air Conditioning Co., Inc., 1233  
 Hayes Furnace Mfg. & Supply Co., 1252-1253  
 Industrial Engineering & Equipment Co., 1306  
 Mammoth Furnace Co., The, 1278  
 Modine Mfg. Co., 1290-1291  
 National Heater Co., 1280-1281  
 Resnor Mfg. Co., 1282-1283  
 Edwin L. Wiegand Co., 1308-1309  
 John Zink Co., 1588-1589

#### HEATERS, Electric

Electromode Corp., 1305  
 Industrial Engineering & Equipment Co., 1306  
 Trade-Wind Motorfans, Inc., 1405  
 Wesix Electric Heater Co., 1307  
 Edwin L. Wiegand Co., 1308-1309

#### HEATERS, Feed Water

American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Bell & Gossett Co., 1598-1599  
 Packard Water Conditioner Div., Packard Mfg. Co., 1575  
 Patterson-Kelley Co., Inc., The, 1363  
 Warren Webster & Co., 1638-1639  
 Worthington Corp., 1241

#### HEATERS, Fuel Oil

American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Bell & Gossett Co., 1598-1599  
 Campbell Heating Co., 1268-1269  
 Cyclotherm, Div. of National-U. S. Radiator Corp., 1545  
 Dravo Corp., 1272-1273  
 General Fittings Co., 1596  
 Industrial Engineering & Equipment Co., 1306  
 Johnson Heater Corp., 1274-1275  
 E. B. Kaiser Co., 1648-1649  
 Killebrew Engineering Corp., 1597  
 Mammoth Furnace Co., The, 1278  
 National Heater Co., 1280-1281  
 Arthur A. Olson & Co., 1279  
 Patterson-Kelley Co., Inc., The, 1363  
 Preferred Utilities Mfg. Corp., 1560  
 Taco Heaters, Inc., 1602  
 H. A. Thrush & Co., 1600-1601  
 Titusville Iron Works Co., The, (Div. of Struthers-Wells Corp.), 1564-1565  
 Tjernlund Mfg. Co., 1285  
 Vapor Heating Corp., 1567  
 Edwin L. Wiegand Co., 1308-1309

#### HEATERS, Gas

Airtemp Div., Chrysler Corp., 1248-1249

Airtherm Mfg. Co., 1522

American Foundry & Furnace Co., 1266-1267  
 E. K. Campbell Co., 1270  
 Campbell Heating Co., 1268-1269  
 Cyclotherm Div. of National-U. S. Radiator Corp., 1545  
 Dravo Corp., 1272-1273  
 Hayes Furnace Mfg. & Supply Co., 1252-1253  
 Johnson Heater Corp., 1274-1275  
 Lee Corp., 1277  
 Mammoth Furnace Co., The, 1278  
 Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
 National Heater Co., 1280-1281  
 Arthur A. Olson & Co., 1279  
 Resnor Mfg. Co., 1282-1283  
 Rheem Mfg. Co., 1260-1261  
 Vapor Heating Corp., 1567  
 Westinghouse Electric Corp., Sturtevant Div., 1410  
 John Zink Co., 1588-1589

#### HEATERS, Hot Water Service

Aero Corp., 1595  
 Air Devices, Inc., 1316, 1432  
 Airtemp Div., Chrysler Corp., 1248-1249  
 Aldrich Co., 1541  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Bell & Gossett Co., 1598-1599  
 Bryan Steam Corp., 1543  
 Burnham Corp., 1526-1527  
 Columbia Boiler Co., 1546-1547  
 Crane Co., 1528-1529  
 Cyclotherm Div. of National-U. S. Radiator Corp., 1545  
 Dewey-Shepard Boiler Co., 1550  
 Dutton Boilers, Div. Hapman-Dutton Co., 1551  
 Fitzgibbons Boiler Co., Inc., 1552-1553  
 General Fittings Co., 1596  
 Hydrotherm, Inc., 1555  
 S. T. Johnson Co., 1582-1583  
 Johnston Bros., Inc., 1557  
 Kewanee Boiler Div. of American-Standard, 1558-1561  
 Killebrew Engineering Corp., 1597  
 Mueller Climatrol, Div. of Worthington Corp., 1254-1255  
 National-U. S. Radiator Corp., 1530-1533  
 Patterson-Kelley Co., Inc., The, 1363  
 Raypak Co., Inc., 1563  
 Rheem Mfg. Co., 1260-1261  
 H. B. Smith Co., Inc., The, 1537  
 Taco Heaters, Inc., 1602  
 Titusville Iron Works Co., The, (Div. of Struthers-Wells Corp.), 1564-1565  
 Vapor Heating Corp., 1567  
 Weil-McLain Co., 1540

#### HEATERS, Unit

Airtherm Mfg. Co., 1522  
 American Blower Corp., 1220-1221  
 American Foundry & Furnace Co., 1266-1267  
 Bishop & Babcock Mfg. Co., The, (Massachusetts Blower Div.), 1363  
 Buffalo Forge Co., 1382  
 Burnham Corp., 1526-1527  
 Campbell Heating Co., 1268-1269  
 Carrier Corp., 1226-1227  
 Chicago Steel Furnace Co., 1271  
 Clargene Fan Co., 1225, 1387  
 Crane Co., 1528-1529  
 Dravo Corp., 1272-1273  
 C. A. Dunham Co., 1618-1621  
 Fedders-Quigan Corp., 1286  
 Governor Corp., 1232  
 Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
 Hastings Air Conditioning Co., Inc., 1233  
 Ilg Electric Ventilating Co., 1287, 1393  
 Jackson & Church Co., 1276  
 Johnson Heater Corp., 1274-1275  
 Kennard Corp., 1234  
 Lee Corp., 1277  
 Mammoth Furnace Co., The, 1278  
 Mario Coil Co., 1355  
 McQuay, Inc., 1288-1289  
 Modine Mfg. Co., 1290-1291  
 Muckle Mfg. Co., 1421

#### HEATERS, Indirect

Aero Corp., 1595  
 Aerofin Corp., 1359-1361  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Bell & Gossett Co., 1598-1599  
 Campbell Heating Co., 1268-1269  
 General Fittings Co., 1596  
 Killebrew Engineering Corp., 1597  
 Patterson-Kelley Co., Inc., The, 1363  
 Taco Heaters, Inc., 1602  
 H. A. Thrush & Co., 1600-1601  
 York-Shipley, Inc., 1590

#### HEATERS, Space, Direct-Fired

Airtherm Mfg. Co., 1522

American Foundry & Furnace Co., 1266-1267  
 Campbell Heating Co., 1268-1269  
 Chicago Steel Furnace Co., 1271  
 Johnson Heater Corp., 1484-1485  
 National Heater Co., 1280-1281  
 Arthur A. Olson & Co., 1279  
 Thermobloc Div., Prat-Daniel

Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
D. J. Murray Mfg. Co., 1292  
National Heater Co., 1280-1281  
National-U. S. Radiator Corp.,  
1530-1533  
Herman Nelson, American Air  
Filter Co., Inc., 1296-1297  
John J. Nesbitt, Inc., 1293-1295  
New York Blower Co., 1399  
Niagara Blower Co., 1235  
Arthur A. Olson & Co., 1279  
Reznor Mfg. Co., 1282-1283  
Rheem Mfg. Co., 1260-1261  
Rittling Corp., The, 1364  
Roberts-Gordon Appliance Corp.,  
1577  
Sheldons Engineering Ltd., 1404  
Thermobloc Div., Prat-Daniel  
Corp., 1284  
Tjernlund Mfg. Co., 1285  
Trane Co., The, 1298-1301  
Union Asbestos & Rubber Co., 1265  
Vapor Heating Corp., 1567  
Warren Webster & Co., 1638-1639  
Western Blower Co., 1409  
Westinghouse Electric Corp., Stur-  
tevant Div., 1410  
Edwin L. Wiegand Co., 1308-1309  
L. J. Wing Mfg. Co., 1302-1303  
Young Radiator Co., 1304  
John Zink Co., 1588-1589

**HEATERS, Unit, Electric**  
Electromode Corp., 1305  
Ilg Electric Ventilating Co., 1287,  
1393  
West Electric Heater Co., 1307  
Edwin L. Wiegand Co., 1308-1309  
L. J. Wing Mfg. Co., 1302-1303

**HEATERS, Unit, Gas Fired**  
Airtherm Mfg. Co., 1522  
American Blower Corp., 1220-1221  
American Foundry & Furnace Co.,  
1266-1267  
Burnham Corp., 1528-1527  
Campbell Heating Co., 1268-1269  
Carrier Corp., 1295-1297  
Dravo Corp., 1272-1273  
Feddors-Quigan Corp., 1286  
Hastings Air Conditioning Co., Inc.,  
1233  
Hayes Furnace Mfg. & Supply Co.,  
1352-1353  
Ilg Electric Ventilating Co., 1287,  
1393  
Johnson Heater Corp., 1274-1275  
Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
Modine Mfg. Co., 1290-1291  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Heater Co., 1280-1281  
National-U. S. Radiator Corp.,  
1530-1533  
Herman Nelson, American Air  
Filter Co., Inc., 1296-1297  
John J. Nesbitt, Inc., 1293-1295  
Norman Products Co., 1257  
Arthur A. Olson & Co., 1279  
Reznor Mfg. Co., 1282-1283  
Rheem Mfg. Co., 1260-1261  
Sonner-Burner Co., The, 1578  
Thermobloc Div., Prat-Daniel  
Corp., 1284  
Tjernlund Mfg. Co., 1285  
Trane Co., The, 1298-1301  
Vapor Heating Corp., 1567  
Warren Webster & Co., 1638-1639  
Westinghouse Electric Corp., Stur-  
tevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303  
John Zink Co., 1588-1589

**HEATERS, Unit, Oil Fired**  
Airtherm Mfg. Co., 1522  
American Foundry & Furnace Co.,  
1266-1267  
Campbell Heating Co., 1268-1269  
Chicago Steel Furnace Co., 1271  
Dravo Corp., 1272-1273  
Johnson Heater Corp., 1274-1275  
Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Heater Co., 1280-1281  
Arthur A. Olson & Co., 1279  
Thermobloc Div., Prat-Daniel  
Corp., 1284  
Tjernlund Mfg. Co., 1285

**HEATING DUCTS, Under Con-  
crete Floor Slabs (See Ducts,  
Under Concrete Floor Slabs)**

**HEATING SYSTEMS, Air, Heavy  
Duty**  
Airtherm Mfg. Co., 1522  
American Foundry & Furnace Co.,  
1266-1267  
Armstrong Furnace Co., 1246-1247  
E. K. Campbell Co., 1270  
Campbell Heating Co., 1268-1269  
Chicago Steel Furnace Co., 1271  
Dravo Corp., 1272-1273  
Lee Corp., 1277  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Clay Pipe Mfgs., The,  
1516-1521  
National Heater Co., 1280-1281  
Niagara Blower Co., 1235  
Arthur A. Olson & Co., 1279  
Ray Oil Burner Co., 1584-1585  
Tjernlund Mfg. Co., 1285  
Trane Co., The, 1298-1301

**HEATING SYSTEMS, Air Resi-  
dence**  
Airtemp Div., Chrysler Corp.,  
1248-1249  
American-Standard, Air Condition-  
ing Div., 1244-1245  
Armstrong Furnace Co., 1246-1247  
Burnham Corp., 1528-1527  
Jackson & Church Co., 1276  
Johnson Heater Corp., 1274-1275  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Clay Pipe Mfgs., The,  
1516-1521  
Pennsylvania Furnace & Iron Co.,  
1258  
Roberts-Gordon Appliance Corp.,  
1577  
Serval, Inc., 1262-1263  
Trane Co., The, 1298-1301  
National-U. S. Radiator Corp.,  
1530-1533  
Edwin L. Wiegand Co., 1308-1309  
York Shipley, Inc., 1590  
John Zink Co., 1588-1589

**HEATING SYSTEMS, Automa-  
tic**  
Airtemp Div., Chrysler Corp.,  
1248-1249  
Airtherm Mfg. Co., 1522  
American Foundry & Furnace  
Co., 1266-1267  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
American-Standard, Air Condition-  
ing Div., 1244-1245  
Burnham Corp., 1528-1527

E. K. Campbell Co., 1270  
Campbell Heating Co., 1268-1269  
Chicago Steel Furnace Co., 1271  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
Dravo Corp., 1272-1273  
C. A. Dunham Co., 1618-1621  
General Electric Co., 1230  
Hayes Furnace Mfg. & Supply Co.,  
1252-1253  
Hoffman Specialty Mfg. Corp., 1622-  
1623  
Hydraline Products Div., Borg-  
Warner Corp., 1251  
Hydrotherm, Inc., 1555  
Illinois Engineering Co., 1626-1627  
Jackson & Church Co., 1276  
Johnson Heater Corp., 1274-1275  
S. T. Johnson Co., 1582-1583  
Kewanee Boiler Div. of American-  
Standard, 1558-1561  
Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Heater Co., 1280-1281  
National-U. S. Radiator Corp.,  
1530-1533  
Arthur A. Olson & Co., 1279  
Pennsylvania Furnace & Iron Co.,  
1258  
Ray Oil Burner Co., 1584-1585  
Reznor Mfg. Co., 1282-1283  
Rheem Mfg. Co., 1260-1261  
Sarco Co., Inc., 1634-1635  
Sarcotherm Controls, Inc., 1633  
Titusville Iron Works Co., The,  
(Div. of Struthers-Wells Corp.),  
1564-1565  
Trane Co., The, 1298-1301  
Vapor Heating Corp., 1567  
Weil-McLain Co., 1540  
York Shipley, Inc., 1590

**HEATING SYSTEMS, Coal Fired**  
American Foundry & Furnace Co.,  
1266-1267  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
American-Standard, Air Condition-  
ing Div., 1244-1245  
E. K. Campbell Co., 1270  
Campbell Heating Co., 1268-1269  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
Fitzgibbons Boiler Co., Inc., 1552-  
1553  
Kewanee Boiler Div. of American-  
Standard, 1558-1561  
Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Clay Pipe Mfgs., The,  
1516-1521  
National Heater Co., 1280-1281  
National-U. S. Radiator Corp.,  
1530-1533  
Arthur A. Olson & Co., 1279

**HEATING SYSTEMS, Electric**  
Electromode Corp., 1305  
Industrial Engineering & Equip-  
ment Co., 1306  
West Electric Heater Co., 1307  
Edwin L. Wiegand Co., 1308-1309

**HEATING SYSTEMS, Furnace**  
Airtemp Div., Chrysler Corp., 1248-  
1249  
Airtherm Mfg. Co., 1522  
American Foundry & Furnace Co.,  
1266-1267

## Index to Modern Equipment

American-Standard, Air Condition-  
ing Div., 1244-1245  
Armstrong Furnace Co., 1246-1247  
E. K. Campbell Co., 1270  
Campbell Heating Co., 1268-1269  
Chicago Steel Furnace Co., 1271  
Crane Co., 1528-1529  
Dravo Corp., 1272-1273  
General Electric Co., 1230  
Jackson & Church Co., 1276  
S. T. Johnson Co., 1582-1583  
Johnson Heater Corp., 1274-1275  
Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Clay Pipe Mfgs., The,  
1516-1521  
National Heater Co., 1280-1281  
Norman Products Co., 1257  
Arthur A. Olson & Co., 1279  
Ray Oil Burner Co., 1584-1585  
Rheem Mfg. Co., 1260-1261  
Tjernlund Mfg. Co., 1285  
York Shipley, Inc., 1590

**HEATING SYSTEMS, Gas Fired**  
Airtemp Div., Chrysler Corp., 1248-  
1249  
Airtherm Mfg. Co., 1522  
American Foundry & Furnace Co.,  
1266-1267  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
American-Standard, Air Condition-  
ing Div., 1244-1245  
Bryan Steam Corp., 1543  
E. K. Campbell Co., 1270  
Campbell Heating Co., 1268-1269  
Chicago Steel Furnace Co., 1271  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
Dewey-Shepard Boiler Co., 1550  
Dravo Corp., 1272-1273  
Fitzgibbons Boiler Co., Inc., 1552-  
1553  
General Automatic Products Corp.,  
1513  
Hayes Furnace Mfg. & Supply Co.,  
1252-1253  
Hydrotherm, Inc., 1555  
Jackson & Church Co., 1276  
Johnson Heater Corp., 1274-1275  
Kewanee Boiler Div. of American-  
Standard, 1558-1561  
Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Clay Pipe Mfgs., The,  
1516-1521  
National Heater Co., 1280-1281  
National-U. S. Radiator Corp.,  
1530-1533  
Norman Products Co., 1257  
Arthur A. Olson & Co., 1279  
Reznor Mfg. Co., 1282-1283  
Rheem Mfg. Co., 1260-1261  
Roberts-Gordon Appliance Corp.,  
1577  
Titusville Iron Works Co., The,  
(Div. of Struthers-Wells Corp.),  
1564-1565  
Tjernlund Mfg. Co., 1285  
L. J. Wing Mfg. Co., 1302-1303  
York Shipley, Inc., 1590  
John Zink Co., 1588-1589

**HEATING SYSTEMS, High-  
temperature Fluid**  
International Boiler Works Co.,  
The, 1556

Parks-Cramer Co., 1236-1237  
Titusville Iron Works Co., The,  
(Div. of Struthers-Wells Corp.),  
1564-1565

**HEATING SYSTEMS, Hot Water**  
Air Devices, Inc., 1310, 1432  
Airtemp Div., Chrysler Corp.,  
1248-1249  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Bell & Gossett Co., 1598-1599  
Bryan Steam Corp., 1543  
Burnham Corp., 1528-1527  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Durant Insulated Pipe Co., 1647  
Durant International Corp., 1647  
Fitzgibbons Boiler Co., Inc., 1552-  
1553  
General Automatic Products Corp.,  
1513  
General Electric Co., 1230  
Hoffman Specialty Mfg. Corp.,  
1622-1623  
Hydraline Products, Div. Borg-  
Warner Corp., 1251  
Hydrotherm, Inc., 1555  
S. T. Johnson Co., 1582-1583  
E. B. Kaiser Co., 1648-1649  
Kewanee Boiler Div. of American-  
Standard, 1558-1561  
Jas. P. Marsh Corp., 1628-1629  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National-U. S. Radiator Corp.,  
1530-1533  
Pennsylvania Furnace & Iron Co.,  
1258  
Raypak Co., Inc., 1663  
Refrigeration Engineering, Inc.,  
1373  
Ric-wil, Inc., 1651  
Sarco-Sarcotherm, 1633-1635  
H. B. Smith Co., Inc., The, 1537  
Taco Heaters, Inc., 1602  
Trane Co., The, 1298-1301  
H. A. Thrush & Co., 1600-1601  
Vapor Heating Corp., 1567  
Vulcan Radiator Co., The, 1367  
Warren Webster & Co., 1638-1639  
York Shipley, Inc., 1590

**HEATING SYSTEMS, Oil Fired**  
Airtemp Div., Chrysler Corp.,  
1248-1249  
Airtherm Mfg. Co., 1522  
American Foundry & Furnace Co.,  
1266-1267  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
American-Standard, Air Condition-  
ing Div., 1244-1245  
Bryan Steam Corp., 1543  
Burnham Corp., 1528-1527  
E. K. Campbell Co., 1270  
Campbell Heating Co., 1268-1269  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
Dewey-Shepard Boiler Co., 1550  
Dravo Corp., 1272-1273  
Fitzgibbons Boiler Co., Inc., 1552-  
1553  
General Automatic Products Corp.,  
1513  
Jackson & Church Co., 1276  
S. T. Johnson Co., 1582-1583  
Johnson Heater Corp., 1274-1275  
Kewanee Boiler Div. of American-  
Standard, 1558-1561

Lee Corp., 1277  
Mammoth Furnace Co., The, 1278  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National Clay Pipe Mfgs., The,  
1516-1521  
National Heater Co., 1280-1281  
National-U. S. Radiator Corp., 1530-  
1533  
Arthur A. Olson & Co., 1279  
Ray Oil Burner Co., 1584-1585  
Rheem Mfg. Co., 1260-1261  
Tjernlund Mfg. Co., 1285  
York Shipley, Inc., 1590

**HEATING SYSTEMS, Steam**  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Barnes & Jones, Inc., 1616  
Bryan Steam Corp., 1543  
Burnham Corp., 1528-1527  
Columbia Boiler Co., 1546-1547  
Crane Co., 1528-1529  
Dole Valve Co., The, 1640  
C. A. Dunham Co., 1618-1621  
Durant Insulated Pipe Co., 1647  
Durant International Corp., 1647  
Fitzgibbons Boiler Co., Inc., 1552-  
1553  
Hoffman Specialty Mfg. Corp.,  
1622-1623  
Illinois Engineering Co., 1626-1627  
S. T. Johnson Co., 1582-1583  
E. B. Kaiser Co., 1648-1649  
Kewanee Boiler Div. of American-  
Standard, 1558-1561  
Jas. P. Marsh Corp., 1628-1629  
Mueller Climatrol, Div. of Worth-  
ington Corp., 1254-1255  
National-U. S. Radiator Corp.,  
1530-1533  
Pennsylvania Furnace & Iron Co.,  
1258  
Ric-wil, Inc., 1651  
Sarco-Sarcotherm, 1633-1635  
H. B. Smith Co., Inc., The, 1537  
Titusville Iron Works Co., The,  
(Div. of Struthers-Wells Corp.),  
1564-1565  
Trane Co., The, 1298-1301  
Vapor Heating Corp., 1567  
Vulcan Radiator Co., The, 1367  
Warren Webster & Co., 1638-1639  
L. J. Wing Mfg. Co., 1302-1303  
York Shipley, Inc., 1590

**HEATING SYSTEMS, Under  
Concrete Floor Slabs**  
National Clay Pipe Mfgs., The,  
1516-1521

**HEATING SYSTEMS, Vacuum**  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
American-Standard, Air Condition-  
ing Div., 1244-1245  
Barnes & Jones, Inc., 1616  
Columbia Boiler Co., 1546-1547  
C. A. Dunham Co., 1618-1621  
General Electric Co., 1230  
Hoffman Specialty Mfg. Corp.,  
1622-1623  
Illinois Engineering Co., 1626-1627  
Kewanee Boiler Div. of American-  
Standard, 1558-1561  
Jas. P. Marsh Corp., 1628-1629  
National-U. S. Radiator Corp.,  
1530-1533  
Sarco-Sarcotherm, 1633-1635  
Warren Webster & Co., 1638-1639

**HEATING SYSTEMS, Vapor**  
Airtemp Div., Chrysler Corp., 1248-  
1249



American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
Barnes & Jones, Inc., 1616  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625

Illinois Engineering Co., 1626-1627  
Kewanee Boiler Div., American Standard, 1558-1561  
Jas. P. Marsh Corp., 1628-1629  
National-U. S. Radiator Corp., 1530-1533

Sarco Co., Inc., 1634-1635  
Sarcotherm Controls, Inc., 1633  
Titusville Iron Works Co., The (Div. of Struthers-Wells Corp.), 1564-1565

Trane Co., The, 1298-1301  
Vapor Heating Corp., 1567  
Warren Webster & Co., 1638-1639  
York-Shipley, Inc., 1590

**HOSE, Flexible**  
Aerquip Corp., 1312  
Wiremold Co., The, 1469

**HOSE, Flexible, Metal**  
American Brass Co., The, 1310-1311  
T. R. Finn & Co., Inc., 1685  
Flexonics Corp., 1507  
Henry Valve Co., 1482

**HOT WATER HEATING SYSTEMS** (See Heating Systems, Hot Water)

**HUMIDIFIERS**  
Air & Refrigeration Corp., 1219  
American Blower Corp., 1220-1221  
American Moistening Co., 1222  
American-Standard, Air Conditioning Div., 1244-1245

Armstrong Machine Works, 1614-1615  
Bahnsen Co., The, 1223  
Binks Mfg. Co., 1344-1345

Buensod-Stacey, Inc., 1224  
Buffalo Forge Co., 1382  
Clarage Fan Co., 1225, 1387  
Farr Co., 1332-1333

Maid-O'-Mist, Inc., 1630-1632  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Mueller Climatrol, Div. of Worthington Corp., 1254-1255

Niagara Blower Co., 1235  
Parks-Cramer Co., 1236-1237  
Research Products Corp., 1338  
Somers Corp., 1339

Trane Co., The, 1298-1301  
Viking Air Products, Div. National-U. S. Radiator Corp., 1408  
Walton Laboratories, Inc., 1239

**HUMIDIFIERS, Central Plant**  
Air & Refrigeration Corp., 1219  
American Moistening Co., 1222  
Armstrong Machine Works, 1614-1615

Bahnsen Co., The, 1223  
Bayley Blower Co., 1376  
Buensod-Stacey, Inc., 1224  
Buffalo Forge Co., 1382

Clarage Fan Co., 1225, 1387  
Farr Co., 1332-1333  
Johnson Service Co., 1484-1485  
Marlo Coil Co., 1355

Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Niagara Blower Co., 1235  
Parks-Cramer Co., 1236-1237

Powers Regulator Co., The, 1496-1498  
Trane Co., The, 1298-1301  
Westinghouse Electric Corp., Sturtevant Div., 1342

**HUMIDIFIERS, Convactor**  
Maid-O'-Mist, Inc., 1630-1632

**HUMIDIFIERS, Industrial**  
American Moistening Co., 1222  
Armstrong Machine Works, 1614-1615

Bahnsen Co., The, 1223  
Binks Mfg. Co., 1344-1345  
Maid-O'-Mist, Inc., 1630-1632  
Parks-Cramer Co., 1236-1237  
Walton Laboratories, Inc., 1239

**HUMIDIFIERS, Spray**  
American Moistening Co., 1222  
Bahnsen Co., The, 1223  
Binks Mfg. Co., 1344-1345  
Maid-O'-Mist, Inc., 1630-1632  
Walton Laboratories, Inc., 1239

**HUMIDIFIERS, Unit**  
American Moistening Co., 1222  
Armstrong Machine Works, 1614-1615

Bahnsen Co., The, 1223  
Buffalo Forge Co., 1382  
Farr Co., 1332-1333  
Marlo Coil Co., 1355

D. J. Murray Mfg. Co., 1292  
Niagara Blower Co., 1235  
Parks-Cramer Co., 1236-1237  
Somers Corp., 1339  
Trane Co., The, 1298-1301

Walton Laboratories, Inc., 1239

**HUMIDITY AND TEMPERATURE CONTROL**  
American Moistening Co., 1222  
Armstrong Machine Works, 1614-1615

Bahnsen Co., The, 1223  
Barber-Colman Co., 1437, 1473  
Buensod-Stacey, Inc., 1224  
Desomatic Products, Inc., 1228

C. A. Dunham Co., 1618-1621  
Johnson Service Co., 1484-1485  
Mercoir Corp., The, 1489  
Minneapolis-Honeywell Regulator Co., 1490-1491

Parks-Cramer Co., 1236-1237  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498

Taylor Instrument Cos., 1503  
White-Rodgers Electric Co., 1504

**HUMIDITY RECORDERS AND INDICATORS**  
American Moistening Co., 1222  
Barber-Colman Co., 1437, 1473

Johnson Service Co., 1484-1485  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Moeller Instrument Co., 1493

Parks-Cramer Co., 1236-1237  
Powers Regulator Co., The, 1496-1498  
Taylor Instrument Cos., 1503

Walton Laboratories, Inc., 1239

**HYGROMETERS** (See Humidity Recorders and Indicators)  
American Moistening Co., 1222  
Moeller Instrument Co., 1493  
Parks-Cramer Co., 1236-1237

Taylor Instrument Cos., 1503  
Walton Laboratories, Inc., 1239

**IGNITION, Oil Burner** (See Transformers)

**INDUCED DRAFT COOLING TOWERS** (See Cooling Towers, Forced Draft, Mechanical Draft)

Acme Industries, Inc., 1358  
Baltimore Aircoil Co., Inc., 1346  
Binks Mfg. Co., 1344-1345

Fluor Corp. Ltd., The, 1347  
E. D. Goodfellow, Inc., 1348  
Governair Corp., 1232  
Kennard Corp., 1234

Lillie-Hoffmann Cooling Towers, Inc., 1353  
Marley Co., The, 1354  
Marlo Coil Co., 1355  
Phillips Cooling Tower Co., Inc., 1356

**INSTRUMENTS, Indicating, Controlling and Recording**  
Barber-Colman Co., 1437, 1473  
Combustion Control Div., Electronics Corp. of America, 1475

Desomatic Products, Inc., 1228  
Electric Auto-Lite Co., The, Instrument & Gauge Div., 1476  
General Controls, 1480-1481  
Illinois Testing Laboratories, Inc., 1486

Johnson Service Co., 1484-1485  
Jas. P. Marsh Corp., 1628-1629  
Minneapolis-Honeywell Regulator Co., 1490-1491

Moeller Instrument Co., 1493  
Powers Regulator Co., The, 1496-1498  
Taylor Instrument Cos., 1503

**INSULATION, Acoustical** (See Insulation, Sound Deadening)

**INSULATION, Aluminum**  
Infra Insulation, Inc., 1679  
Reflectal Corp., 1682  
Silvercote Products, Inc., 1680-1681

**INSULATION, Anchors and Adhesives** (See Anchors, Adhesive)

**INSULATION, Asbestos** (See Covering, Pipe)

**INSULATION, Building**  
American Flange & Mfg. Co., Inc., 1678  
Armstrong Cork Co., 1665

Philip Carey Mfg. Co., The, 1656-1657  
Celotex Corp., The, 1666  
Dow Chemical Co., The, 1667

L.O.F. Glass Fibers Co., 1655  
Infra Insulation, Inc., 1679  
Insulite, 1668-1669

Johns-Manville, 1670-1671  
Kimberly-Clark Corp., 1672-1673  
Lockport Mills, Inc., 1674  
Owens-Corning Fiberglas Corp., 1658, 1663

Pacific Lumber Co., The, 1675  
Pittsburgh Corning Corp., 1662  
Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664

H. W. Porter & Co., Inc., 1650  
Reflectal Corp., 1682  
Reid Hayden, Inc., 1650  
Silvercote Products, Inc., 1680-1681

Tectum Div., Peoples Research & Mfg. Co., 1676  
Wood Conversion Co., 1677

**INSULATION, Calcium Silicate**  
Johns-Manville, 1670-1671

## Index to Modern Equipment

Owens-Corning Fiberglas Corp., Kaylo, 1658

**INSULATION, Cellular Glass**  
Pittsburgh Corning Corp., 1663

**INSULATION, Cork**  
Armstrong Cork Co., 1665  
H. W. Porter & Co., Inc., 1650  
Reid Hayden, Inc., 1650

**INSULATION, Cotton**  
Lockport Mills, Inc., 1674

**INSULATION, Ducts, Ventilating, Air Conditioning**  
Armstrong Cork Co., 1665  
Celotex Corp., The, 1666  
Dow Chemical Co., The, 1667

B. F. Goodrich, Sponge Products Div., 1683  
Infra Insulation, Inc., 1679  
Johns-Manville, 1670-1671

Kimberly-Clark Corp., 1672-1673  
L.O.F. Glass Fibers Co., 1655  
Lockport Mills, Inc., 1674  
Owens-Corning Fiberglas Corp., Kaylo, 1658

Pittsburgh Corning Corp., 1663  
Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664  
Reflectal Corp., 1682  
Wood Conversion Co., 1677

**INSULATION, Felt**  
Philip Carey Mfg. Co., 1656-1657  
Johns-Manville, 1670-1671  
L.O.F. Glass Fibers Co., 1655

Lockport Mills, Inc., 1674  
Owens-Corning Fiberglas Corp., 1658  
Wood Conversion Co., 1677

**INSULATION, Fiber**  
Celotex Corp., The, 1666  
Insulite, 1668-1669  
Johns-Manville, 1670-1671

Kimberly-Clark Corp., 1672-1673  
L.O.F. Glass Fibers Co., 1655  
Lockport Mills, Inc., 1674  
Owens-Corning Fiberglas Corp., 1658

Pacific Lumber Co., The, 1675  
Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664  
Wood Conversion Co., 1677

**INSULATION, Fibrous Glass**  
Armstrong Cork Co., 1665  
L.O.F. Glass Fibers Co., 1655  
Owens-Corning Fiberglas Corp., 1336, 1658

**INSULATION, Low Temperature**  
American Flange & Mfg. Co., Inc., 1678  
Dow Chemical Corp., The, 1667

Infra Insulation, Inc., 1679  
Johns-Manville, 1670-1671  
Lockport Mills, Inc., 1674  
Owens-Corning Fiberglas Corp., 1658

Pacific Lumber Co., The, 1675  
Pittsburgh Corning Corp., 1662  
Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664  
Reflectal Corp., 1682

**INSULATION, Magnesia**  
Philip Carey Mfg. Co., The, 1656-1657  
Johns-Manville, 1670-1671

**INSULATION, Metal**  
American Flange & Mfg. Co., Inc., 1678

Infra Insulation, Inc., 1679  
Silvercote Products, Inc., 1680-1681

**INSULATION, Mineral**  
American Gilsonite Co., 1646  
Owens-Corning Fiberglas Corp., Kaylo, 1658

Tectum Div., Peoples Research & Mfg. Co., 1676

**INSULATION, Mineral Wool** (See Insulation, Building)

**INSULATION, Pipes and Surfaces** (See Covering, Pipe and Surface)

**INSULATION, Plastic**  
Dow Chemical Co., The, 1667

**INSULATION, Reflective**  
American Flange & Mfg. Co., Inc., 1678  
Celotex Corp., The, 1666  
L.O.F. Glass Fibers Co., 1655

Infra Insulation, Inc., 1679  
Kimberly-Clark Corp., 1672-1673  
Lockport Mills, Inc., 1674  
Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664

Reflectal Corp., 1682  
Silvercote Products, Inc., 1680-1681

**INSULATION, Refractory**  
Philip Carey Mfg. Co., The, 1656-1657  
Johns-Manville, 1670-1671

**INSULATION, Sheets, Stainless Steel**  
American Flange & Mfg. Co., Inc., 1678

**INSULATION, Sound Deadening** (See also Felt, Sound Deadening)  
Philip Carey Mfg. Co., The, 1656-1657

Celotex Corp., The, 1666  
T. R. Finn & Co., Inc., 1686  
Insulite, 1668-1669

Johns-Manville, 1670-1671  
Kimberly-Clark Corp., 1672-1673  
Korfund Co., Inc., The, 1687  
L.O.F. Glass Fibers Co., 1655

Lockport Mills, Inc., 1674  
Owens-Corning Fiberglas Corp., 1336, 1658

Pacific Lumber Co., The, 1675  
Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664

Tectum Div., Peoples Research & Mfg. Co., 1676  
Vibration Mountings, Inc., 1688  
Wood Conversion Co., 1677

**INSULATION, Steel**  
American Flange & Mfg. Co., Inc., 1678

**INSULATION, Structural**  
American Flange & Mfg. Co., Inc., 1678  
Celotex Corp., The, 1666

Insulite, 1668-1669  
Johns-Manville, 1670-1671  
Kimberly-Clark Corp., 1672-1673  
Pittsburgh Corning Corp., 1662

Pittsburgh Plate Glass Co., Fiber Glass Div., 1337, 1664  
Wood Conversion Co., 1677

**INSULATION, Tubing**  
B. F. Goodrich, Sponge Products Div., 1683

**INSULATION, Underground Steam Pipe**  
American Gilsonite Co., 1646

Durant Insulated Pipe Co., 1647  
Durant International Corp., 1647  
Johns-Manville, 1670-1671

E. B. Kaiser Co., 1648-1649  
Owens-Corning Fiberglas Corp., Kaylo, 1658

Pittsburgh Corning Corp., 1663  
H. W. Porter & Co., Inc., 1650  
Reid Hayden, Inc., 1650  
Ric-wil, Inc., 1651

Stillwater Clay Products Co., The, 1652  
Z-Crete Div., Zonolite Co., 1653

**INSULATION, Water**  
April Showers Co., Inc., 1644

**ISOLATION, VIBRATION, Shock & Noise** (See Acoustical Control, Vibration Absorbers, Sound Isolators)

**JOINTS, EXPANSION** (See Expansion joints)

**LABORATORY RESEARCH AND TESTING** (See Testing Laboratory)

**LABORATORY VENTILATION** (See Exhausters, Laboratory Fume; Fume Disposal Units (Hoods) Laboratory)

**LIQUID LEVEL CONTROLS**  
Alco Valve Co., 1472  
Barber-Colman Co., 1437, 1473  
Fulton Syphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479

General Controls, 1480-1481  
Heller Laboratories, Inc., 1352  
Johnson Service Co., 1484-1485  
Leslie Co., 1487

Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498

Spence Engineering Co., Inc., 1501  
Taylor Instrument Cos., 1503

**LIQUID LEVEL GAGES** (See Gages, Liquid Level)

**LOUVERS** (Also see Grilles, Registers)  
A-J Mfg. Co., 1426-1427  
Air-Factors, Inc., 1433

American Foundry & Furnace Co., 1266-1267  
Auer Register Co., The, 1436  
Barber-Colman Co., 1437, 1473

Hart & Cooley Mfg. Co., 1444-1445  
Hendrick Mfg. Co., 1446-1447  
Independent Register Co., The, 1448  
Lima Register Co., 1450-1451

Pyle-National Co., The, (Multi-Vent Div.), 1454-1455  
Register & Grille Mfg. Co., Inc., 1453  
Standard Stamping & Perforating Co., 1456

Stewart Mfg. Co., Inc., 1457  
Swartwout Co., The, 1423  
Titus Mfg. Corp., 1458-1459  
United States Register Co., 1462-1463

Waterloo Register Co., Inc., 1465  
L. J. Wing Mfg. Co., 1302-1303

**MACHINED RINGS** (See Rings, Machined)**MECHANICAL DRAFT APPARATUS** See Blowers, Forced Draft, Exhausters Laboratory Fume, Laboratory Ventilation)

American Blower Corp., 1220-1221  
 Clavage Fan Co., 1225, 1387  
 DeBotheat Fans Div., American Machine & Metals, Inc., 1388-1389  
 General Blower Co., 1391  
 Kewanee Mfg. Co., 1411  
 E. H. Sheldon Equipment Co., 1412-1413  
 Westinghouse Electric Corp., Sturtevant Div., 1410

**MECHANICAL DRAFT COOLING TOWERS** (See Cooling Towers, Forced Draft, Induced Draft)

Acme Industries, Inc., 1358  
 Baltimore Acoil Co., Inc., 1346  
 Binks Mfg. Co., 1344-1345  
 Fluor Corp., Ltd., The, 1347  
 E. D. Goodfellow Co., Inc., 1348  
 Havens Structural Steel Co., 1349  
 Kennard Corp., 1234  
 Lillie-Hoffmann Cooling Towers, Inc., 1353  
 Marley Co., The, 1354  
 Marlo Coil Co., 1355  
 McQuay, Inc., 1288-1289  
 Phillips Cooling Tower Co., Inc., 1356

**METAL INSULATION** (See Insulation, Metal)**METAL SKYLIGHTS** (See Skylights, Metal and Ventilating)

**METERS, Air**  
 Anemostat Corp. of America, 1434-1435  
 Illinois Testing Laboratories, Inc., 1486

**METERS, Flow**  
 Minneapolis-Honeywell Regulator Co., 1490-1491  
 Taylor Instrument Cos., 1503

**MIXERS, Hot-Cold Water, Steam-Water**  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
 Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
 General Fittings Co., 1506  
 Powers Regulator Co., The, 1496-1498  
 Taco Heaters, Inc., 1602

**MIXERS, Steam and Water**  
 Fulton-Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
 Powers Regulator Co., The, 1496-1498

**MOTORS, Damper**  
 Barber-Colman Co., 1437, 1473  
 Mercoid Corp., The, 1489  
 Minneapolis-Honeywell Regulator Co., 1490-1491  
 Penn Controls, Inc., 1494  
 Powers Regulator Co., Inc., 1496-1498

**MOTORS, Electric**  
 Peerless Electric Co., 1400  
 Propellair Div., Robbins & Myers, Inc., 1401

**MOUNTINGS, Spring**  
 Karfund Co., Inc., The, 1637  
 Vibration Mountings, Inc., 1688

**NOISE ELIMINATORS** (See Tubing, Flexible; Sound Deadeners; Vibration Absorbers)

**NON-FERROUS METAL CONDUIT** (See Conduit, Non-ferrous Metal)

**NOZZLES, Air Diffusion, Air Washing, Brine Spraying, Humidifying, Oil Burner, Water Cooling** (See Spray Nozzles)

**NOZZLES, Oil Burner**  
 Monarch Mfg. Works, Inc., 1357

**OIL BURNER MOTORS** (See Motors, Electric)

**OIL BURNER TUBING, Flexible** (See Tubing, Flexible, Metallic)

**OIL BURNERS**  
 Aldrich Co., 1541  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
 Bryan Steam Corp., 1543  
 Cleaver-Brooks Co., 1544, 1580  
 Columbia Boiler Co., 1546-1547  
 Dewey-Shepard Boiler Co., 1550  
 Eddington Metal Specialty Co., 1591  
 Enterprise Engine & Machinery Co., Burner Div., Sub. of General Metals Corp., 1581  
 Preferred Utilities Mfg. Corp., 1566  
 Ray Oil Burner Co., 1584-1585

**OIL BURNERS, Automatic**  
 Aldrich Co., 1541  
 Airtemp Div., Chrysler Corp., 1248-1249  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
 American-Standard, Air Conditioning Div., 1244-1245  
 Armstrong Furnace Co., 1246-1247  
 Cleaver-Brooks Co., 1544, 1580  
 Columbia Boiler Co., 1546-1547  
 Dewey-Shepard Boiler Co., 1550  
 Eddington Metal Specialty Co., 1591  
 Enterprise Engine & Machinery Co., Burner Div., Sub. of General Metals Corp., 1581  
 Fitzgibbons Boiler Co., Inc., 1552-1553  
 General Automatic Products Corp., 1513  
 S. T. Johnson Co., 1582-1583  
 Johnston Bros., Inc., 1557  
 Mueller Climatrol Div. of Worthington Corp., 1254-1255  
 National-U. S. Radiator Corp., 1530-1533  
 Pacific Steel Boiler Div., National-U. S. Radiator Corp., 1534-1535  
 Preferred Utilities Mfg. Corp., 1566  
 Ray Oil Burner Co., 1584-1585  
 Rayfield-Staffco Burner Co., 1586  
 National-U. S. Radiator Corp., 1530-1533  
 Webster Engineering Co., The, 1579  
 York-Shipley Inc., 1590

**OIL BURNERS, Variable Capacity**  
 Enterprise Engine & Machinery Co., Burner Div., Sub. of General Metals Corp., 1581  
 Rayfield-Staffco Burner Co., 1586  
 York-Shipley, Inc., 1590

**OIL BURNERS, Pressure Atomizing**  
 Airtemp Div., Chrysler Corp., 1248-1249

Aldrich Co., 1541  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
 Babcock & Wilcox Co., The, 1542  
 Burnham Corp., 1526-1527  
 Cleaver-Brooks Co., 1544, 1580  
 Columbia Boiler Co., 1546-1547  
 Crane Co., 1528-1529  
 Dewey-Shepard Boiler Co., 1550  
 Eddington Metal Specialty Co., 1591  
 Enterprise Engine & Machinery Co., Burner Div., Sub. of General Metals Corp., 1581  
 Fitzgibbons Boiler Co., Inc., 1552-1553  
 General Automatic Products Corp., 1513  
 S. T. Johnson Co., 1582-1583  
 Mueller Climatrol Div. of Worthington Corp., 1254-1255  
 Orr & Sombower, Inc., 1562  
 Ray Oil Burner Co., 1584-1585  
 Rayfield-Staffco Burner Co., 1586  
 Sonner Burner Co., The, 1578  
 National-U. S. Radiator Corp., 1530-1533  
 John Zink Co., 1588-1589

**OIL BURNERS, Rotary**  
 Enterprise Engine & Machinery Co., Burner Div., Sub. of General Metals Corp., 1581  
 S. T. Johnson Co., 1582-1583  
 Johnston Bros., Inc., 1557  
 Preferred Utilities Mfg. Corp., 1566  
 Ray Oil Burner Co., 1584-1585  
 Rayfield-Staffco Burner Co., 1586

**OIL BURNERS, Steam Atomizing**  
 Babcock & Wilcox Co., The, 1542  
 Webster Engineering Co., The, 1579  
 John Zink Co., 1588-1589

**OIL BURNERS, Variable Capacity**  
 Enterprise Engine & Machinery Co., Burner Div., Sub. of General Metals Corp., 1581  
 Rayfield-Staffco Burner Co., 1586  
 York-Shipley, Inc., 1590

**OIL BURNING EQUIPMENT**  
 Airtemp Div., Chrysler Corp., 1248-1249  
 Aldrich Co., 1541  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
 Eddington Metal Specialty Co., 1591  
 Enterprise Engine & Machinery Co., Burner Div., Sub. of General Metals Corp., 1581  
 General Electric Co., 1230  
 Mueller Climatrol Div. of Worthington Corp., 1254-1255  
 National-U. S. Radiator Corp., 1530-1533  
 Pacific Steel Boiler Div., National-U. S. Radiator Corp., 1534-1535  
 Preferred Utilities Mfg. Corp., 1566  
 Ray Oil Burner Co., 1584-1585  
 Rayfield-Staffco Burner Co., 1586  
 Servel, Inc., 1262-1263  
 Webster Engineering Co., The, 1579  
 John Zink Co., 1588-1589

**OIL BURNING SYSTEMS, Industrial**  
 Enterprise Engine & Machinery Co., Burner Div., Sub. of General Metals Corp., 1581  
 S. T. Johnson Co., 1582-1583  
 Preferred Utilities Mfg. Corp., 1566  
 Ray Oil Burner Co., 1584-1585  
 Rayfield-Staffco Burner Co., Inc., 1586

**OIL TANK GAGES** (See Gages, Tank)

**ORIFICES, Radiator**  
 C. A. Dunham Co., 1618-1621  
 Illinois Engineering Co., 1626-1627  
 Johnson Service Co., 1484-1485  
 Minneapolis-Honeywell Regulator Co., 1490-1491  
 Warren Webster & Co., 1638-1639

**ORNAMENTAL GRILLS** (See Deflection Grilles, Grilles, Registers and Ornamental Metal Work, Louvers, Registers)

**PADS, Rubber**  
 Korfund Co., Inc., The, 1637  
 Vibration Mountings, Inc., 1688

**PANEL GRIDS** (See Grids, Panel)

**PANEL BOARD** (For Mounting Switch Controls)  
 Will-Burt Co., The, 1569

**PANEL HEATING**  
 American Radiator & Standard Sanitary Corp., (Plumbing & Heating Div.), 1523-1525  
 Crane Co., 1528-1529  
 Kritzer Radiant Coils, Inc., 1514  
 Sarcoterm Controls, Inc., 1633  
 Shaw-Perkins Mfg. Co., 1515  
 Edwin L. Wiegand Co., 1308-1309

**PANELS, Air Distributing**  
 Pyle-National Co., The, (Multi-Vent Div.), 1454-1455

**PANELS, Ceiling** (See Ceiling, Panels)

**PERFORATED METALS**  
 A-J Mfg. Co., 1426-1427  
 Auer Register Co., 1436  
 Hart & Cooley Mfg. Co., 1444-1445  
 Hendrick Mfg. Co., 1446-1447  
 Pyle-National Co., The, (Multi-Vent Div.), 1454-1455  
 Standard Stamping & Perforating Co., 1456  
 United States Register Co., 1462-1463

**PILLOW BLOCKS**  
 Lau Blower Co., The, 1398-1397

**PILOTS, Safety**  
 General Controls, 1480-1481  
 Milwaukee Gas Specialty Co., 1492  
 Penn Controls, Inc., 1494  
 White-Rodgers Electric Co., 1504

**PIPE ALIGNMENT GUIDES**  
 American District Steam Div., Adco Industries, Inc., 1505, 1594

**PIPE ANCHORS**  
 American District Steam Div., Adco Industries, Inc., 1505, 1594

**PIPE BENDING**  
 Acme Industries, Inc., 1358  
 Parks-Cramer Co., 1236-1237

**PIPE, Brass**  
 American Brass Co., The, 1310-1311  
 Revere Copper and Brass Incorporated, 1313

**PIPE CONDUITS** (See Conduits, Underground Pipe)

**PIPE, Copper**  
 American Brass Co., The, 1310-1311  
 Revere Copper and Brass Incorporated, 1313

**PIPE, Corrosion-Proof**  
 Johns-Manville, 1670-1671  
 National Clay Pipe Mfgs., The, 1516-1521  
 Stillwater Clay Products Co., The, 1652

**PIPE COVERING** (See Covering, Pipe)

**PIPE, Fabricated**  
 Dutton Boilers, Div. Hapman-Dutton Co., 1551  
 Farrar & Trefa Div., Adco Industries, Inc., 1554  
 Fluor Corp., Ltd., The, 1347

**PIPE FITTINGS** (See Fittings, Pipe)

**PIPE, FURNACE** (See Furnace, Pipe and Fittings)

**PIPE, Gas Vent**  
 Johns-Manville, 1670-1671  
 Metalbestos Div., William Wallace Co., 1592-1593

**PIPE HANGERS** (See Hangers, Pipe)

**PIPE HEATING**  
 Edwin L. Wiegand Co., 1308-1309

**PIPE, Spiral Welded**  
 Taylor Forge & Pipe Works, 1510

**PIPE, Steel**  
 Taylor Forge & Pipe Works, 1510

**PIPE SUPPORTS, For Underground Conduits**  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Durant Insulated Pipe Co., 1647  
 Durant International Corp., 1647  
 E. B. Kaiser Co., 1648-1649  
 H. W. Porter & Co., Inc., 1650  
 Reid Hayden, Inc., 1650  
 Ric-wil Co., The, 1651  
 Stillwater Clay Products Co., The, 1652  
 Z-Crete Div., Zonolite Co., 1653

**PIPE VITRIFIED CLAY, Heating Ducts**  
 National Clay Pipe Mfgs., The, 1516-1521  
 Stillwater Clay Products Co., The, 1652

**PITOT TUBES** (See Air Measuring and Recording Instruments)

**PLASTER BASE, Fire Retarding**  
 Celotex Corp., The, 1666

**PLASTER BASE, Insulative**  
 Celotex Corp., The, 1666  
 Insulite, 1668-1669  
 Wood Conversion Co., 1677

**PLASTER BASE, Sound Deadening**  
 Celotex Corp., The, 1666  
 Insulite, 1668-1669  
 Wood Conversion Co., 1677

**PLATES, Stainless Steel**  
 United States Steel, 1425

**PLATES, Steel**  
 United States Steel, 1425

**PNEUMATIC RELAYS** (See Relays, Electrical and Pneumatic)

**PRECIPITATING EQUIPMENT**  
 Dollinger Corp., 1330-1331  
 Trion, Inc., 1340  
 Westinghouse Electric Corp., Sturtevant Div., 1342

**PREFABRICATED DUCT CONNECTORS** (See Duct Connectors, Prefabricated)

**PREHEATERS, Fuel Oil**  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Bell & Gossett Co., 1598-1599  
 E. B. Kaiser Co., 1648-1649  
 Kewanee Boiler Div., American-Standard, 1558-1561  
 Killebrew Engineering Corp., 1597  
 Preferred Utilities Mfg. Corp., 1566  
 Taco Heaters, Inc., 1602  
 H. A. Thrush & Co., 1600-1601  
 Edwin L. Wiegand Co., 1308-1309  
 Western Blower Co., 1409

**PRESSURE REDUCING VALVES** (See Regulators, Pressure)

**PROCESS HEATING UNITS**  
 Air Devices, Inc., 1316, 1432  
 Niagara Blower Co., 1235  
 Trane Co., The, 1298-1301  
 L. J. Wing Mfg. Co., 1302-1303

**PROCESS HEATING UNITS, Fluid Heating and Cooling**  
 American District Steam Div., Adco Industries, Inc., 1505, 1594  
 Killebrew Engineering Corp., 1597  
 Arthur A. Olson & Co., 1279  
 Trane Co., The, 1298-1301  
 Edwin L. Wiegand Co., 1308-1309

**PROPELLER FANS** (See Fans, Propeller)

**PSYCHROMETERS** (See Air Measuring, Indicating and Recording Instruments)  
 American Moistening Co., 1222  
 Bahnsen Co., The, 1223  
 Illinois Testing Laboratories, Inc., 1486

**JOHNSON SERVICE CO., 1484-1485**  
 Moeller Instrument Co., 1493  
 Parks-Cramer Co., 1236-1237  
 Powers Regulator Co., 1496-1498  
 Taylor Instrument Cos., 1503

**PUBLICATIONS**  
 Air Conditioning, Heating and Ventilating, 1639  
 American Airman, 1694  
 American Society of Refrigerating Engineers, 1690

Coal-Heat, 1691  
Domestic Engineering, 1692  
Heating & Plumbing Equipment  
News, 1689  
Heating & Air Conditioning Con-  
tractor, 1693  
Heating, Piping and Air Condition-  
ing, 1694  
Journal of Plumbing-Heating & Air  
Conditioning, The, 1693  
Snips Magazine, 1695

#### PUMP CONTROLLERS (See Con- trollers, Pump)

#### PUMP MOTORS (See Motors, Electric)

#### PUMPS, Ammonia

Worthington Corp., 1241  
York Corp., 1242

#### PUMPS, Boiler Feed

Aurora Pump Div., The New York  
Air Brake Co., 1603  
Buffalo Pumps, Inc., 1604  
Chicago Pump Co., 1606-1607  
Crane Co., 1528-1529  
Domestic Pump & Mfg. Corp., 1605  
C. A. Dunham Co., 1618-1621  
Dutton Boilers, Div. Hapman-  
Dutton Co., 1551  
Hoffman Specialty Mfg. Corp.,  
1622-1625  
Nash Engineering Co., The, 1608-  
1609  
Skidmore Corp., 1611  
Spence Engineering Co., Inc., 1501  
Sterling, Inc., 1502  
Worthington Corp., 1241

#### PUMPS, Brine

Aurora Pump Div., The New York  
Air Brake Co., 1603  
Buffalo Pumps, Inc., 1604  
Chicago Pump Co., 1606-1607  
Domestic Pump & Mfg. Corp., 1605  
Worthington Corp., 1241

#### PUMPS, Centrifugal

Aurora Pump Div., The New York  
Air Brake Co., 1603  
Bell & Gossett Co., 1598-1599  
Buffalo Pumps, 1604  
Chicago Pump Co., 1606-1607  
Domestic Pump & Mfg. Corp., 1605  
C. A. Dunham Co., 1618-1621  
Kraissl Co., Inc., The, 1610  
Skidmore Corp., 1611  
Taco Heaters, Inc., 1602  
Trane Co., The, 1298-1301  
Worthington Corp., 1241

#### PUMPS, Circulating (See Cir- culators)

Aurora Pump Div., The New York  
Air Brake Co., 1603  
Bell & Gossett Co., 1598-1599  
Buffalo Pumps, 1604  
Chicago Pump Co., 1606-1607  
Domestic Pump & Mfg. Corp., 1605  
C. A. Dunham Co., 1618-1621  
Kraissl Co., Inc., 1610  
Minneapolis-Honeywell, Regulator  
Co., 1490-1491  
Taco Heaters, Inc., 1602  
H. A. Thrush & Co., 1600-1601  
Trane Co., The, 1298-1301  
Worthington Corp., 1241

#### PUMPS, Condensation

Aurora Pump Div., The New York  
Air Brake Co., 1603

Buffalo Pumps, 1604  
Chicago Pump Co., 1606-1607  
Crane Co., 1528-1529  
Domestic Pump & Mfg. Corp., 1605  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp.,  
1622-1625  
Illinois Engineering Co., 1620-1627  
Nash Engineering Co., The, 1608-  
1609  
Sarco-Sarcotherm, 1633-1635  
Skidmore Corp., 1611  
Sterling, Inc., 1502  
Trane Co., The, 1298-1301

#### PUMPS, Fuel Oil

Kraissl Co., Inc., The, 1610  
Preferred Utilities Mfg. Corp., 1666  
Ray Oil Burner Co., 1584-1585  
Rayfield-Staffco Burner Co., Inc.,  
1586

#### PUMPS, Sump

Aurora Pump Div., The New York  
Air Brake Co., 1603  
Buffalo Pumps, 1604  
Chicago Pump Co., 1606-1607  
Skidmore Corp., 1611

#### PUMPS, Turbine

Aurora Pump Div., The New York  
Air Brake Co., 1603  
Chicago Pump Co., 1606-1607  
Skidmore Corp., 1611

#### PUMPS, Vacuum

Chicago Pump Co., 1606-1607  
Domestic Pump & Mfg. Corp., 1605  
C. A. Dunham Co., 1618-1621  
Joy Mfg. Co., 1394-1395  
Kraissl Co., Inc., 1610  
Nash Engineering Co., The, 1608-  
1609  
Sarco-Sarcotherm, 1633-1635  
Skidmore Corp., 1611  
Sterling, Inc., 1502  
Worthington Corp., 1241

#### PUMPS, Water Supply

Aurora Pump Div., The New York  
Air Brake Co., 1603

#### PURGERS, Refrigeration

Armstrong Machine Works, 1614-  
1615  
York Corp., 1242

#### PURIFIERS AND SCRUBBERS,

Air Gas and Steam  
V. D. Anderson Co., The, 1612-1613

#### PYROMETERS, Portable and Stationary

Illinois Testing Laboratories, 1486  
Minneapolis-Honeywell Regulator  
Co., 1490-1491

#### QUADRANTS, Damper

Duro-Dyne Corp., 1466-1467

#### RADIANT COOLING

Burgess-Manning Co., 1438

#### RADIANT HEATING

American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Burgess-Manning Co., 1438  
Burnham Corp., 1526-1527  
Campbell Heating Co., 1268-1269

Crane Co., 1528-1529  
Electromode Corp., 1305  
Hoffman Specialty Mfg. Corp., 1622-  
1625  
Hydrotherm, Inc., 1555  
Kritzer Radiant Coils, Inc., 1514  
National-U. S. Radiator Corp.,  
1530-1533  
Raypak Co., Inc., 1563  
Sarcotherm Controls, Inc., 1633  
Shaw-Perkins Mfg. Co., 1515  
Weil-McLain Co., 1540  
West Electric Heater Co., 1307  
Edwin L. Wiegand Co., 1308-1309

#### RADIATION, Aluminum

Kritzer Radiant Coils, Inc., 1514  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1366  
Trane Co., The, 1298-1301  
Young Radiator Co., 1304

#### RADIATION, Baseboard, Fer- rous

American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Burnham Corp., 1526-1527  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Fedders-Quigan Corp., 1286  
Kritzer Radiant Coils, Inc., 1514  
Rittling Corp., The, 1364  
Sarcotherm Controls, Inc., 1633  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1366  
H. B. Smith Co., Inc., The, 1537  
Trane Co., The, 1298-1301  
National-U. S. Radiator Corp.,  
1530-1533  
Union Asbestos & Rubber Co., 1265  
Vulcan Radiator Co., The, 1367  
Weil-McLain Co., 1540  
West Electric Heater Co., 1307

#### RADIATION, Baseboard Non- ferrous

American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Columbia Boiler Co., 1546-1547  
C. A. Dunham Co., 1618-1621  
Fedders-Quigan Corp., 1286  
G & O Mfg. Co., The, 1362  
General Automatic Products Corp.,  
1513  
Hoffman Specialty Mfg. Corp., 1622-  
1625  
Kritzer Radiant Coils, Inc., 1514  
National-U. S. Radiator Corp.,  
1530-1533  
Herman Nelson, American Air  
Filter Co., Inc., 1296-1297  
John J. Nesbitt, Inc., 1293-1295  
Rittling Corp., The, 1364  
Sarcotherm Controls, Inc., 1633  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1366  
H. B. Smith Co., Inc., The, 1537  
Trane Co., The, 1298-1301  
Tuttle & Bailey, Inc., 1460-1461  
Union Asbestos & Rubber Co., 1265  
Vulcan Radiator Co., The, 1367  
Warren Webster & Co., 1638-1639  
York-Shipley, Inc., 1590

#### RADIATION, Cast-Iron

American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Burnham Corp., 1526-1527  
Crane Co., 1528-1529

### Index to Modern Equipment

D. J. Murray Mfg. Co., 1292  
National-U. S. Radiator Corp.,  
1530-1533  
Weil-McLain Co., 1540

#### RADIATION, Copper

Airtherm Mfg. Co., 1522  
C. A. Dunham Co., 1618-1621  
Fedders-Quigan Corp., 1286  
G & O Mfg. Co., The, 1362  
General Automatic Products Corp.,  
1513  
Hoffman Specialty Mfg. Corp., 1622-  
1625  
Modine Mfg. Co., 1290-1291  
Rittling Corp., The, 1364  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1366  
Trane Co., The, 1298-1301  
Union Asbestos & Rubber Co., 1265  
York-Shipley, Inc., 1590  
Young Radiator Co., 1304

#### RADIATION, Plain, Extended Surface

American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Burgess-Manning Co., 1438  
C. A. Dunham Co., 1618-1621  
Fedders-Quigan Corp., 1286  
G & O Mfg. Co., The, 1362  
General Automatic Products Corp.,  
1513  
Modine Mfg. Co., 1290-1291  
National-U. S. Radiator Corp.,  
1530-1533  
Herman Nelson, American Air  
Filter Co., Inc., 1296-1297  
John J. Nesbitt, Inc., 1293-1295  
Rittling Corp., The, 1364  
Sarcotherm Controls, Inc., 1633  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1366  
H. B. Smith Co., Inc., The, 1537  
Trane Co., The, 1298-1301  
Union Asbestos & Rubber Co., 1265  
Warren Webster & Co., 1638-1639  
Young Radiator Co., 1304

#### RADIATION, Underfloor

National Clay Pipe Mfgs., The,  
1516-1521

#### RADIATOR BRACKETS (See Brackets, Radiator)

#### RADIATOR ENCLOSURES AND SHIELDS

American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
National-U. S. Radiator Corp.,  
1530-1533  
Sarcotherm Controls, Inc., 1633  
Slant-Fin Radiator Corp., 1366  
Somers Corp., 1339

#### RADIATOR HANGERS (See Hangers, Radiator)

#### RADIATOR HEAT REFLEC- TORS

Infra Insulation, Inc., 1679  
Reflectal Corp., 1682  
Silvercote Products, Inc., 1680-1681

#### RADIATORS, Cabinet

Airtherm Mfg. Co., 1522  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621

Fedders-Quigan Corp., 1286  
Modine Mfg. Co., 1290-1291  
National-U. S. Radiator Corp.,  
1530-1533

Herman Nelson, American Air  
Filter Co., Inc., 1296-1297  
Rittling Corp., The, 1364  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1366  
Union Asbestos & Rubber Co., 1265  
Weil-McLain Co., 1540  
Young Radiator Co., 1304

#### RADIATORS, Concealed

Airtherm Mfg. Co., 1522  
American Radiator & Standard  
Sanitary Corp., (Plumbing &  
Heating Div.), 1523-1525  
Burnham Corp., 1526-1527  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Fedders-Quigan Corp., 1286  
Kritzer Radiant Coils, Inc., 1514  
Modine Mfg. Co., 1290-1291  
National-U. S. Radiator Corp.,  
1530-1533  
Herman Nelson, American Air  
Filter Co., Inc., 1296-1297  
Rittling Corp., The, 1364  
Shaw-Perkins Mfg. Co., 1515  
Slant-Fin Radiator Corp., 1366  
Union Asbestos & Rubber Co., 1265  
Warren Webster & Co., 1638-1639  
Weil-McLain Co., 1540  
Young Radiator Co., 1304

#### RANGES, Cooking, Hotel, Hos- pital, etc.

Air Devices, Inc., 1316, 1432  
Ray Oil Burner Co., 1584-1585

#### RECEIVERS, Air

Curtis Mfg. Co., Refrigeration Div.,  
1370  
Farrar & Trefts Div., Adco In-  
dustries, Inc., 1554  
International Boiler Works Co.,  
The, 1556  
Joy Mfg. Co., 1394-1395  
Worthington Corp., 1241

#### RECEIVERS, Condensation

Domestic Pump & Mfg. Corp., 1605  
Hoffman Specialty Mfg. Corp.,  
1622-1625  
Illinois Engineering Co., 1626-1627  
Worthington Corp., 1241

#### RECEIVERS, Refrigerants

Acme Industries, Inc., 1358  
Worthington Corp., 1241  
York Corp., 1242

#### RECORDERS, Humidity, Tem- perature

American Moistening Co., 1222  
Electric Auto-Lite Co., The Instru-  
ment & Gauge Div., 1478  
Johnson Service Co., 1484-1485  
Moeller Instrument Co., 1493  
Powers Regulator Co., The, 1498-  
1499  
Taylor Instrument Cos., 1503

#### REFRATORIES, Cement, Ma- terials

Armstrong Cork Co. (Building Ma-  
terials Div.), 1665  
Babcock & Wilcox Co., The, 1542  
Philip Carey Mfg. Co., The, 1656-  
1657  
Johns-Manville, 1670-1671

#### REFRIGERANT DRIERS (See Driers, Refrigerant)

### REFRIGERATING EQUIP- MENT, Absorption

Carrier Corp., 1226-1227

### REFRIGERATING EQUIP- MENT, Centrifugal

Bell & Gossett Co., 1598-1599  
Carrier Corp., 1226-1227  
Trane Co., The, 1298-1301  
Worthington Corp., 1241  
York Corp., 1242

### REFRIGERATING EQUIP- MENT, Steam Jet

Worthington Corp., 1241

### REFRIGERATING MACHIN- ERY

Addison Products Co., 1243  
Airtemp Div., Chrysler Corp., 1248-  
1249  
American Blower Corp., 1220-1221  
Brunner Mfg. Co., 1368  
Carrier Corp., 1226-1227  
Curtis Mfg. Co., Refrigeration Div.,  
1370  
Copeland Refrigeration Corp., 1369  
Frick Co., 1371  
Niagara Blower Co., 1235  
Ready-Power Co., The, 1372  
Refrigeration Engineering, Inc.,  
1373  
Servel, Inc., 1262-1263  
Trane Co., The, 1298-1301  
Worthington Corp., 1241  
York Corp., 1242

### REFRIGERATION CONTROLS

Aleo Valve Co., Inc., 1472  
General Controls, 1480-1481  
Hubbell Corp., The, 1483  
Meroid Corp., The, 1480  
Penn Controls, Inc., 1494  
White-Rodgers Electric Co., 1504

### REFRIGERATION TUBE, Cop- per (See Tubes and Tubing, Cop- per)

### REGISTERS (See Grilles, Registers and Ornamental Metal Work)

A-J Mfg. Co., 1426-1427  
Air Control Products, Inc., 1428-  
1431  
Air-Factors, Inc., 1433  
Auer Register Co., The, 1436  
Barber-Colman Co., 1437, 1473  
Dole Valve Co., The, 1640  
General Register Corp., 1442-1443  
Hart & Cooley Mfg. Co., 1444-1445  
Hendrick Mfg. Co., 1446-1447  
Independent Register Co., The,  
1448  
Lima Register Co., 1450-1451  
Louvra Mfg. & Sales Co., 1452  
National-U. S. Radiator Corp.,  
1530-1533  
Pyle-National Co., The, (Multi-  
Vent Div.), 1454-1455  
Register & Grille Mfg. Co., Inc.,  
1453  
Stewart Mfg. Co., Inc., 1457  
Titus Mfg. Corp., 1458-1459  
Tuttle & Bailey, Inc., 1460-1461  
United States Register Co., 1462-  
1463  
Waterloo Register Co., Inc., 1465  
Young Regulator Co., 1470-1471

### REGULATORS, Air Volume

A-J Mfg. Co., 1426-1427  
Barber-Colman Co., 1437, 1473  
Duro-Dyne Corp., 1466-1467

Hart & Cooley Mfg. Co., 1444-1445  
Powers Regulator Co., 1496-1498  
Young Regulator Co., 1470-1471

**REGULATORS, Back Pressure**  
Alco Valve Co., 1472  
Hubbell Corp., 1483

**REGULATORS, Damper**  
A-J Mfg. Co., 1426-1427  
Barber-Colman Co., 1437, 1473  
Duro-Dyne Corp., 1466-1467  
Field Control Div., of H. D. Conkey & Co., 1477  
Hart & Cooley Mfg. Co., 1444-1445  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Powers Regulator Co., The, 1496-1498  
Spence Engineering Co., Inc., 1501  
Trane Co., The, 1298-1301  
Young Regulator Co., 1470-1471

**REGULATORS, Draft**  
Field Control Div., of H. D. Conkey & Co., 1477  
Simplex Mfg. Co., 1500

**REGULATORS, Evaporator Pressure**  
Alco Valve Co., 1472  
Hubbell Corp., The, 1483

**REGULATORS, Feed Water**  
Heller Laboratories, Inc., 1352  
McDonnell & Miller, Inc., 1570-1573

**REGULATORS, Furnace**  
Field Control Div., of H. D. Conkey & Co., 1477  
Mercoid Corp., The, 1489  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
White-Rodgers Electric Co., 1504

**REGULATORS, Gas**  
General Controls, 1480-1481  
Maxitrol Co., 1488  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
Webster Engineering Co., The, 1579

**REGULATORS, Humidity (See Humidity Control)**

**REGULATORS, Pressure**  
Alco Valve Co., 1472  
Bell & Gossett Co., 1598-1599  
A. W. Cash Co., 1617  
C. A. Dunham Co., 1618-1621  
Fulton Syphon Div., The Robertshaw-Fulton Controls Co., 1478-1479

General Controls, 1480-1481  
Hoffman Specialty Mfg. Corp., 1622-1625  
Hubbell Corp., The, 1483  
Illinois Engineering Co., 1626-1627  
Johnson Service Co., 1484-1485  
Leslie Co., 1487  
Jas. P. Marsh Corp., 1628-1629  
Maxitrol Corp., 1488  
McDonnell & Miller, Inc., 1570-1573  
Mercoid Corp., The, 1489  
Monarch Mfg. Works, Inc., 1357  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498  
Spence Engineering Co., Inc., 1501  
Strong, Carlisle & Hammond Co., 1637

Swartwout Co., The, 1423  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**REGULATORS, Remote Control**  
Alco Valve Co., 1472  
Fulton Syphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
Hubbell Corp., 1483  
Leslie Co., 1487  
Mercoid Corp., The, 1489  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
Powers Regulator Co., 1496-1498  
Young Regulator Co., 1470-1471

**REGULATORS, Temperature (See Temperature Control)**

**REGULATORS, Time Controls**  
General Controls, 1480-1481  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Powers Regulator Co., The, 1496-1498

**RELAYS Electrical and Pneumatic**  
Potter & Brumfield, 1495

**RELIEF VALVES (See Valves, Relief)**

**RESTRICTOR TUBING (See Tubing, Restrictor)**

**RINGS, Backing**  
Robvon Backing Ring Co., The, 1509

**RINGS, Chill**  
Robvon Backing Ring Co., The, 1509

**RINGS, Machined**  
Robvon Backing Ring Co., The, 1509

**RINGS, Welding**  
Robvon Backing Ring Co., The, 1509  
Tube Turns, A Div. of National Cylinder Gas Co., 1511

**ROOF COOLERS**  
April Showers Co., Inc., 1644  
Muellermist Irrigation Co., 1645

**RUST PREVENTATIVE (See Corrosion, Treatment of)**

**SAFETY CONTROLS (See Burner Protection, Gas and Oil)**

**SAFETY VALVES (See Valves, Safety)**

**SCREENING**  
Kaiser Aluminum & Chemical Sales, Inc., 1684-1685  
Reflectal Corp., 1682

**SCREENS, Perforated Metal**  
Hendrick Mfg. Co., 1446-1447

**SEPARATORS, Air**  
V. D. Anderson Co., The, 1612-1613  
Barnebey-Cheney Co., 1322-1323  
Dollinger Corp., 1330-1331  
C. A. Dunham Co., 1618-1621  
Pur Air Div., Barnebey-Cheney Co., 1322-1323

Strong, Carlisle & Hammond Co., 1637

**SEPARATORS, Blow Down**  
Pennsylvania Separator Co., 1574

**SEPARATORS, Dust**  
American Air Filter Co., 1319-1321  
V. D. Anderson Co., The, 1612-1613  
Dollinger Corp., 1330-1331  
Farr Co., 1332-1333

**SEPARATORS, Gas**  
V. D. Anderson Co., The, 1612-1613  
Pennsylvania Separator Co., 1574

**SEPARATORS, Oil**  
Acme Industries, Inc., 1358  
Air-Maze Corp., 1318  
Dollinger Corp., 1330-1331  
Illinois Engineering Co., 1626-1627  
Kraissl Co., Inc., The, 1610  
York Corp., 1242

**SEPARATORS, Refrigerant Oil**  
Acme Industries, Inc., 1358

**SEPARATORS, Steam**  
American District Steam Div., Adcoo Industries, Inc., 1505, 1594  
V. D. Anderson Co., The, 1612-1613  
Illinois Engineering Co., 1626-1627  
Pennsylvania Separator Co., 1574  
Strong, Carlisle & Hammond Co., 1637

**SHEET METAL TOOLS (See Tools, Sheet Metal)**

**SEPARATORS, Vapor**  
V. D. Anderson Co., The, 1612-1613

**SHEETS, Aluminum**  
Revere Copper and Brass Incorporated, 1313

**SHEETS, Asbestos, Flat, and Corrugated**  
Phillip Carey Mfg., Co., The, 1656-1657  
Johns-Manville, 1670-1671

**SHEETS, Copper Alloy**  
American Brass Co., The, 1310-1311  
Revere Copper and Brass, Incorporated, 1313  
Standard Stamping & Perforating Co., 1456

**SHEETS, Copper Bearing Steel**  
United States Steel, 1425

**SHEETS, Galvanized Steel**  
United States Steel, 1425

**SHEETS, High-Strength Steel**  
United States Steel, 1425

**SHEETS, Porcelain Enameling**  
United States Steel, 1425

**SHEETS, Special Finish**  
United States Steel, 1425

**SHEETS, Stainless Steel**  
American Flange & Mfg. Co., Inc., 1678  
Standard Stamping & Perforating Co., 1456  
United States Steel, 1425

**SHEETS, Steel**  
American Flange & Mfg. Co., Inc., 1678  
United States Steel, 1425

## Index to Modern Equipment

**SHUTTERS, Automatic**  
American Foundry & Furnace Co., 1266-1267  
Ilg Electric Ventilating Co., 1287, 1393  
Herman Nelson, American Air Filter Co., Inc., 1296-1297  
Peerless Electric Co., The, 1400  
Reed Unit-Fans, Inc., 1402  
L. J. Wing Mfg. Co., 1302-1303

**SIGNAL, Liquid Level**  
Scully Signal Co., 1499

**SIGNAL, Tank Filling**  
Scully Signal Co., 1499

**SKYLIGHTS, Insulated**  
American 3 Way-Luxfer Prism Co., 1660  
Owens-Illinois, 1661  
Pittsburgh Corning Corp., 1663

**SKYLIGHTS, Metal and Ventilating**  
American 3 Way-Luxfer Prism Co., 1660

**SLAB, Heating Concrete**  
National Clay Pipe Mfgs., The, 1516-1521

**SMOKE DETECTORS AND INDICATORS (For Flues and Ducts)**  
Combustion Control Div., Electronics Corp. of America, 1475  
Trion, Inc., 1340

**SMOKE VENTILATORS (See Ventilators, Smoke)**

**SOOT DESTROYER**  
John Zink Co., 1589-1589

**SOUND DEADENING (See Vibration Absorbers)**

**SOUND ISOLATORS**  
Korlund Co., Inc., The, 1687  
Vibration Mountings, Inc., 1688

**SPOT WELDERS (See Welders, Spot)**

**SPRAY DRYER (See Spray Equipment)**

**SPRAY EQUIPMENT**  
Bayley Blower Co., 1376  
Binks Mfg. Co., 1344-1345  
Monarch Mfg. Works, Inc., 1357  
D. J. Murray Mfg. Co., 1292

**SPRAY NOZZLE COOLING SYSTEM**

American Moistening Co., 1222  
April Showers Co., Inc., 1644  
Bahnsen Co., The, 1223  
Binks Mfg. Co., 1344-1345  
Fluor Corp., Ltd., The, 1347  
Lillie-Hoffman Cooling Towers, Inc., 1353  
Marley Co., The, 1354  
Monarch Mfg. Works, Inc., 1357  
D. J. Murray Mfg. Co., 1292  
Phillips Cooling Tower Co., Inc., 1356

**SPRAY NOZZLES**  
American Moistening Co., 1222  
April Showers Co., Inc., 1644  
Bahnsen Co., The, 1223  
Binks Mfg. Co., 1344-1345

Buensod-Stacey, Inc., 1224  
Buffalo Forge Co., 1382  
Fluor Corp., Ltd., The, 1347  
Marley Co., The, 1354  
Monarch Mfg. Works, Inc., 1357  
D. J. Murray Mfg. Co., 1292

**STEAM AND WATER MIXERS (See Mixers, Steam and Water)**

**STEAM GENERATORS, Unit**  
Babcock & Wilcox Co., The, 1542  
Combustion Engineering, Inc., 1548-1549  
Cyclotherm Div. of National-U.S. Radiator Corp., 1545  
Dutton Boilers, Div. Hapman-Dutton Co., 1551  
Farrar & Trefle Div., Adcoo Industries, Inc., 1554  
Fitzgibbons Boiler Co., Inc., 1552-1553  
Johnston Brothers, Inc., 1557  
Orr & Sember, Inc., 1562  
Preferred Utilities Mfg. Corp., 1566  
Titusville Iron Works Co., 1564-1565  
Vapor Heating Corp., 1567  
Worthington Corp., 1241  
York-Shipley, Inc., 1590

**STEAM HEATING SYSTEMS (See Heating Systems, Steam)**

**STEEL INSULATION (See Insulation, Steel)**

**STOKER MOTORS (See Motors, Electric)**

**STOKERS, Mechanical, Anthracite**

Airtemp Div., Chrysler Corp., 1248-1249  
Combustion Engineering, Inc., 1548-1549  
Detroit Stoker Co., 1568

**STOKERS, Mechanical, Bituminous**

Airtemp Div., Chrysler Corp., 1248-1249  
Combustion Engineering, Inc., 1548-1549  
Crane Co., 1528-1529  
Detroit Stoker Co., 1568  
Will-Burt Co., The, 1569

**STOKERS, Refuse Burning**  
Combustion Engineering, Inc., 1548-1549  
Detroit Stoker Co., 1568

**STRAINERS, Air**  
Maid-O'-Mist, Inc., 1630-1632

**STRAINERS, Dirt**  
American District Steam Div., Adcoo Industries, Inc., 1505, 1594  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
C. A. Dunham Co., 1618-1621  
Edington Metal Specialty Co., 1591  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Kraissl Co., Inc., The, 1610  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502  
Warren Webster & Co., 1638-1639

**STRAINERS, Refrigerant**

Alco Valve Co., 1472  
Henry Valve Co., 1482  
Hubbell Corp., The, 1483  
Maid-O'-Mist, Inc., 1630-1632  
Penn Controls, Inc., 1494  
Sarco Co., Inc., 1634-1635

**STRAINERS, Steam**  
Alco Valve Co., 1472  
American District Steam Div., Adcoo Industries, Inc., 1505, 1594  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
A. W. Cash Co., 1617  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Illinois Engineering Co., 1626-1627  
Kraissl Co., Inc., The, 1610  
Leslie Co., 1487  
Maid-O'-Mist, Inc., 1630-1632  
Monarch Mfg. Works, Inc., 1357  
Penn Controls, Inc., 1494  
Sarco Co., Inc., 1634-1635  
Spence Engineering Co., Inc., 1501  
Sterling, Inc., 1502  
Trane Co., The, 1298-1301

**SWITCHES, Electric and Time**  
April Showers Co., 1644

**SWITCHES, Float**  
Alco Valve Co., 1472  
McDonnell & Miller, Inc., 1570-1573  
Mercoid Corp., The, 1489

**SWITCHES, Flow Control**  
McDonnell & Miller, Inc., 1570-1573

**SWITCHES, Mercury**  
Mercoid Corp., The, 1489  
Minneapolis-Honeywell Regulator Co., 1490-1491

**SWITCHES, Pneumatic**  
Powers Regulator Co., The, 1496-1498

**SWITCHES, Stack Safety**  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
White-Rodgers Electric Co., 1504

**SWITCHES, Time**  
April Showers, Inc., 1844  
General Controls, 1480-1481

**TANK COILS** (See Coils, Tank)

**TANK COVERING** (See Covering Pipe)

**TANK HEATERS** (See Heaters, Tank)

**TANKS, Blow-off**  
American District Steam Div., Adco Industries, Inc., 1505, 1504  
International Boiler Works Co., The, 1558

**TANKS, Pressure**  
Farrar & Trefts, Div., Adco Industries, Inc., 1554  
International Boiler Works Co., The, 1558  
Killebrew Engineering Corp., 1597  
Trane Co., The, 1298-1301

**TANKS, Storage**  
Rheem Mfg. Co., 1260-1261  
Western Blower Co., 1409

**TEMPERATURE CONTROL**  
Barber-Colman Co., 1437, 1473  
Cam-Stat, Inc., Div. of the Paul Henry Co., 1474  
Combustion Control Div., Electronics Corp. of America, 1475  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Illinois Testing Laboratories, Inc., 1486  
Johnson Service Co., 1484-1485  
Leslie Co., 1487  
Jas. P. Marsh Corp., 1628-1629  
Mercoir Corp., 1489  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498  
Sarco-Sarcotherm, 1633-1635  
Spence Engineering Co., Inc., 1501  
Sterling, Inc., 1502  
Taylor Instrument Cos., 1503  
Warren Webster & Co., 1638-1639  
West Electric Heater Co., 1307  
Young Regulator Co., 1470-1471

**TEMPERING VALVES** (See Valves, Tempering)

**THERMOMETERS, Distance Type**  
Electric Auto-Lite Co., The Instrument & Gauge Div., 1476  
Illinois Testing Laboratories, Inc., 1486  
Jas. P. Marsh Corp., 1628-1629  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Moeller Instrument Co., 1493  
Powers Regulator Co., The, 1496-1498

Sarco Co., Inc., 1634-1635  
Taylor Instrument Cos., 1503

**THERMOMETERS, Indicating**  
Electric Auto-Lite Co., The Instrument & Gauge Div., 1476  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
Illinois Testing Laboratories, Inc., 1486  
Johnson Service Co., 1484-1485  
Jas. P. Marsh Corp., 1628-1629  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Moeller Instrument Co., 1493  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Taylor Instrument Cos., 1503

**THERMOMETERS, Recording**  
Electric Auto-Lite Co., The Instrument & Gauge Div., 1476  
Johnson Service Co., 1484-1485  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Moeller Instrument Co., 1493  
Powers Regulator Co., The, 1496-1498

**THERMOSTATS**  
Barber-Colman Co., 1437, 1473  
Cam-Stat, Inc., Div. of the Paul Henry Co., 1474  
Combustion Control Div., Electronics Corp. of America, 1475  
Crane Co., 1528-1529  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Hoffman Specialty Mfg. Corp., 1622-1625  
Johnson Service Co., 1484-1485  
Mercoir Corp., The, 1489  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sarcotherm Controls, Inc., 1633  
H. A. Thrush & Co., 1600-1601  
West Electric Heater Co., 1307  
Edwin L. Wiegand Co., 1308-1309

**TIME SWITCHES** (See Switches, Time)

**TIMERS, Electric, Interval**  
Barber-Colman Co., 1437, 1473

**TOOLS, Sheet Metal**  
Duro-Dyne Corp., 1486-1487

**TOWERS, Cooling.** (See Cooling Towers)

**TRANSFORMERS**  
General Controls, 1480-1481

**TRAPS, Air**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Sarco Co., Inc., 1634-1635  
Strong, Carlisle & Hammond Co., 1637

**TRAPS, Bucket**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615

Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Jas. P. Marsh Corp., 1628-1629  
Sarco Co., Inc., 1634-1635  
Strong, Carlisle & Hammond Co., 1637  
Trane Co., The, 1298-1301

**TRAPS, Float**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Sarco Co., Inc., 1634-1635  
Strong, Carlisle & Hammond Co., 1637  
Trane Co., The, 1298-1301

**TRAPS, Float and Thermostatic**  
V. D. Anderson Co., The, 1612-1613  
Barnes & Jones, Inc., 1616  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Sarco Co., Inc., 1634-1635  
Strong, Carlisle & Hammond Co., 1637  
Trane Co., The, 1298-1301

**TRAPS, Radiator**  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502  
Strong, Carlisle & Hammond Co., 1637  
Trane Co., The, 1298-1301  
Warren Webster & Co., 1638-1639

**TRAPS, Return**  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502  
Trane Co., The, 1298-1301

**TRAPS, Scale**  
Henry Valve Co., 1482  
Illinois Engineering Co., 1626-1627

**TRAPS, Scale, Refrigerant**  
Henry Valve Co., 1482

**TRAPS, Steam**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502

**TRAPS, Scale, Refrigerant**  
Henry Valve Co., 1482

**TRAPS, Steam**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502

**TRAPS, Steam**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502

**TRAPS, Steam**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502

**TRAPS, Steam**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502

**TRAPS, Steam**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502

**TRAPS, Steam**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502

## Index to Modern Equipment

Strong, Carlisle & Hammond Co., 1637  
Trane Co., The, 1298-1301  
Warren Webster & Co., 1638-1639

**TRAPS, Thermostatic**  
Barnes & Jones, Inc., 1616  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502  
Trane Co., The, 1298-1301  
Warren Webster & Co., 1638-1639

**TRAPS, Vacuum**  
V. D. Anderson Co., The, 1612-1613  
Armstrong Machine Works, 1614-1615  
Barnes & Jones, Inc., 1616  
Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Sarco Co., Inc., 1634-1635  
Strong, Carlisle & Hammond Co., 1637

**TUBES, Boiler**  
Babcock & Wilcox Tube Co., The, 1542

**TUBES and TUBING, Copper**  
American Brass Co., The, 1310-1311  
Revere Copper and Brass Incorporated, 1313  
Wolverine Tube, 1314-1315

**TUBES, Pitot** (See Air Measuring and Recording Instruments)

**TUBING, Aluminum**  
American Brass Co., The, 1310-1311  
Revere Copper and Brass Incorporated, 1313  
Wolverine Tube, 1314-1315

**TUBING, Fabricated**  
Revere Copper and Brass Incorporated, 1313  
Wolverine Tube, 1314-1315

**TUBING, Finned**  
G & O Mfg. Co., The, 1362  
General Automatic Products Corp., 1513  
Kritzer Radiant Coils, Inc., 1514  
Rittling Corp., The, 1364  
Rome-Turney Radiator Co., The, 1365  
Wolverine Tube, 1314-1315

**TUBING, Flexible**  
Wiremold Co., The, 1469

**TUBING, Flexible, Metallic**  
Aeroquip Corp., 1312  
American Brass Co., The, 1310-1311  
Flexonics Corp., 1507

**TUBING, Insulation** (See Insulation, Tubing)

**TUBING, RESTRICTOR**  
American Brass Co., The, 1310-1311  
Wolverine Tube, 1314-1315

**TUBING, Steel**  
Revere Copper and Brass Incorporated, 1313  
Wolverine Tube, 1314-1315

**TUBING, Unicellular Rubber**  
B. F. Goodrich, Sponge Products Div., 1883

**TURBINES**  
Pyle-National Co., The, 1454-1455  
L. J. Wing Mfg. Co., 1302-1303  
Worthington Corp., 1241

**UNDERGROUND PIPE CONDUITS** (See Conduits, Underground Pipe)

**UNIT HEATERS** (See Heaters, Unit)

**UNIT STEAM GENERATORS**  
(See Steam Generators, Unit)

**UNIT VENTILATORS** (See Ventilators, Unit)

**UNITS, Air Conditioning** (See Air Conditioning Units)

**VACUUM HEATING SYSTEMS**  
(See Heating Systems, Vacuum)

**VALVES, Air**  
V. D. Anderson Co., The, 1612-1613  
Crane Co., 1528-1529  
Desomat Products, Inc., 1223  
C. A. Dunham Co., 1618-1621  
Fairbanks Co., The, 1641  
Hammond Brass Works, 1642  
Hoffman Specialty Mfg. Corp., 1622-1625  
Jenkins Bros., 1643  
Jas. P. Marsh Corp., 1628-1629

**VALVES, Angle, Globe and Cross**  
Crane Co., 1528-1529  
Fairbanks Co., The, 1641  
Frick Co., 1371  
Hammond Brass Works, 1642  
Henry Valve Co., 1482  
Jenkins Bros., 1643

**VALVES, Automatic**  
Barber-Colman Co., 1437, 1473  
A. W. Cash Co., 1617  
Combustion Control Div., Electronics Corp. of America, 1475  
Dole Valve Co., 1640  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
Hubbell Corp., The, 1483  
Johnson Service Co., 1484-1485  
Leslie Co., 1487  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498  
Sarcotherm Controls, Inc., 1633  
White-Rodgers Electric Co., 1504

**VALVES, Back Pressure**  
Aco Valve Co., 1472  
A. W. Cash Co., 1617  
Hubbell Corp., The, 1483  
Illinois Engineering Co., 1626-1627

**VALVES, Balancing**  
Hammond Brass Works, 1642

**VALVES, Gate**  
Crane Co., 1528-1529

**VALVES, Gas**  
Combustion Control Div., Electronics Corp. of America, 1475  
Fairbanks Co., The, 1641  
Hammond Brass Works, 1642  
Jenkins Bros., 1643  
Penn Controls, Inc., 1494  
White-Rodgers Electric Co., 1504

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

Hoffman Specialty Mfg. Corp., 1622-1625  
Illinois Engineering Co., 1626-1627  
Johnson Service Co., 1484-1485  
Maid-O'-Mist Inc., 1630-1632  
Sarco-Sarcotherm, 1633-1635  
H. A. Thrush & Co., 1600-1601

**VALVES, Blowoff**  
Fairbanks Co., The, 1641  
Jenkins Bros., 1643

**VALVES, By-Pass**  
Henry Valve Co., 1482  
Jenkins Bros., 1643  
Johnson Service Co., 1484-1485

**VALVES, Check**  
Fairbanks Co., The, 1641  
Hammond Brass Works, 1642  
Henry Valve Co., 1482  
Hubbell Corp., The, 1483  
Jenkins Bros., 1643

**VALVES, Corrosion Resisting**  
Crane Co., 1628-1629  
Jenkins Bros., 1643

**VALVES, Diaphragm**  
A. W. Cash Co., 1617  
Crane Co., 1528-1529  
General Controls, 1480-1481  
Henry Valve Co., 1482  
Hubbell Corp., The, 1483  
Johnson Service Co., 1484-1485  
Powers Regulator Co., The, 1496-1498  
Taylor Instrument Cos., 1503  
White-Rodgers Electric Co., 1504

**VALVES, Expansion**  
Aco Valve Co., 1472  
Crane Co., 1528-1529  
Henry Valve Co., 1482

**VALVES, Float**  
Aco Valve Co., 1472  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
Hubbell Corp., The, 1483  
Illinois Engineering Co., 1626-1627  
Maid-O'-Mist, Inc., 1630-1632  
McDonnell & Miller, Inc., 1570-1573

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
H. A. Thrush & Co., 1600-1601  
Warren Webster & Co., 1638-1639

**VALVES, Flow Control**  
Bell & Gossett Co., 1598-1599  
Crane Co., 1528-1529  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton-Sylphon Div., The Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1



Fairbanks Co., The, 1641  
Hammond Brass Works, 1642  
Jenkins Bros., 1643

**VALVES, Humidifier**  
Maid-O'-Mist, Inc., 1630-1632  
McDonnell & Miller, Inc., 1570-1573

**VALVES, Hydraulic**  
A. W. Cash Co., 1617  
Jenkins Bros., 1643

**Valves, Magnetic**  
Alco Valve Co., 1472  
General Controls, 1480-1481  
Hubbell Corp., The, 1483  
McDonnell & Miller, Inc., 1570-1573  
Milwaukee Gas Specialty Co., 1492  
Penn Controls, Inc., 1494

**VALVES, Mixing, Thermostatic**  
Dole Valve Co., 1640  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635

**VALVES, Motor Operated**  
Barber-Colman Co., 1437, 1473  
Bell & Gossett Co., 1598-1599  
Desomatic Products, Inc., 1228  
General Controls, 1480-1481  
Hoffman Specialty Mfg. Corp., 1622-1623  
Illinois Engineering Co., 1626-1627  
Jenkins Bros., 1643  
Johnson Service Co., 1484-1485  
Milwaukee Gas Specialty Co., 1492  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Warren Webster & Co., 1638-1639

**VALVES, Non-Return**  
Fairbanks Co., The, 1641  
Hammond Brass Works, 1642  
Illinois Engineering Co., 1626-1627  
Jenkins Bros., 1643

**VALVES, Packless**  
C. A. Dunham Co., 1618-1619  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
Henry Valve Co., 1482  
Hoffman Specialty Mfg. Corp., 1622-1623  
Illinois Engineering Co., 1626-1627  
Johnson Service Co., 1484-1485  
Jas. P. Marsh Corp., 1628-1629  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502

**VALVES, Pressure Reducing (See Regulators, Pressure)**

**VALVES, Radiant Heating**  
Hammond Brass Works, 1642  
Sarcotherm Controls, Inc., 1633  
H. A. Thrush & Co., 1600-1601

**VALVES, Radiator**  
American Radiator & Standard Sanitary Corp. (Plumbing & Heating Div.), 1523-1525  
Barnes & Jones, Inc., 1616

Crane Co., 1528-1529  
Dole Valve Co., The, 1640  
C. A. Dunham Co., 1618-1621  
Fairbanks Co., The, 1641  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
Hammond Brass Works, 1642  
Hoffman Specialty Mfg. Corp., 1622-1623  
Illinois Engineering Co., 1626-1627  
Jenkins Bros., 1643  
Maid-O'-Mist, Inc., 1630-1632  
Jas. P. Marsh Corp., 1628-1629  
Minneapolis-Honeywell Regulator Co., 1490-1491  
National-U. S. Radiator Corp., 1530-1533  
Powers Regulator Co., The, 1496-1498  
Sarco Co., Inc., 1634-1635  
Sterling, Inc., 1502  
Trane Co., The, 1298-1301  
Warren Webster & Co., 1638-1639

**VALVES, Radiator, Convactor**  
Powers Regulator Co., The, 1496-1498

**VALVES, Radiator, Humidifying**  
Maid-O'-Mist, Inc., 1630-1632

**VALVES, Radiator Orifice**  
Barnes & Jones, Inc., 1616  
C. A. Dunham Co., 1618-1621  
Hammond Brass Works, 1642  
Illinois Engineering Co., 1626-1627  
Sarco Co., Inc., 1634-1635  
Warren Webster & Co., 1638-1639

**VALVES, Radiator, Pneumatic Diaphragm**  
Johnson Service Co., 1484-1485  
Minneapolis-Honeywell Regulator Co., 1490-1491  
Powers Regulator Co., The, 1496-1498

**VALVES, Reducing**  
Bell & Gossett Co., 1598-1599  
A. W. Cash Co., 1617  
Crane Co., 1528-1529  
C. A. Dunham Co., 1618-1621  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
Hoffman Specialty Mfg. Corp., 1622-1623  
Illinois Engineering Co., 1626-1627  
Leslie Co., 1487  
Strong, Carlisle & Hammond Co., 1637  
H. A. Thrush & Co., 1600-1601

**VALVES, Refrigerant Line**  
Aeroquip Corp., 1312  
Alco Valve Co., 1472  
Hammond Brass Works, 1642  
Henry Valve Co., 1482  
Worthington Corp., 1241  
York Corp., 1242

**VALVES, Relief**  
V. D. Anderson Co., The, 1612-1613  
Bell & Gossett Co., 1598-1599  
A. W. Cash Co., 1617  
C. A. Dunham Co., 1618-1621  
Henry Valve Co., 1482  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Monarch Mfg. Works, Inc., 1357  
Taco Heaters, Inc., 1602  
H. A. Thrush & Co., 1600-1601  
Trane Co., The, 1298-1301  
York Corp., 1242

**VALVES, Safety**  
Combustion Control Div., Electronics Corp. of America, 1475  
Frick Co., 1371  
General Controls, 1480-1481  
Henry Valve Co., 1482  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573

**VALVES, Solenoid**  
Alco Valve Co., 1472  
Combustion Control Div., Electronics Corp. of America, 1475  
General Controls, 1480-1481  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Milwaukee Gas Specialty Co., 1492  
Penn Controls, Inc., 1494  
Spence Engineering Co., Inc., 1501  
White-Rodgers Electric Co., 1504

**VALVES, Stop and Check (See Valves, Non-Return)**

**VALVES, Tempering**  
Dole Valve Co., The, 1640  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
General Fittings Co., 1596  
Powers Regulator Co., The, 1496-1498  
Taco Heaters, Inc., 1602

**VALVES, Thermostatic**  
Alco Valve Co., 1472  
Barber-Colman Co., 1437, 1473  
Crane Co., 1528-1529  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
General Controls, 1480-1481  
Hoffman Specialty Mfg. Corp., 1622-1623  
Illinois Engineering Co., 1626-1627  
Jas. P. Marsh Corp., 1628-1629  
Powers Regulator Co., The, 1496-1498  
Spence Engineering Co., Inc., 1501  
Sterling, Inc., 1502

**VALVES, Water Flow Regulating**  
Bell & Gossett Co., 1598-1599  
Dole Valve Co., The, 1640  
C. A. Dunham Co., 1618-1621  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
Hoffman Specialty Mfg. Corp., 1622-1623  
Leslie Co., 1487  
McDonnell & Miller, Inc., 1570-1573  
Powers Regulator Co., The, 1496-1498  
Spence Engineering Co., 1501  
Taco Heaters, Inc., 1602  
H. A. Thrush & Co., 1600-1601

**VALVES, Water Level, Float Control**  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479  
Maid-O'-Mist, Inc., 1630-1632  
McDonnell & Miller, Inc., 1570-1573

**VALVES, Water Regulating**  
Alco Valve Co., 1472  
Dole Valve Co., 1640  
C. A. Dunham Co., 1618-1621  
Fulton Sylphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479

Hammond Brass Works, 1642  
Jenkins Bros., 1643  
Leslie Co., 1487  
Jas. P. Marsh Corp., 1628-1629  
McDonnell & Miller, Inc., 1570-1573  
Packard Water Conditioner Div., Packard Mfg. Co., 1575  
Penn Controls, Inc., 1494  
Powers Regulator Co., The, 1496-1498  
Spence Engineering Co., 1501

**VANES, Air Turning**  
Duro-Dyne Corp., 1466-1467  
Elgen Mfg. Corp., 1468  
Louvre Mfg. & Sales Co., 1452  
Miracle Adhesives Corp., 1654

**VAPOR BARRIERS**  
Philip Carey Mfg. Co., 1656-1657  
L-O-F Glass Fibers Co., 1655  
Infra Insulation, Inc., 1679  
Reflectal Corp., 1682  
Silvercote Products, Inc., 1680-1681

**VAPOR HEATING SYSTEMS (See Heating Systems, Vapor)**

**VENT FLUE CAPS (See Caps, Vent Flue)**

**VENT PIPE, Gas or Vents, Gas (See Pipe, Gas Vent, Ducts, Fume Disposal)**

**VENTILATING DUCTS (See Ducts, Ventilating)**

**VENTILATING SKYLIGHTS (See Skylights, Metal and Ventilating)**

**VENTILATORS, Attic (See Fans, Electric, Propeller, Supply and Exhaust)**  
Air Control Products, Inc., 1428-1431  
Allen Cooler & Ventilator, Inc., 1414  
American Blower Corp., 1220-1221  
G. C. Breidert Co., 1416  
Bronson Fan Mfg. Corp., 1378  
Brookside Products Co., Inc., 1379  
Century Fan & Ventilator Co., 1384  
Champion Blower & Forge Co., 1385  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
General Blower Co., 1391  
Genie-Air, Inc., 1418-1419  
Ilg Electric Ventilating Co., 1287, 1393  
Lau Blower Co., The, 1396-1397  
Reed Unit-Fans, Inc., 1402  
Torrington Mfg. Co., The, 1406-1407  
Trade-Wind Motorfans, Inc., 1405  
Western Engrg. & Mfg. Co., 1424  
L. J. Wing Mfg. Co., 1302-1303

**VENTILATORS, Ceiling**  
Genie-Air, Inc., 1418-1419  
Trade-Wind Motorfans, Inc., 1405

**VENTILATORS, Floor and Wall**  
A-J Mfg. Co., 1426-1427  
Aerovent Fan Co., Inc., 1374  
Air Control Products, Inc., 1428-1431  
C. L. Ammerman Co., 1415  
G. C. Breidert Co., 1416  
Gallaher Co., The, 1417  
Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Penn Ventilator Co., 1422  
Westinghouse Electric Corp., Sturtevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

Ilg Electric Ventilating Co., 1287, 1393  
Independent Register Co., The, 1448  
Knives Mushroom Ventilator Co., 1449  
Lima Register Co., 1450-1451  
Louvre Mfg. & Sales Co., 1452  
Penn Ventilator Co., 1422  
Propellair Div., Robbins & Myers, Inc., 1401  
Reed Unit-Fans, Inc., 1402  
Register & Grille Mfg. Co., Inc., 1453  
Titus Mfg. Corp., 1458-1459  
Trane Co., The, 1298-1301  
United States Register Co., 1462-1463  
Universal Diffuser Corp., 1464  
Waterloo Register Co., Inc., 1465

**VENTILATORS, Laboratory**  
Gallaher Co., The, 1417  
Kewanee Mfg. Co., 1411  
Muckle Mfg. Co., 1421  
E. H. Sheldon Equipment Co., 1412-1413

**VENTILATORS, Roof**  
Aerovent Fan Co., Inc., 1374  
Air Control Products, Inc., 1428-1431  
Air Devices, Inc., 1316, 1432  
Aladdin Heating Corp., 1375  
Allen Cooler & Ventilator, Inc., 1414  
American Blower Corp., 1220-1221  
American Foundry & Furnace Co., 1266-1267  
American 3 Way-Luxfer Prism Co., 1600  
C. L. Ammerman Co., 1415  
Bishop & Babcock Mfg. Co., The, 1377  
G. C. Breidert Co., 1416  
Brookside Products Co., Inc., 1379  
Buffalo Forge Co., 1382  
Century Fan & Ventilator Co., 1384  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
Gallaher Co., The, 1417  
General Blower Co., 1391  
Genie-Air, Inc., 1418-1419  
Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Hirschman-Pohle Co., Inc., 1420  
Ilg Electric Ventilating Co., 1287, 1393  
Muckle Mfg. Co., 1421  
New York Blower Co., 1399  
Peerless Electric Co., The, 1400  
Penn Ventilator Co., 1422  
Propellair Div., Robbins & Myers, Inc., 1401  
Sheldons Engineering Ltd., 1404  
Swartwout Co., The, 1423  
Trade-Wind Motorfans, Inc., 1405  
Trane Co., The, 1298-1301  
Western Engrg. & Mfg. Co., 1424  
Westinghouse Electric Corp., Sturtevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

**VENTILATORS, Ship**  
Air Devices, Inc., 1316, 1432  
C. L. Ammerman Co., 1415  
G. C. Breidert Co., 1416  
Gallaher Co., The, 1417  
Hartzell Propeller Fan Co., Div. of Castle Hills Corp., 1392  
Penn Ventilator Co., 1422  
Westinghouse Electric Corp., Sturtevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

**VENTILATORS, Smoke**  
American 3 Way-Luxfer Prism Co., 1660

**VENTILATORS, Unit**  
Aerovent Fan Co., Inc., 1374  
Air & Refrigeration Corp., 1219  
Allen Cooler & Ventilator, Inc., 1414  
American Blower Corp., 1220-1221  
C. L. Ammerman Co., 1415  
Brookside Products Co., Inc., 1379  
DeBothezat Fans Div., American Machine & Metals, Inc., 1388-1389  
General Blower Co., 1391  
Genie Air, Inc., 1418-1419  
Ilg Electric Ventilating Co., 1287, 1393  
Muckle Mfg. Co., 1421  
Herman Nelson, American Air Filter Co., Inc., 1296-1297  
John J. Nesbitt, Inc., 1293-1295  
Propellair Div., Robbins & Myers, Inc., 1401  
Rittling Corp., The, 1364  
Swartwout Co., The, 1423  
Trade-Wind Motorfans, Inc., 1405  
Trane Co., The, 1298-1301  
Westinghouse Electric Corp., Sturtevant Div., 1410  
L. J. Wing Mfg. Co., 1302-1303

**VENTILATORS, Wall**  
Allen Cooler & Ventilator, Inc., 1414

**VENTILATORS, Window**  
Ilg Electric Ventilating Co., 1287, 1393  
Lau Blower Co., The, 1396-1397  
Muckle Mfg. Co., 1421  
Reed Unit-Fans, Inc., 1402  
L. J. Wing Mfg. Co., 1302-1303

**VERMICULITE (See Insulation)**

**VIBRATION ABSORBERS (See Sound Densifying)**  
American Brass Co., The, 1310-1311  
Celotex Corp., The, 1666  
T. R. Finn & Co., Inc., 1686  
Flexonics Corp., 1507  
Korfund Co., Inc., The, 1687  
Lockport Mills, Inc., 1674  
Vibration Mountings, Inc., 1688

**VIBRATION ISOLATORS**  
Elgen Mfg. Corp., 1468  
T. R. Finn & Co., 1686  
Korfund Co., Inc., The, 1687  
Vibration Mountings, Inc., 1688

**VITRIFIED CLAY PIPE (See Pipe, Vitrified Clay, Heating Ducts)**

**WALLBOARD ANCHORS AND ADHESIVES**  
Devises, Inc., 1654  
Miracle Adhesives Corp., 1654

**WALLBOARD, Insulating**  
Celotex Corp., The, 1666  
Insulite, 1668-1669  
Johns-Manville, 1670-1671  
Wood Conversion Co., 1677

**WARM AIR FURNACES (See Furnaces, Warm Air)**

**WARM AIR HEATING SYSTEM (See Heating Systems, Furnace)**

**WASHERS, Air (See Air Washers)**

**WATER CONDITIONING EQUIPMENT**

Packard Water Conditioner Div., Packard Mfg. Co., 1575

**WATER COOLING** (See *Cooling Equipment, Water, Cooling Towers*)

Acme Industries, Inc., 1358

Aerofin Corp., 1359-1361

Airtemp Div., Chrysler Corp., 1248-1249

Baltimore Aircoil Co., Inc., 1346

Binks Mfg. Co., 1344-1345

Brunner Mfg. Co., 1368

Carrier Corp., 1226-1227

Curtis Mfg. Co., Refrigeration Div., 1370

Fluor Corp., Ltd., The, 1347

E. D. Goodfellow, Inc., 1348

Governair Corp., 1232

Halstead &amp; Mitchell, 1350-1351

Havens Structural Steel Co., 1349

Heller Laboratories, Inc., 1352

Hydraline Products, Div. Borg-Warner Corp., 1251

Kennard Corp., 1234

Lillie-Hoffman Cooling Towers, Inc., 1353

Marley Co., The, 1354

Marlo Coil Co., 1355

McQuay, Inc., 1289-1289

Modine Mfg. Co., 1290-1291

John J. Nesbitt, Inc., 1293-1295

Niagara Blower Co., 1235

Packard Water Conditioner Div., Packard Mfg. Co., 1575

Patterson-Kelley Co., Inc., The, 1363

Phillips Cooling Tower Co., Inc., 1356

Servel, Inc., 1262-1263

Trane Co., The, 1298-1301

Westinghouse Electric Corp., Air Conditioning Div., 1240

Worthington Corp., 1241

York Corp., 1242

Young Radiator Co., 1304

**WATER COOLING, Spray Systems**

Air &amp; Refrigeration Corp., 1219

April Showers, Co., Inc., 1644

Binks Mfg. Co., 1344-1345

Copeland Refrigeration Corp., 1369

Muellermist Irrigation Co., 1645

Niagara Blower Co., 1235

Pittsburgh Electrodryer Corp., 1238

Refrigeration Engineering, Inc., 1373

Trane Co., The, 1298-1301

Westinghouse Electric Corp., Air Conditioning Div., 1240

York Corp., 1242

**WATER COOLING TOWERS**(See *Cooling Towers, Water*)**WATER FEEDERS** (See *Feeders, Boiler Water*)**WATER HEATERS** (See *Heaters, Hot Water Service*)**WATER LEVEL CONTROLS** (See *Controls, Water Level*)**WATER MIXERS, Thermostatic**(See *Valves, Tempering*)

Bell &amp; Gossett Co., 1598-1599

Dole Valve Co., The, 1640

Fulton Syphon Div., The, Robertshaw-Fulton Controls Co., 1478-1479

Powers Regulator Co., The, 1496-1498

Taco Heaters, Inc., 1602

**WATER TREATMENT**

Heller Laboratories, Inc., 1352

Packard Water Conditioner Div., Packard Mfg. Co., 1575

Worthington Corp., 1227

**WELDERS, Spot**

Duro Dyne Corp., 1466-1467

**WELDING FITTINGS** (See *Fittings, Welding*)**WELDING RINGS** (See *Rings, Welding*)**WELDING ROD**

American Brass Co., The, 1310-1311

Revere Copper and Brass Incorporated, 1313

**WHEELS, Blower**

Aerovent Fan Co., Inc., 1374

Airfan Engineering Co., 1343

Bishop &amp; Babcock Mfg. Co., The, (Massachusetts Blower Div.), 1377

Brookside Products Co., Inc., 1379

Brundage Co., The, 1380-1381

Champion Blower &amp; Forge Co., 1385

Clarage Fan Co., 1225, 1387

Garden City Fan Co., 1390

General Blower Co., 1391

Lau Blower Co., The, 1396-1397

Morrison Products, Inc., 1398

Peerless Electric Co., The, 1400

Revcor, 1403

Torrington Mfg. Co., The, 1406-1407

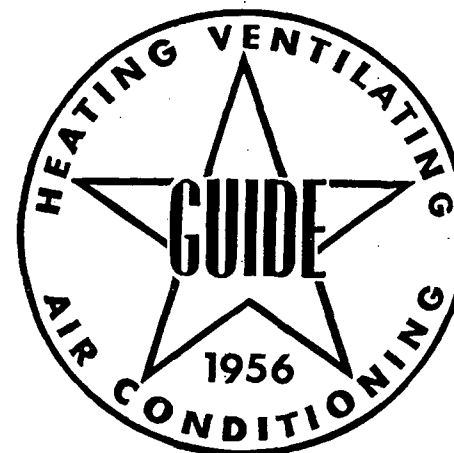
Viking Air Products, Div. National-U. S. Radiator Corp., 1408

WHEELS, Spray (See *Spray Equipment*)**WINDOWS, Fire Observation**

Detroit Stoker Co., 1568

# MANUFACTURERS' CATALOG DATA

(PAGES 1219-1696)





On pages 1219-1696 will be found the Catalog Data of 335 manufacturers whose products are described and illustrated.

For the convenience of the user of THE GUIDE 1956 there are eleven main divisions:

|                                          |           |
|------------------------------------------|-----------|
| Air Conditioning.....                    | 1219-1309 |
| Air Conditioning and Heating Piping..... | 1310-1315 |
| Air System Equipment.....                | 1316-1471 |
| Controls and Instruments.....            | 1472-1504 |
| Expansion Joints.....                    | 1505-1507 |
| Fittings and Flanges.....                | 1508-1511 |
| Floats.....                              | 1512      |
| Heating Systems.....                     | 1513-1643 |
| Insulation.....                          | 1644-1685 |
| Vibration.....                           | 1686-1688 |
| Publications.....                        | 1689-1695 |

On pages 1187-1216, under each of the index headings—Air Cleaning Equipment, Fans, Humidifiers, Ventilators, etc., will be found a list of manufacturers of any desired products, fully cross-indexed, and the page numbers in the Catalog Data Section where the products are described.

By reference to these indices, the manufacturers' names and the page numbers, any item of equipment or materials, and the producer's address, may be located quickly.

## Air & Refrigeration Corporation

439 Madison Avenue, New York 22, N. Y.

271 Milton Avenue, S. E., Atlanta, Ga.

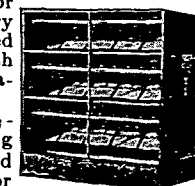
Representatives in all major cities  
Air Conditioning, Humidifying, Dehumidifying, Cooling,  
Scrubbing, Air Washing and Purification Apparatus



Air & Refrigeration Corporation specializes in the design and manufacture of industrial and comfort-conditioning apparatus where maintenance of suitable humidity and temperature within closely controllable limits is essential. This specialization is based on technical knowledge and ingenuity born of extensive experience in the solution of the more difficult problems of air conditioning. A complete line of air conditioning equipment is available to contractors and owners for all phases of humidifying, dehumidifying, cooling and washing.

\* Capillary Air Washers provide a superior type humidifying, dehumidifying, air washing, cleaning and cooling unit for central station apparatus. For most purposes the Capillary Washer requires  $\frac{1}{2}$  the volume of water at  $\frac{1}{2}$  the pressure used by conventional spray equipment. They are available with factory insulated casings and tank for central station applications. For complete data, see Capillary Bulletin.

\* Capillary Unit Conditioners are factory insulated and assembled, ready for use. They include fan, motor, drive, heating coils, Capillary Cells with suitable sprays, spray pump and mixing dampers. Units are designed for floor mounting or for ceiling suspension, and can be arranged for the reception of cooling coils, if required. Complete description and engineering data will be found in Capillary Unit Bulletin.



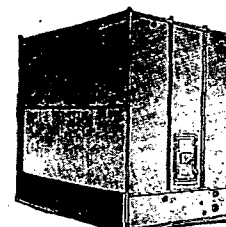
Factory Insulated Class I  
Capillary Air Washer

Spray Type Air Washers for washing, humidifying and dehumidifying air are all basically the same. A & R Spray Washers include special features of design developed to insure more efficient and dependable operation, lower maintenance costs, and, in many cases, lower installation costs. Such features relate especially to eliminators, collecting tanks, flooded baffles, nozzle arrangement, etc. Spray Washers can be supplied with factory insulated casings and tank for central station applications. For details, see Air Washer Bulletin.

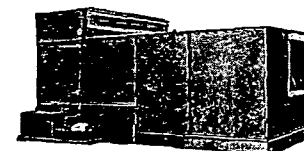
Sprayed Coil Dehumidifiers for year-round treatment of air are complete with cooling coils, sprays, circulating pump and glass mat eliminators. Sprayed coil dehumidifiers are factory insulated and complete, ready for assembly in the field. Special features in design insure continuous washing and cleaning of finned surfaces and easy accessibility to all parts. For engineering information and detailed description, see Sprayed Coil Bulletin.

A & R Insulated Panels consist of insulation between metal sheet on one side and hard fiber board on the other, the three laminated and cemented together. This unique panel design includes the structural frame to form units which require only bolting together to make enclosures of any required shape for plenum chambers and many other purposes. Panels are available in widths from 3 in. to 48 in., and in lengths to 12 ft. Their use insures tremendous economies in field labor. For details, see Panel Bulletin. Write for catalog and engineering data.

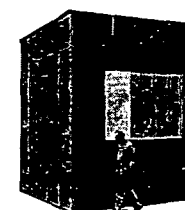
\*Registered Trade Mark



Type 2S Air Washer  
Factory Insulated



Factory Insulated Size #3-4  
Capillary Unit Conditioner



Factory Insulated  
Plenum Chamber

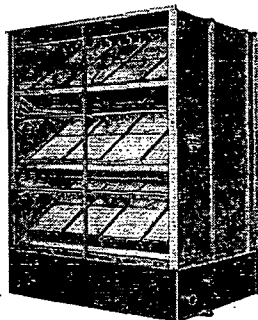
## American Blower Corporation



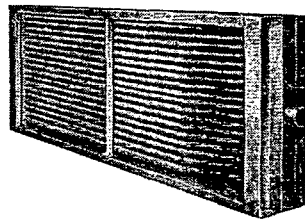
Detroit 32, Michigan  
CANADIAN SIROCCO COMPANY, LTD.  
310 Ellis Street, Windsor, Ontario  
Branch Offices in Principal Cities

Division of AMERICAN - Standard

AIR CONDITIONING — HUMIDIFYING — DEHUMIDIFYING — COOLING  
— VENTILATING — HEATING — VAPOR-ABSORPTION — DRYING — AIR  
WASHING AND PURIFICATION — EXHAUSTING EQUIPMENT AND  
MECHANICAL DRAFT APPARATUS

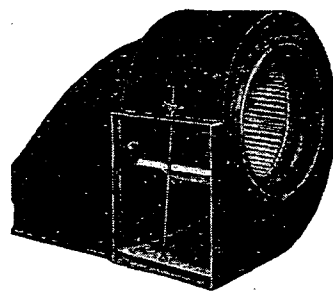


Capillary Air Washers—above, for high efficiency in cleaning, humidification, cooling and dehumidification of air. Air is forced at low resistance through long, irregular passages of small size formed by a large amount of thoroughly wetted glass surface. Write for *Bulletin 4023*.

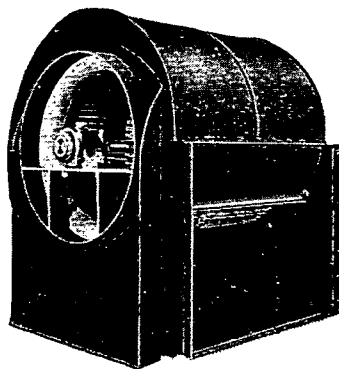


Heating & Cooling Coils—above, American Blower heating and cooling coils offer a number of improvements in design and construction. Available in a complete range of sizes and types, including:

- Bulletin B-1218** Type S steam coils  
Type D double tube coils  
Type U return blend coils  
Type B booster coils  
Type W water coils  
Type C cleanable water coils  
Type X direct expansion coils  
**Bulletin B-1318** Type H heavy duty coils



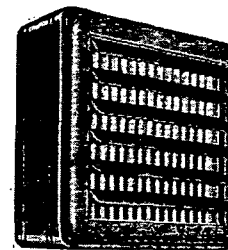
"ABC" Utility Sets—complete packaged units, directly connected or V-belt short coupled drive for duct applications. Equipped with Aileron Control consisting of scroll sheet adjusted by connecting rod. Fan outlet is modified to give efficient operation over a wide range of air volumes and pressures. Sizes for a wide variety of ventilating problems. Quiet, compact. Complete technical information in *Bulletin 2814*.



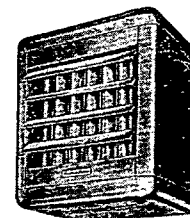
Double Inlet "ABC" Multiblade Fan—above, is a heavy duty ventilating fan. The wheel has narrow, forward pitched blades. Low tip speeds assure quiet operation. Request *Bulletin A-801*. *Bulletin A-603* describes backwardly inclined, nonoverloading HS Fan.

## TYPES OF AMERICAN BLOWER CORPORATION AIR HANDLING AND CONDITIONING EQUIPMENT

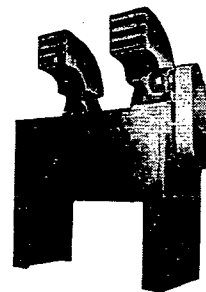
All types of air handling and air conditioning equipment for industrial applications, process work, drying, cooling; also equipment for stores, offices, shops, public buildings, power plants, etc., and attic and kitchen ventilation for homes.



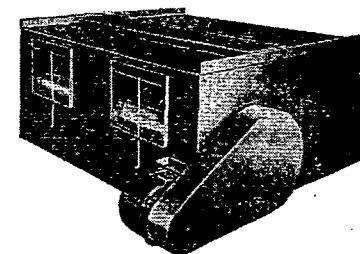
Unit Heaters—for many general purpose heating jobs. Wall or ceiling mounted. Streamline construction, rugged heating elements. Steam or hot water. Request *Bulletin 7517*.



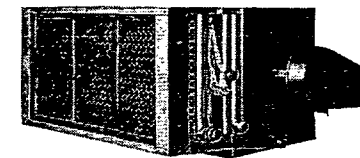
Gas Fired Unit Heater—self contained—for clean, automatic, instantaneous heating. Adjustable louvers assure efficient heat distribution throughout the work area. A. G. A approved. Write for *Bulletin 8517*.



Centrifugal Type Unit Heaters—for use with or without duct systems, for large hard to heat areas. Ideal for floor mounting. Request *Bulletin 7727*.



Heating and Ventilating Units—with air filters and Aileron control. Ideal wherever attractive, quiet and economical heating and ventilation units are required. Wall, floor or ceiling mounting. Offer great flexibility of design and arrangement to meet specific needs. *Bulletin 7227*.



American Blower Air Conditioning Units.—Three basic types are available in twelve sizes, with capacities from 600 to 48,000 cfm. Type A (shown) is designed for all normal unitary-type commercial and industrial applications: Summer cooling and dehumidifying, using chilled water, direct-expanded refrigerant, or brines; winter heating, using steam or hot water. Type S is same basic unit as Type A, plus spray system, water recirculating pump and eliminators; combines the washing, air cleaning, humidifying, and evaporative cooling of an air washer with the cooling and heating of the basic unit conditioner. Type AB Multi-Zone Unit is furnished in a single arrangement for either horizontal or vertical air flow. Plenum and diffusion device between fans and coils provides even air distribution over coils. Request *Bulletin 8427*.

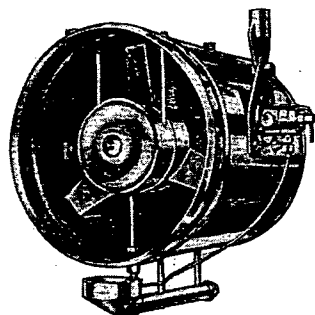
## American Moistening Company

Providence 1, R. I.

ATLANTA, GA. BOSTON, MASS. CAMDEN, N. J. CHARLOTTE, N. C.

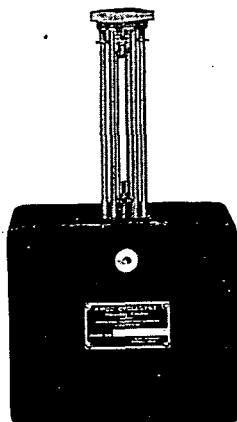
# AMCO

Humidification Systems since 1888



### AMCO ATOMIZER NO. 6

The automatically self-cleaning Amco No. 6 micro-spray atomizer delivers a smoke-like spray to a great distance for balanced distribution of humidity. Its fine performance and ease of maintenance make this atomizer popular for new installations and replacements. These units require compressed air for operation and obtain their water supply from a constant level, float controlled tank.



### AMCO MODEL 35 HUMIDIFIER

Ideally suited for areas of light heat concentration, especially where cost of other types of humidification might be prohibitive. Propeller-type fan draws room air into rear of unit and forces it forward around periphery of atomizer disc—thus carrying atomized water into room where it quickly evaporates into surrounding atmosphere. Housed in stainless steel. Requires only simple water and electrical connections. May be adjusted to evaporate from zero to 22 pounds of water per hour while circulating 1200 cu ft of air per minute. Simple and reliable, it requires a minimum of maintenance.



### AMCO CYCLESTAT HUMIDITY CONTROL

The Amco Cyclestat is easily adjusted and provides exceptionally fine control of relative humidity within limits heretofore believed impractical. This improvement comes from a unique "change anticipating mechanism" which employs jeweled bearings and a principle of operation that converts microscopic changes in its humidity sensing membranes into instantaneous control signals. When properly adjusted and located all variations from the selected relative humidity are immediately counteracted.

## THE *Bahnson* COMPANY • WINSTON-SALEM, N. C.

Air Conditioning • Humidification • Cleaning

1. **AIR WASHER**—Bahnson Type Y and Type DC Air Washers cleanse, cool, and provide humidity control. Available in standard sizes from 6,000 to 250,000 cfm, they can be provided with spray systems best suited for the specific application. Write for Catalog 1A

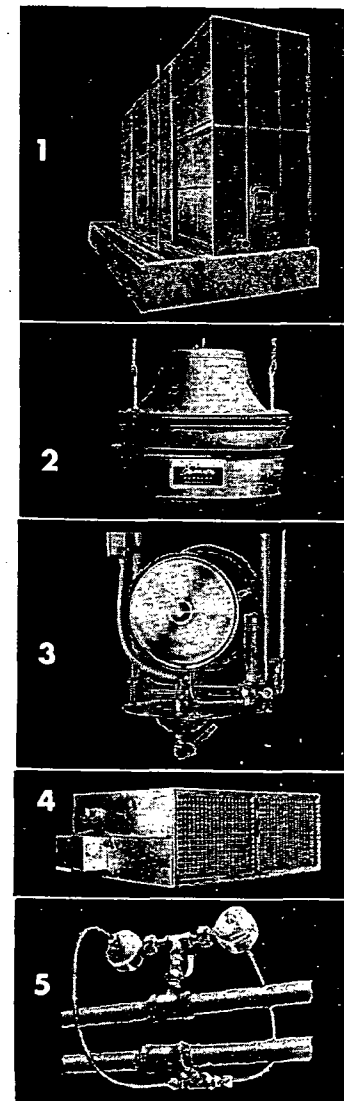
2. **TYPE E HUMIDIFIER**—A self-contained unit with high evaporative capacity for installation in all types of industrial and commercial spaces requiring automatically controlled humidification. Evaporates up to 3 gallons per hour with 360 degree radial distribution of moisture. Requires only water supply and electrical connection. Write for Catalog 16A

3. **CENTRIFUGAL HUMIDIFIER**—A self-contained unit for industrial use. Evaporation up to 12 gph plus directional air flow with fractional horsepower motor. Installed singly or in groups with individual or group automatic control. Requires only water supply, drain, and electrical connection. Write for Catalog 2A

4. **TYPE BA-2 HUMIDIFIER**—A high-capacity unit for overhead suspension in commercial and industrial applications. Adjustable grilles give complete directional control of moist air delivered. Automatically regulated, the unit provides air flow, humidification and filtering. Requires only water supply, drain, and electrical connection; capacity up to 18 gph. Write for Catalog 17A

5. **TYPE ESC-2 ATOMIZER**—A self-cleaning pneumatic atomizer of superior design for direct humidification or supplementary evaporation. Uses air and water under pressure to provide high evaporation and fine spray quality, with minimum air requirements. Modulating control regulates evaporation in direct proportion to the room requirements. Write for Catalog 3A

Other equipment manufactured by Bahnson includes: portable humidifiers, steam humidifiers, air washer suction strainers, spray nozzles, automatic controls, grilles and complete industrial air conditioning systems. Write for descriptive literature on your requirements.



## BUENSOD-STACEY

60 East 42 St.

Richmond, Va.

New York 17, N. Y.

Charlotte, N. C.

Air Conditioning, Humidifying, Cooling, Ventilation Systems

**DUAL DUCT AIR CONDITIONING SYSTEMS.** In multi-story buildings with many separated occupied spaces, Dual Duct air conditioning allows each occupant to select the temperature at which he is most comfortable. For example, it allows one space to be cooled while an adjacent one is being heated. Air does all heating and cooling and insures proper ventilation.

Buensod-Stacey has devoted many years in the development of design techniques and apparatus improvement. In this long study it became apparent that the basic requirement of such a system is constant air flow to all areas. To accomplish this, air mixing units, each with self-contained volume regulators requiring no outside source of power, were developed for use in Dual Duct systems.

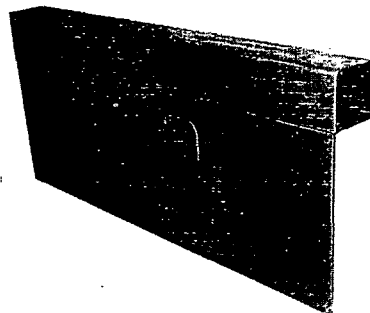
**TYPE V3 DUAL DUCT AIR MIXING AND DISTRIBUTING UNITS** are made in three parts for installation under windows or against walls. They supply air vertically through high velocity outlets. Mixing unit V3 contains pneumatically operated air mixing valve and self-contained volume controller. To this is attached a distributing header, VD, which can be varied in length to suit window width or building module. Part VFC provides a flush, finished front for the entire area under the distributing header and can also be varied in height and length to accommodate the space.

**TYPE H DUAL DUCT AIR MIXING UNITS** have a wider range of sizes than Type V3 and are designed for overhead or under-floor installation. Each one includes an automatic, pneumatically operated, air mixing valve, and self-contained volume controller. The units are arranged to supply air to conditioned spaces through conventional grilles, registers, or diffusers.

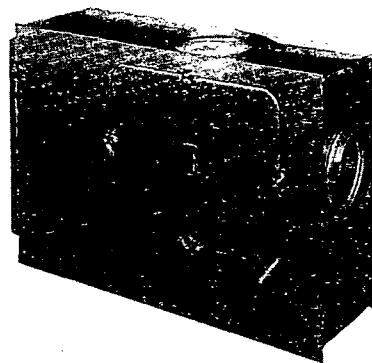
**BUENSOD-STACEY HIGH PRESSURE DEHUMIDIFIERS** for use in high pressure Dual Duct systems have been developed. A series of specially braced, factory insulated, sprayed coil dehumidifiers for use with pressure up to 10 in. wg are described in Bulletin DD-1.



Dual Duct Air Mixing and Distributing Units Under Windows



Type V3 Air Mixing Unit complete with Distributing Header and Front Cover



Type H Air Mixing Unit

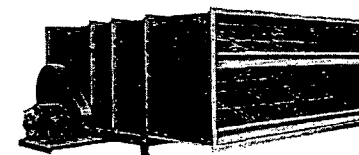
## CLARAGE

**CLARAGE FAN COMPANY**  
Kalamazoo, Mich.

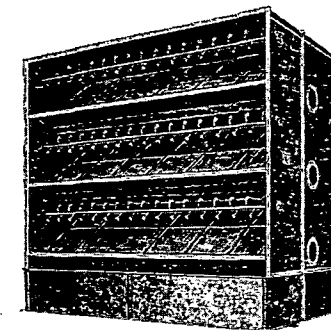
Air Handling and Conditioning Equipment  
Application Engineering Offices in All Principal Cities

For nearly a half century Clarage has been a leading manufacturer of equipment and units for ventilating, exhausting, cooling, air cleaning, humidifying and complete conditioning. Clarage equipment is designed to meet all types of industrial, commercial and public building requirements. For other equipment in the complete Clarage line see "Air System Equipment—Fans and Blowers."

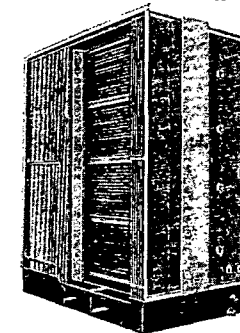
Clarage Multitherms cool and dehumidify in summer, heat and humidify in winter. For comfort applications and process conditioning. Vertical and horizontal types, 10 sizes, capacities 600 to 20,500 cfm.



Clarage Air Washers are built in both capillary and spray types. Sizes range from 2000 to 193,000 cfm. Used for air cleaning, humidifying and dehumidifying purposes. Special constructions can be furnished.



Clarage Unicoil Units are ideal as an integral part of a central station system for heating or cooling, or both; or for complete air conditioning in comfort applications. Wide size range.



We welcome your inquiry on any air handling or conditioning problem. Contact our nearest branch office, or write us at Kalamazoo, Michigan.

## Carrier Corporation • Syracuse 1, N. Y.

### MARINE DIVISION:

385 Madison Ave.  
New York 17, N. Y.

**Carrier**

### INTERNATIONAL DIVISION

385 Madison Ave.  
New York 17, N. Y.

Offices and Dealers in principal cities—refer to your telephone directory.

## **Carrier** AIR CONDITIONING

**Weathermakers**—completely self-contained air conditioners for commercial and industrial applications. Six sizes from 2 to 15 hp cooling capacity.

**Year-Round Weathermakers**—for heating and cooling in residential and commercial applications. Compact, efficient gas heating combined with summer cooling. Six combination sizes.

**Room Weathermakers**—fan-coil units for use with remote sources of refrigeration and heat. Each unit operates independently permitting individual room temperature control. Units are available in  $\frac{1}{2}$ , 1 and  $1\frac{1}{2}$  ton capacities with or without cabinets.

**Zoning Weathermakers**—blow-through fan-coil units for air conditioning systems using remote sources of heat and refrigeration. Six sizes for comfort and industrial applications, 6 to 80 tons.

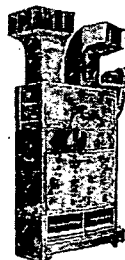
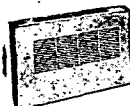
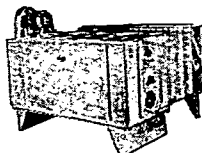
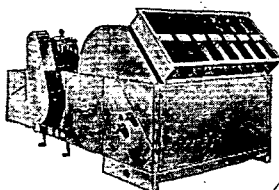
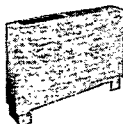
**System Weathermakers**—fan-coil unitary air conditioners for applications to central cooling and heating systems for comfort and industrial use. Seven sizes from 5 to 125 tons, 2,000 to 23,000 cfm.

**Central Station Air Conditioners**—for application with fan and duct systems for large spaces such as stores, theatres, auditoriums and industrial plants.

**Weathermaster Systems**—for air conditioning of multi-story, multi-room buildings such as hotels, hospitals, office and apartment buildings. System consists of room units with individual temperature control, and central station air conditioning. Conditioned air distributed by high velocity conduits to individual Weathermaster units shown.

**Blast Freezers and Cold Diffusers**—for food freezing and storage, meat packing operations, and other industries requiring low temperatures. Units available in suspension or floor models, for use within space to be refrigerated or remotely located and connected by ducts.

Write for descriptive literature.



## **Carrier** REFRIGERATION

**Centrifugal Refrigerating Machines**—for large comfort and industrial air conditioning applications and for process cooling. High efficiency at peak or partial loads. Operate with any standard motor or turbine drive. Available in capacities from 100 to 4000 tons in a single unit.

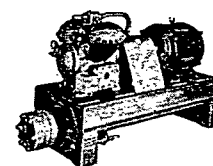
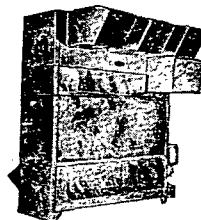
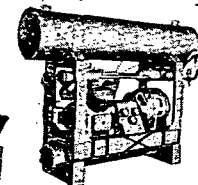
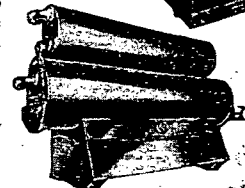
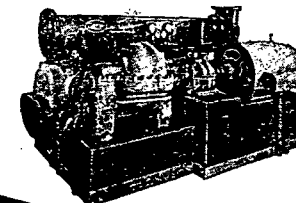
**Absorption Refrigerating Machines**—for producing chilled water at 40 F or higher in fully automatic operation from 0 to 100 per cent capacity. Uses low pressure steam for operation. Available in eleven sizes with capacities from 100 to 700 tons.

**Water Cooling Machines**—Compact, packaged water cooling systems for air conditioning and for industrial process cooling. Direct or belt drive, capacities range from 5 to 200 hp.

**Commercial Refrigerating Machines**—for storage refrigerators, display cases, walk-in coolers and similar duty. Complete with compressor, drive, air or water cooled condenser and controls. All sizes.

**Reciprocating Compressors**—for refrigeration needs of air conditioning and process cooling. Adaptable to all drives and available for "Freon" and ammonia refrigerants. Sizes from 3 to 200 hp.

**Evaporative Condensers**—for use with refrigerating compressors in place of water cooled condensers. Simplify water supply and disposal problems. For indoor or outdoor use. Capacities 10 to 110 tons, for "Freon" or ammonia.

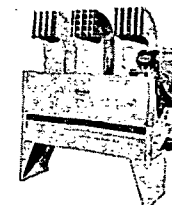
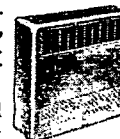
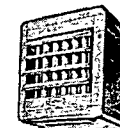
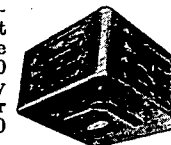


## **Carrier** INDUSTRIAL HEATING

**Unit Heaters**—for commercial and industrial space heating using steam or hot water. Complete range of sizes in three types: 46U Horizontal Discharge (13,400 to 200,000 Btu per hr), 46S Four-way Directed-flow (55,000 to 600,000 Btu per hr) and 46AE Cabinet Heaters (26,200 to 115,000 Btu per hr).

**Gas-Fired Unit Heaters**—for clean, economical heat in offices, stores, factories and similar spaces where gas is available. A.G.A. approved for manufactured, mixed, natural, LP and LP-air gases. Capacities: 50,000 to 230,000 Btu per hour.

**Heat Diffusers**—for ventilating as well as heating large commercial and industrial spaces. Floor, wall or ceiling mounted with coils for steam or hot water. Capacities 47,000 to 2,990,000 Btu per hour at 2 lb steam.



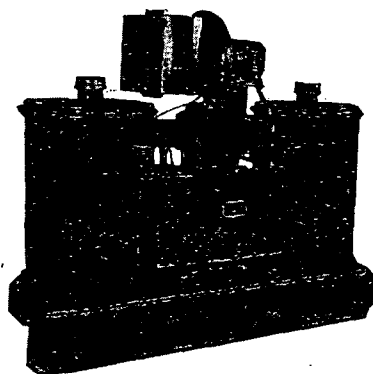
## Desomatic Products, Inc.



1109 West Broad Street  
Falls Church, Virginia

Designers • Engineers • Manufacturers

REPRESENTATIVES IN PRINCIPAL U. S. CITIES AND CANADA



**DESOMATIC MODEL 350.** This Desomatic unit protects materials in storage from corrosion, mold and mildew danger by maintaining low relative humidities in the space, over a temperature range from 0 F to 120 F. **DESOMATIC** Dehumidifiers use a solid sorbent, silica gel, and no replacement of adsorbent is necessary. Customer may specify other desiccants.

Desomatic equipment for dehumidification of air is your answer to efficient moisture control in storage areas, homes, industries and laboratories.

Five standard models to meet your needs. Also custom designed equipment and machines for Class 1, Group D, hazardous locations. All standard models may be modified to meet Military Specifications.

### Standard Desomatic Industrial Dehumidifiers

|                        | SOR-8        | DOR-38       | DOR-100      | DOR-350      | DOR-800      |
|------------------------|--------------|--------------|--------------|--------------|--------------|
| Air Flow cfm           | 25           | 100          | 175          | 500          | 1500         |
| External Pressure      | 1/8" W.G.    | 1/8" W.G.    | 1/8" W.G.    | 1" W.G.      | 2" W.G.      |
| Voltage                | 110 V, 1 Ph. | 110 V, 1 Ph. | 220 V, 3 Ph. | 440 V, 3 Ph. | 220 V, 3 Ph. |
| Load Kw.               | 1            | 1.4          | 3            | 9            | 25           |
| Capacity 70°-35% lb/hr | 1/4          | 1            | 2.5          | 7.5          | 22           |
| Weight, Lbs.           | 48           | 375          | 425          | 1150         | 4000         |
| Length, Inches         | 15           | 54           | 54           | 70           | 108          |
| Width, Inches          | 13           | 20           | 20           | 25           | 61.5         |
| Height, Inches         | 18           | 42.5         | 42.5         | 60           | 92.5         |

Write for full details on Desomatic Dehumidifiers, for low as well as high pressure applications, Pressure Blowers, 4-Port Air Valves, Air Flow Indicators and Humidity Controllers.



SINCE 1910

(Division of National-U. S. Radiator Corporation)

Factory and General Sales Office

3301 Medford St.

Los Angeles 63, California

Representatives in Principal Cities

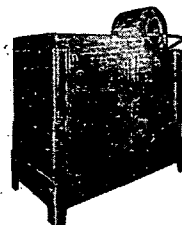
Manufacturers of Air Conditioning and Refrigeration Equipment

REFRIGERATION AND AIR CONDITIONING

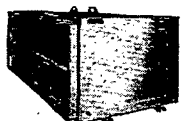


### LEFT COLUMN READING DOWN:

**Multizone-type FZ**—Air conditioners, blow-through type, supply many zones individually by damper control. Horizontal, vertical types.



**Perma-Fan Series PF**—Complete line of blow-through type evaporative condensers, on principle developed by D-H in 1937. 5 to 110-ton capacities.



**HH and HHV types**—for horizontal or vertical air conditioning; central-type systems.



**Water Chiller**—Space-saving, self-contained water cooled or air-cooled units.



**Spotaire Series LRC**—Compact basic or cabinet types for air conditioning individual rooms of multi-room buildings. Overhead installation; takes little headroom.

### RIGHT COLUMN READING DOWN:

**Spotaire Series HRC**—Room unit air conditioning equipment for chilled water, hot water or DX. Concealed basic unit or cabinet models.

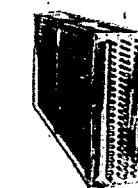
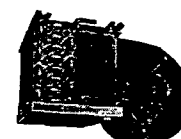
**Spotaire Series VRC**—Handsome, floor-mounted models for chilled or hot water, or "Freon."

**d-h Hot Shot Electric Defrost**—ceiling-type units using D-H's electric automatic defrost patents.

**d-h Spasaver**—Product cooling application for over 34F temperatures. Many sizes.

**d-h Flocold**—Product or produce coolers for under or over 34F; water or ammonia defrost.

**Extended Surface Coils**—Staggered tubes for steam, water, DX, "Freon" or ammonia; removable header or plug-type coils.



# GENERAL ELECTRIC

HOME HEATING AND COOLING DEPARTMENT  
5 Lawrence St., Bloomfield, New Jersey

## REGIONAL SALES OFFICE:

NEW YORK 22, N. Y.—570 LEXINGTON AVE.  
CLEVELAND 15, O.—1010 EUCLID BLDG., ROOM 1101  
CHICAGO 54, ILL.—MERCHANDISE MART, ROOM 1144  
ATLANTA 3, GA.—410 REDROCK BLDG., ROOM 400  
NEW ORLEANS 12, LA.—511 INTERNATIONAL TRADE MART  
LOS ANGELES 17, CALIF.—1052 WEST 6 STREET, ROOM 614

See your classified telephone directory for local sources under:

G-E Furnaces  
G-E Air Conditioning Equipment & Supplies



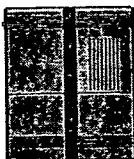
### 1. G-E OIL-FIRED BOILER

Compact, integrated steel boiler units designed exclusively for low-pressure oil burning. Ideal in multiple installation for both central heating and zone heating. High heat transfer rate with low water content and low metal mass. Exclusive G-E features give fuel savings up to 50 per cent: "Turnback Flame"; oil atomization for complete combustion; famous G-E "heat-trap" design. Built-in tank or tankless-type hot water coil. Five models: 100, 140, 200, 300 and 450,000 Btuh output. Listed by *Underwriters' Laboratories, Inc.* Constructed in accordance with ASME Code. Also GAS-FIRED BOILERS—96, 144, 192, 240, 288, 336, and 432,000 Btuh input—Cast Iron Heat Exchanger. For natural, manufactured or mixed gas.



### 2. G-E OIL AND GAS-FIRED WARM AIR FURNACES

Oil-Fired. Fuel savings up to 50 per cent reported by users. Features: G-E Atomized Oil burning, "Turnback Flame," "Spira-Flow" heat transfer surface. 60 to 155,000 Btuh bonnet output. Listed by *Underwriters' Laboratories, Inc.* Gas-Fired. G-E's long-life, cast-iron "Pinpoint" heat transfer sections give superior heating action. Compact, quiet. Listed by *Underwriters' Laboratories, Inc.* approved by A.G.A. Burn manufactured, mixed, natural, natural-SUR or LP gases. 60 to 210,000 Btuh input. Models. G-E Oil and Gas-Fired Furnaces are available in Upflow, Downflow and Horizontal models. Each is "Pre-Paired" to permit addition of G-E Home Cooling at any time.



### 3. G-E'S COOLING UNITS AND YEAR-ROUND AIR CONDITIONERS

Self-contained central system heats, cools, filters, dehumidifies, ventilates and circulates conditioned air. Cooling capacity: 2 to 5 tons. Heating capacity: with gas firing, 60 to 210,000 Btuh input; with oil firing, 60 to 155,000 Btuh, bonnet output. Over 4,784 heating-cooling combinations—permitting accurate sizing of units to fit any home size and design—all climatic conditions. Upflow, Downflow, Horizontal models. Cooling with water-cooled or air-cooled condensers.

### 4. G-E AIR-WALL\* SYSTEM FOR HEATING AND COOLING

Air-Wall—The Air-Wall register spreads a wall of conditioned air over insides of windows and outer walls, protecting against extremes of winter and summer weather. With G-E Year-Round Air Conditioning, or G-E Furnaces or G-E Home Cooling, same registers deliver both heat and cooling. Engineers and architects especially acclaim the coordinated design of the Air-Wall SYSTEM—heating and cooling units, ducts and registers designed to function as a single unit.

\*Reg. Trademark of General Electric Company.

# GENERAL ELECTRIC

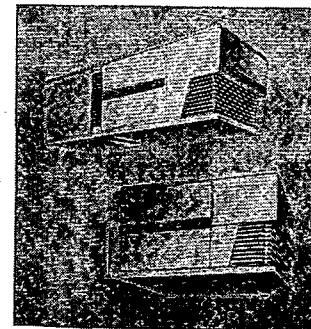
## PACKAGED AIR CONDITIONING

Commercial and Industrial Air Conditioning Department  
5 Lawrence St., Bloomfield, N. J.

## REGIONAL SALES OFFICES

NEW YORK 22, N. Y.—570 LEXINGTON AVE.  
CLEVELAND 15, OHIO—1010 EUCLID BUILDING, RM. 1101  
CHICAGO 54, ILL.—MERCHANDISE MART, RM. 1144  
ATLANTA 3, GA.—410 RED ROCK BUILDING  
NEW ORLEANS 12, LA.—511 INTERNATIONAL TRADE MART  
LOS ANGELES 17, CALIF.—1052 W. 6TH ST.

See your Classified Telephone Directory for local sources under:  
GENERAL ELECTRIC AIR CONDITIONING

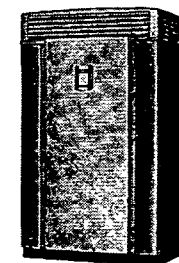


## CEILING-MOUNTED UNITS

The latest additions to the complete G-E Line of Packaged Air Conditioners require no floor space. Instead, these compact, self-contained units are fastened to the ceiling or mounted on shelves. And there are no remote parts to complicate operation or increase danger of refrigerant leakage. Available in water-cooled and air-cooled models—latter designed to eliminate problem of water restriction. For offices, factories, shops, supermarkets, etc. Water-cooled model in 3, 5, and 7½ ton capacities; Air-cooled model in 3 and 5 ton capacities.

## FLOOR-MOUNTED UNITS

These popular G-E Packaged Air-Conditioners are famous for quiet, reliable performance—as they filter, cool, dehumidify and circulate air. They can be installed step-by-step to fit limited budgets—without extensive alterations. Modern, functional styling blends in with any decor. Units can be located in-space or out-of-space. For stores, offices, hotels, restaurants, plants, etc. Capacities: 3, 5, 7½, 10 and 15 tons.



BOTH ceiling-mounted and floor-mounted units have entire cooling system—motor, compressor, condenser—sealed-by-flame to keep dirt and moisture out, vital refrigerant in. Both have completely adjustable air distribution. Both can be supplied with coils for winter heating. And both carry G-E's 5-year warranty covering entire refrigeration system.



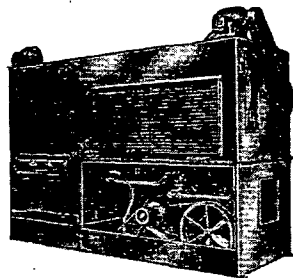
Air Conditioning • Central and Self Contained Air  
Conditioners, Blower Units,  
Coils, Evaporative Condensers

## Governair Corporation

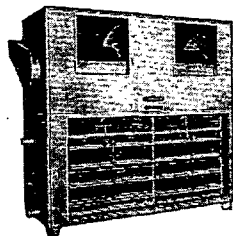
513 North Blackwelder, Oklahoma City 4, Oklahoma

**GOVERNAIR**

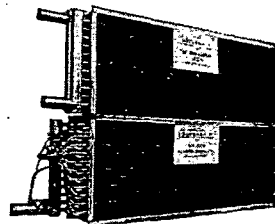
Self-Contained Air Conditioners



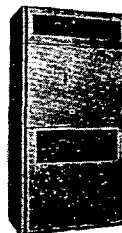
**TYPE SC CONDITIONERS**—for stores, offices, hospitals, homes—3, 5, 7½, 10, 15 ton sizes—heating optional—plenum or duct air distribution for city water or cooling tower use—with quiet hermetic compressor.



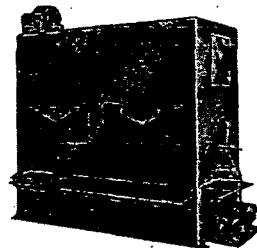
**EVAPORATIVE CONDENSERS**—3 to 100 ton—all prime or fin surface—corrosion resistant steel or non-ferrous construction—internal jacket liner.



**SELF-CONTAINED AIR CONDITIONERS**—completely packaged air conditioners with evaporative condenser. Ready for connection to duct system—3 to 60 ton—single or two separate refrigeration systems—non ferrous condenser available.



**FAN AND COIL CABINETS**—cooling, heating, humidifying, dehumidifying, ventilating, 1 to 100 ton, 500 to 30,000 cfm, vertical or horizontal types. Governair multi-zone fan and coil units are available in sizes ranging from 5 to 60 ton capacities, suitable for individual zoning.



**BLAST COILS**—direct expansion, water steam—hydraulically expanded tubes for close fin spacing—mechanically expanded tubes for wide fin spacing—copper or aluminum fins—complete range of sizes.

Also: Multi-Zone Fan and Coil Units, Cooling Towers, Packaged Water Chillers and Low Temperature Coolers.

Air Conditioning • Central Systems  
Unit Heaters and Coolers

## Hastings Air Conditioning Co., Inc.

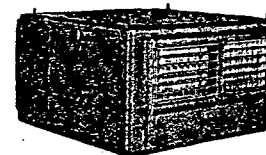
Hastings, Nebr.



Manufacturers of

Cooling, Heating and Ventilating Equipment.  
Water, DX and Steam Coils.  
Gas and Steam Unit Heaters.  
Gas Power Conversion Burners.

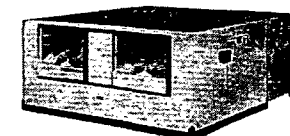
A complete line of air conditioners for chilled or well water, cold city water, and direct expansion. Full range of sizes, 1 to 40 tons. All coils are constructed entirely of copper. Fins are both solder-bonded and mechanically-bonded to the tubes for permanent high efficiency. Flowmeters (to visually indicate water flow) are standard on all water units.



General Utility Models



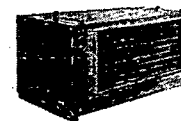
Floor Models



Central Plants



**DOUBLE-KOOL "2-stage" COOLING UNITS**—3 to 56 tons. 2 Tons cooling per compressor hp. Air is first pre-cooled using water up to 70° F, then further cooled and de-humidified by Freon coil. Packaged and remote models. Up to 100 per cent **FRESH AIR** may be used for cooling, regardless of outside conditions. Saves approximately 50 per cent of water and power cost.

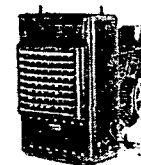


**HOME AIR CONDITIONERS**—2 to 5 tons

Easily attached to any furnace.

**Water Coil Models**—for water up to 60° F.

**Double-Kool Models (Combination Water-DX)**—for water up to 70° F.



**GAS UNIT HEATERS**—50,000 to 220,000 Btu capacity

Equipped with **CENTRIFUGAL** or **PROPELLER** type fans.

**DUCT HEATERS** available for use with remote blowers.

A.G.A. approved for all gases.

Aluminized steel heat exchangers for fast heat transfer and extra long life.

Stainless steel ribbon burners for quiet, efficient combustion. Dual directional, adjustable louvers permit complete control of air delivery.



**HEATWELL POWER GAS CONVERSION BURNERS**—

**Inshot**—To replace oil burners. Up to 370,000 Btu.

**Roundhead**—For any round furnace or boiler. Up to 250,000 Btu.

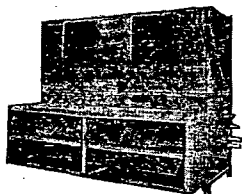
**Adjusto "V"**—Commercial, Multiple-dwelling, and Industrial. Up to 4,000,000 Btu. No combustion chamber required. Adjustable flame placement.

Write for Catalogs, Literature, or Information

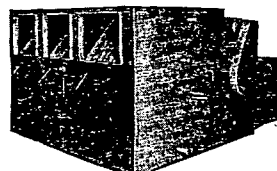
# KENNARD Corporation

1819 So. Hanley Rd., St. Louis 17, Mo.  
Manufacturers of  
AIR CONDITIONING EQUIPMENT

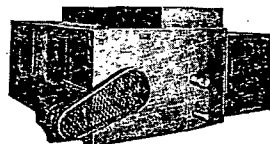
Finned Coils (Heating & Cooling)—Air Conditioning Blower Units—Multi-Zone Units—Heating and Ventilating Units—Sprayed Coil Dehumidifiers—Cooling Towers—Evaporative Condensers—Liquid Chillers



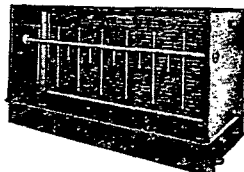
**AIR CONDITIONING BLOWER UNITS**  
13 Sizes. 300 to 21,600 cfm. Horizontal or Vertical. Catalog No. AC.



**MULTI-ZONE UNITS**  
Sizes up to 36 sq ft. Cooling Coil Face Area. Catalog No. MZ.



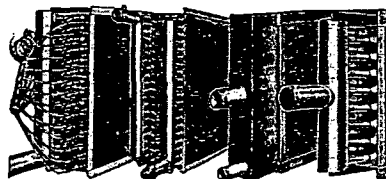
**HEATING AND VENTILATING UNITS**  
Air Volumes 300 to 28,800 cfm, and up to 36 sq ft Coil Face Area. Catalog No. HV.



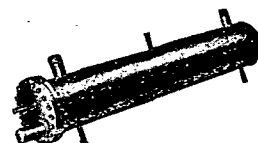
**SPRAYED COIL DEHUMIDIFIERS**  
56 Sizes. Coil Face Areas up to 81 sq ft. Catalog No. SC.



**COOLING TOWERS AND EVAPORATIVE CONDENSERS**  
Sizes from 3 to 15 tons. Centrifugal type fan for quiet Indoor operation-propeller fan water turbine driven for Outdoor operation. EC and CT models for 15 to 75 tons (not shown). Catalogs No. KT and QT.



**FINNED COILS**  
Direct Expansion, Water, Steam Distributing Tube, Standard Steam Coils. Sizes up to 48 in. wide x 132 in. long. Catalogs No. CC and HC.



**LIQUID CHILLERS**  
Direct Expansion, Freon Shell and Tube Liquid Chillers. Internally finned tubing (Pat. Applied For), brass baffles, positive oil return, closed refrigerant circuits without freon gaskets. Catalog No. LC.

## Niagara Blower Company

Executive Offices: 405 Lexington Ave. New York 17, N.Y.

Sales representatives in Principal Cities of U. S. and Canada

Over 35 Years' Experience in Industrial Air Conditioning

### NIAGARA AIR CONDITIONING SYSTEMS

For human comfort and for all industrial applications requiring controlled conditions of temperature, relative humidity, air purity and air movement.

#### NIAGARA AIR CONDITIONER, TYPE A, AND CONTROLLED HUMIDITY METHOD USING HYGROL LIQUID ABSORBENT

High precision apparatus using saturation to obtain control of R. H. to 1 per cent for laboratory work and control of hygroscopic materials. Ask for *Bulletins 112 and 122*

#### NIAGARA AIR CONDITIONER, TYPE C

A year around air conditioning unit providing heating and humidifying or dehumidifying. Ask for *Bulletin 80*.

#### NIAGARA FAN COOLER AND DISK FAN COOLER

For comfort cooling, process cooling, low temperature storage for dairies, fruits, meats, food products, fur storage vaults, etc. *Bulletin 72*.

#### NIAGARA SPRAY COOLER

For all cooling applications requiring high humidity or high capacity in small space. Ask for *Bulletin 110*.

#### NIAGARA "NO FROST" SYSTEM

Using Niagara "No Frost" Liquid in spray coolers prevents frosting of cooling coils, automatically keeps spray solution at proper concentration, gives freedom from brine troubles, corrosion. Constant, efficient operation. Temperature to -100F. Ask for *Bulletin 105 (Food)* or *Bulletin 95 (Industrial)*.

#### NIAGARA AEROPASS CONDENSER

Saves power and water cost utilizing atmospheric air to remove heat of condensation. Patented Duo-Pass prevents scaling, saves power. "OILOUT" positively removes oil and dirt from refrigerant lines, assuring always full capacity. Balanced Wet Bulb Control assures operation of refrigeration plant at minimum head pressure regardless of weather or load conditions. Capacities up to 400 tons refrigeration. Ask for *Bulletins 103, 111 and 123*.

#### NIAGARA "DUAL" COOLERS

Simultaneously cools a room and furnishes chilled water as a refrigerant. Saves equipment cost, operating expense. Patented. Ask for *Bulletin 70*.

#### NIAGARA AERO HEAT EXCHANGER

For cooling industrial liquids, water, oils, solutions, chemicals, compressed air and gases, with Niagara "Balanced Wet-Bulb" temperature control to improve efficiency and obtain precise results. Capacities up to 30,000,000 Btu. Patented (U. S. Nos. 2,296,946 and R. I. 22,553). Ask for *Bulletins 120 and 124*.

#### NIAGARA INDUSTRIAL LIQUID COOLER

Furnishes refrigerated water or aqueous solution in any quantity up to 220 gpm. Positive control of temperature regardless of load variation. Delivers "sweet" water at 33F without danger of freezing damage. Ask for *Bulletin 104*.

#### NIAGARA FAN HEATERS AND HIGH PRESSURE STEAM FAN HEATERS

For heating and ventilating large areas. Units of the highest quality in engineering, material and workmanship. Ask for *Bulletins 73 and 109*.

#### NIAGARA MOTOR BLOWERS

One, two and three-fan units. High and low static pressure models. Ask for *Bulletin 89*.

## Parks-Cramer Company

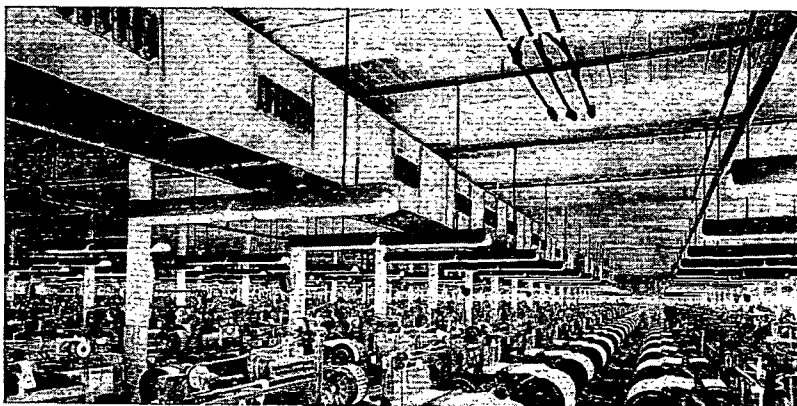
Fitchburg, Mass.

Charlotte, N. C.

Atlanta, Ga.

### CERTIFIED CLIMATE

Industrial air conditioning systems, including humidifying or dehumidifying, cooling by evaporation or refrigeration, ventilating, filtering, air washing; with automatic control of humidity, temperature and air change. Engineered, manufactured, installed and serviced by Parks-Cramer.



### CENTRAL STATION AIR CONDITIONING

A complete system for conditioning the factory atmosphere, with positive circulation and controlled ventilation. One or more air washer units. High humidifying and evaporative cooling capacity. Heating, filtering, and refrigerated cooling where needed. Ducts with adjustable outlets distribute conditioned air uniformly. Slight air pressure also improves uniformity. Centralized maintenance. Used with or without booster humidification. Under gradual acting automatic control. Exclusive multi-speed control of fan improves economy.

Central Station Air Washer Units. Nozzles and Self-Cleaning Tank Screens for Central Station Air Washers.



### LABORATORY AIR CONDITIONING

An essential of a good testing laboratory is adequate and dependable air conditioning. Accuracy in testing is maintained only when samples and testing equipment are free from fluctuations in both temperature and humidity. A vertical or horizontal unit is located within or adjacent to the laboratory. Includes equipment for heating, humidifying, dehumidifying, refrigeration, circulation, and adjustable recorder-controller. Heat by steam or electricity.



## Parks-Cramer Company

Fitchburg, Mass.

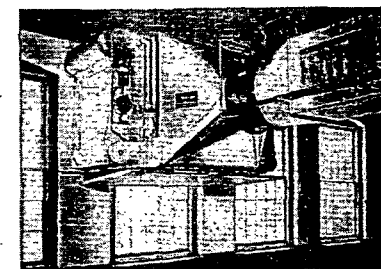
Charlotte, N. C.

Atlanta, Ga.

Industrial Humidifying and Air Conditioning Since 1904

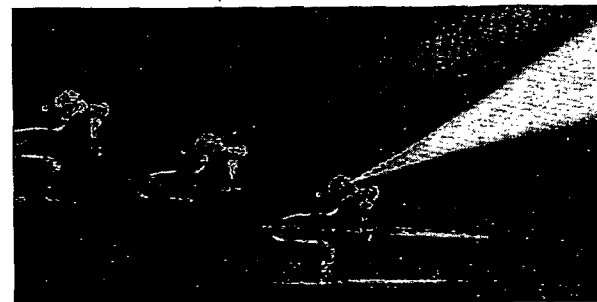
### AUTOMATIC AIRCHANGER

An improved system of forced air change and distribution used with direct humidification. Insures fixed uniform humidity and maximum evaporative cooling. Amount of air change and operation of humidifiers controlled by humidity and temperature Psychrostat. Designed for either complete new installations or for supplementing existing direct humidifying equipment, especially Gradumatics. Includes heating, refrigeration, filtering, where needed.



### GRADUMATIC HUMIDIFYING SYSTEM

Vastly improved direct humidifying system for use alone, with Airchangers, or as booster for Central Station system. Air and water under pressure, water pressure always less than air. Safe. Economical. Humidifier is self-cleaning.



Has few component parts, easy to take apart and reassemble. Proper operation assured without testing. No adjustment required. When humidification is needed, heads operate continuously, evaporative output being varied gradually and automatically by Certified Climate Psychrostat to suit requirements for constant humidity at all times.

### CERTIFIED CLIMATE PSYCHROSTAT

For gradual control of humidity and temperature. Improved model more sensitive than ever before. Rugged and reliable. Use of the wet and dry bulb principle permits Psychrostat to perform the many and varied tasks in the field of humidity and temperature control which contribute to the success of Certified Climate systems.



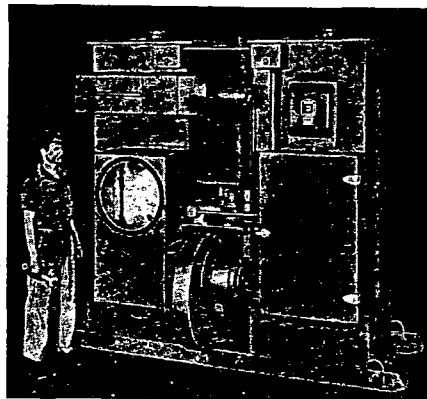
### THE PETTIFOGGER (not illustrated)

A compact centrifugal humidifier, with fan, for offices, storerooms, experimental rooms, hospitals, or other isolated departments. Self-contained in lacquered copper casing. Easily connected to water and electrical supplies. Automatic control. Adjustable capacity.

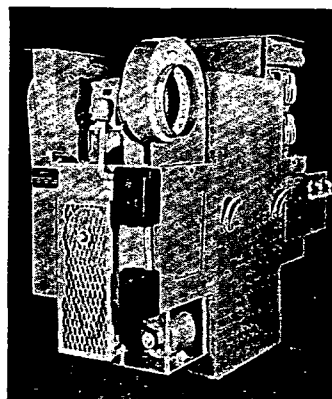
## Pittsburgh LECTRODRYER Corporation

Foot of 32nd Street

Pittsburgh, 30, Pa.



*This machine protects equipment in storage by maintaining a relative humidity of 35 per cent or lower.*



*Small automatic air conditioning type LECTRODRYER used for providing lowered relative humidities.*

### FOR INDEPENDENT CONTROL OF DEHUMIDIFICATION IN COMFORT AND INDUSTRIAL AIR CONDITIONING

The results of years of experience in the independent control of industrial dehumidification are now available for comfort air conditioning in the form of sturdy, dependable, thoroughly tested machines for controlled adsorption dehumidification.

**LECTRODRYER** equipment using Activated Alumina, a solid adsorbent, is widely used in maintaining lower than normal relative humidities in the chemical, pharmaceutical and other industries.

In comfort air conditioning these machines handle the latent heat load with only the sensible heat load left for refrigeration or water cooling. With this type

system, only the air needed for the sensible heat load is cooled and no reheat is required.

Machines are available for steam, gas or electric operation, whichever the purchaser specifies. Standard machines are available in several sizes ranging from 350 cfm upward.

**LECTRODRYERS** are shipped complete as self-contained automatic units in that they require no regular manual attention except for starting. They are built for continuous operation with reactivation being carried on simultaneously with the drying operation.

Write for full details.

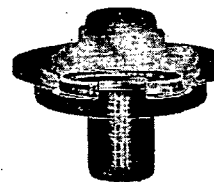
## Walton Laboratories, Inc.

Irvington 11, New Jersey

MANUFACTURERS OF

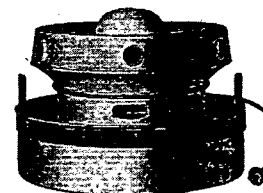
*Walton*

HUMIDIFIERS  
and AQUA-SORBER  
DEHUMIDIFIERS



**WALTON PATENTED CENTRIFUGAL ATOMIZER** principle has been embodied in all of the Walton humidifiers for over 25 years. Positive humidification is available continuously without the need for pressure devices, nozzles and other auxiliary equipment.

**PORTABLE ROOM HUMIDIFIERS** are available in table and automatically controlled console models, attractive design; uses no heating coils, nozzles or filters.



**INDUSTRIAL HUMIDIFIERS** self contained, easy to install. Water and electrical connections are the only requirements. No costly ducts, compressors or drain piping are used. Sizes and types to accommodate small and large installations requiring humidification up to 100 per cent.

**DUCT OR WARM AIR SYSTEMS** can utilize Walton Model WF which can supply positive humidification without plates, drip pans, or jets, unaffected by mineral content in water.



Available to engineers, architects, and industrial designers is the complete new Walton Catalog file including—

- "Industrial Humidification"
- "Humidification for Textiles"
- "Humidification for Knitting"
- "Humidification for Graphic Arts"
- "Humidification for Hospitals"
- "Humidification for Home and Office"
- "Humidification for Warm Air Systems"
- "Dehumidification for all Applications"



## Westinghouse Electric Corporation Air Conditioning Division

Self-contained Air Conditioners—2 to 25 tons;  
Heat Pumps; Field-assembled  
Air Conditioning Equipment

Staunton

Offices in all principal cities

Virginia

### AIR CONDITIONING UNITS

Type HP Heat Pumps are flameless, water-less, all-electric units which will heat the home in the winter and cool it in the summer, automatically. Recommended for areas where extremes of temperature are not of long duration. Available in nominal 3 and 5 hp ratings.

Type RG/RO Year-Round Air Conditioners heat in summer and cool in winter. Features ingenious slip-in cooling package, economical gas or oil burner operation, year-round thermostat control. (A.G.A. approved.) Available in 2 or 3-ton cooling capacities.

Type RU Unitaire Conditioners for residential and commercial cooling requiring duct work. Installed with new or existing forced-air heating system, or independently with own duct work. Features compact design, sturdy welded-frame construction. In 3 and 5-ton capacities.

Type ACU Air-Cooled Condensing Units for residential cooling applications with new or existing forced air furnaces. May be installed indoor or outdoor with cooling coil in furnace discharge duct or plenum. Full nominal capacity at high ambient. Features durable bonderized cabinet, waterproof electrical panel, versatile vertical discharge arrangement. In 2, 3 and 5-ton capacities.

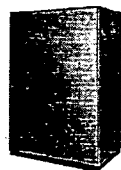
Type SU and MU Unitaire Conditioners are designed for commercial and industrial use. They cool, dehumidify, filter and circulate air. Accessory heating coil available. Dual refrigeration cycles on MU Unitaire provide 50 and 100 per cent capacity operation. Available in 3, 5, 7½, 10 and 15-ton capacities.

Type LU Central Plant Unitaire Conditioners for installation with supply and return air ducts. In capacities of 20 to 28 ton.

**REFRIGERATION COMPRESSORS**  
Type CLS Refrigeration Compressors are hermetically sealed, direct connected units with refrigerant cooled motors made in 12 sizes from 2 to 125 ton.

### WATER COOLED CONDENSERS

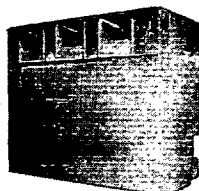
They are constructed with integrally finned copper tubing, steel sheels and silver soldered tube sheets. Manufactured in accordance with the recommendations of the ASME Boiler Construction Code, Section VIII. Available in 16 sizes within 2 to 125 ton range.



Type HP Heat Pump



RO & RG Year 'Round  
Residential Unit



Central Plant Unitaire



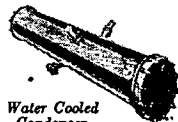
RU-Unitaire



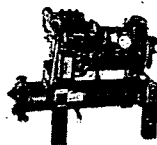
Type ACU Air-Cooled  
Condensing Unit.



SU Unitaire



Water Cooled  
Condenser



2, 3, 5, 8 Ton Compressors  
and Condensing  
Units

## Worthington Corporation

### Air Conditioning and Refrigeration Division

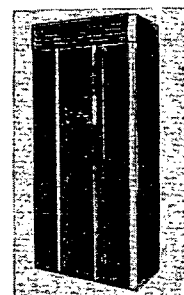
General Offices: HARRISON, NEW JERSEY

|            |            |                   |              |                |                    |
|------------|------------|-------------------|--------------|----------------|--------------------|
| ALBANY     | CHICAGO    | FORT WORTH        | LOUISVILLE   | PHOENIX        | SAN FRANCISCO      |
| ATLANTA    | CINCINNATI | GALVESTON         | MILWAUKEE    | PITTSBURGH     | SEATTLE            |
| BALTIMORE  | CLEVELAND  | GREENVILLE, S. C. | NEW HAVEN    | PORTLAND, ORE. | SPRINGFIELD, MASS. |
| BIRMINGHAM | DALLAS     | HOUSTON           | NEW ORLEANS  | PROVIDENCE     | SYRACUSE           |
| BOSTON     | DENVER     | KANSAS CITY       | NEW YORK     | ST. LOUIS      | TULSA              |
| BUFFALO    | DETROIT    | KNOXVILLE         | OMAHA        | ST. PAUL       | WASHINGTON, D. C.  |
| CHARLOTTE  | EL PASO    | LOS ANGELES       | PHILADELPHIA | SALT LAKE CITY | WILMINGTON, DEL.   |

Representatives in all Principal Cities

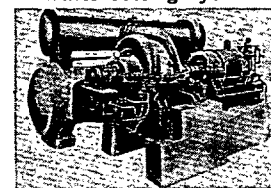
A.O.25

### Packaged Air Conditioners



Provide cooling (and heating, if desired), dehumidification, ventilation, and air cleaning for commercial and industrial applications. 3, 5, 7½, 10, 15, 20, and 25 ton capacities.

### Centrifugal Refrigeration Water Cooling Systems



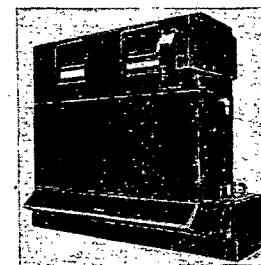
150 to 1,200 tons, 56 unit sizes. Freon centrifugal compressor, water cooler and water-cooled condenser in compact unit assembly. Electric motor or steam turbine drive.

### Reciprocating Compressors Freon



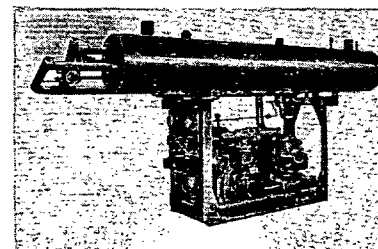
V and W type, to 150 tons with Freon-12 and to 170 tons with Freon-22. Full force feed lubrication above 10 hp. Capacity reduction and unloaded starting by gas unloaders. Mounted on steel base, with water cooled condenser or for use with separate evaporative condenser.

### Evaporative Condensers



Series ECZ, 10 to 150 tons. Sectionalized construction, all parts easily accessible. Bare copper coils for Freon-12.

### Packaged Liquid Chillers



Series LCP Freon-22 Packaged Liquid Chillers for process cooling, refrigeration, or air conditioning. 14 sizes, 7½ to 150 hp; 4 to 303 tons. Incorporate a complete refrigeration cycle with all necessary components. Factory assembled, 7½ to 80 hp; field connected, 100 to 150 hp.

## York Corporation

York, Pennsylvania

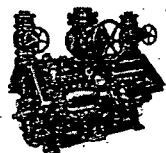
Factory Branches and Distributor Engineering and Sales Offices throughout the World.



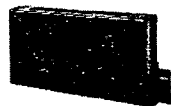
Air Conditioning and Refrigeration for maintaining proper atmospheric conditions for industrial processes or comfort requirements. Installations of unit and central systems in a wide range of capacities and types for every design need.



**Turbomatic Compressor**—a completely assembled "packaged" compressor with a capacity range from 115 ton to 350 ton. Factory assembly speeds installation of complete system jobs. Single stage aluminum alloy impeller, reduced shaft diameter, simplified shaft seal, permit higher rpm, less friction than in multi-stage equipment, assure longer service life. Model L-95, York's largest Turbomatic, weighs only 1600 lb.



Other turbos available over wide range of capacities—up to 2500 ton refrigeration for Freon water cooling duty—suitable for steam turbine or motor drive. Self-contained dynamically balanced, non-vibrating V/W type reciprocating compressors available in capacities up to 350 ton refrigeration in a single unit, with water cooled or economizer type condensers. Efficient automatic capacity reduction available for economical operation at reduced load.

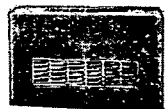


**Yorkaire Complete Systems**—Three basic types available for big building applications. Designed for maximum flexibility in each case.

**York CI System** utilizes York Turbo or V/W Compressor as cooling source, with one air intake, usually at top of building. Air brought in by fan, filtered, dehumidified. Sound trap eliminates fan noise. Units in individual rooms also provide heat in winter by hooking into existing hot water system.



**York CF System** cools in summer, heats in winter, uses Turbo or V/W compressor for cooling, building's hot water system for heating. Air intake located in unit in each room. Economical for buildings where space is at a premium. No large fan room required; units individually operated.



**York CSA System**—Individual room units cool in summer, heat in winter, require no fan room for cooling equipment, hook easily into existing hot water system. Units can be added one room at a time; no extensive alterations required.



## ADDISON PRODUCTS COMPANY

Addison, Michigan

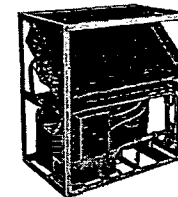
Specialists in Air Conditioning Systems  
Contract Manufacturers

Addison Units are built to Customer Specifications

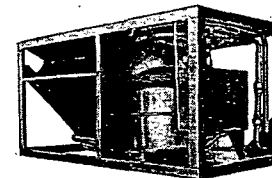
WATER COOLED

AIR COOLED

Addison air conditioning systems are available in vertical or horizontal types for water cooled operation.



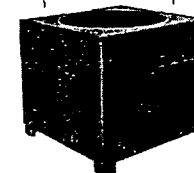
The vertical system is available in 2 hp, 3 hp and 5 hp sizes. 2 hp and 3 hp sizes mounted within a 24 in. x 20 in. x 40 in. frame. 5 hp unit available with single compressor or two compressor, two stage cooling operation. Both 5 hp models mounted within a 38 in. x 24 in. x 40 in. frame. Vertical units are designed to install easily in companion cabinet for hi-boy type furnace installations or, if desired, in hi-boy type cabinet for space cooling.



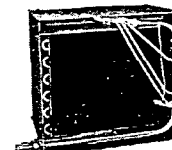
The horizontal type is available in 2 hp or 3 hp sizes. The entire assembly is mounted within a 21½ in. x 21½ in. x 42¾ in. frame. Louvered or solid drain pans are optional. The horizontal system is ideal for a companion cabinet installed with hi-boy furnace installation. It may also be used in limited spaces such as crawl space or attic type of installations.



The horizontal attic air conditioning system is available in Economy 2 hp size. This system was designed primarily for small home operation where economy is especially important. Dampened air flow in evaporator plenum provides zone cooling.



Air cooled systems are also available in 2, 3 and 5 hp sizes. Condensing assembly is designed for outdoor operation with vertical or horizontal evaporators designed to fit in plenum of existing air ducts of heating system. These units are ideal for areas where water supply is critical.



All systems are designed and engineered to customer specifications and requirements, subject to Addison high quality standards. All sheet metal parts have a corrosion resistant finish. All service connections are of standard size in construction and easily accessible. Equipment is Underwriters' Laboratories approved.



## AMERICAN-Standard AIR CONDITIONING DIVISION ELYRIA, OHIO

Executive Offices: 40 West 40th St., New York 18, N. Y.  
A Division of American Radiator & Standard Sanitary Corporation

Distributors are listed under "Air Conditioning Equipment & Supplies"  
or "Furnaces" in the yellow pages of your telephone directory.

### AMERICAN-STANDARD SUMMER AIR CONDITIONERS



HCA-2H



HCA-2



AC-2A



RC-2V



RC-2HA



HCA-3F



CCA-5

**RESIDENTIAL UNITS—WATER COOLED.** All are compactly designed and have 100 per cent hermetically sealed refrigerant circuits covered by American-Standard Air Conditioning Division 5 Year Protection Plan. Models HCA-2H and HCA-3H, 2 hp and 3 hp horizontal units, less blower, utilize the blower of new or existing furnace, as do Models HCA-2, -3, -5, offering choice of 2, 3 or 5 hp cooling. Models HCA-2F, -3F, -5F, equipped with blower, can be used either with forced air furnace, or independently with their own ducts, for 2, 3 or 5 hp cooling.

**RESIDENTIAL UNITS—AIR COOLED.** New, outdoor air-cooled condensing units AC-2A (2 hp) and AC-3A (3 hp) have 100 per cent hermetically sealed refrigerant circuits covered by 5 Year Protection Plan. Easily connected to evaporator unit installed in discharge air duct of new or existing forced air furnace. Evaporator units RC-2HA and RC-3HA (2 hp and 3 hp respectively) are for horizontal air flow; RC-2V and RC-3V (2 hp and 3 hp respectively) are for vertical air flow.

**COMMERCIAL UNITS.** These are self-contained, water-cooled package units for 2, 3 or 5 hp cooling of shops, offices, restaurants and other business establishments. All have 100 per cent hermetically sealed refrigerant circuits covered by 5 Year Protection Plan and are finished in Coltan—a neutral shade that blends with any color scheme.

### AMERICAN-STANDARD YEAR 'ROUND AIR CONDITIONERS



C-G-W



C-OB-W

**GAS-FIRED HEATING WITH 2 hp OR 3 hp COOLING.** A complete winter-summer unit under a single jacket. Choice of 7 size combinations ranging up to 150,000 Btuh input winter heating with 3 hp cooling for summer air conditioning. The 100 per cent hermetically sealed refrigerant circuit is covered by 5 Year Protection Plan; slides in or out as a complete unit for easier installation or servicing. The air conditioner is available less cooling circuit for owners who need immediate winter air conditioning but prefer to add summer air conditioning at a later date.

**OIL FIRED HEATING WITH 2 hp OR 3 hp COOLING.** This unit, complete under single jacket, has the same easy slide-out refrigerant circuit as the gas-fired model listed above; may be obtained less cooling circuit. Choice of 2 hp or 3 hp cooling and either 85,000 or 112,000 Btuh winter heating output at bonnet. Features include heavy gauge steel heating element specifically designed for oil firing to insure efficient, economical combustion of fuel.

### AMERICAN-STANDARD GAS-FIRED FURNACES



GLA

SG



GUA

GCA



SHC

**GAS BASEMENT.** Model GLA low-boy completely assembled and wired, blower-equipped, in 8 sizes, from 75,000 to 300,000 Btuh input, all Installation Tested\* at the factory. Model SG gravity furnace, equipped with automatic controls, in 4 sizes, from 85,000 to 150,000 Btuh input.

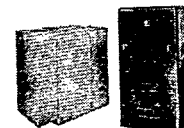
**GAS UTILITY.** Compact, narrow-width Model GUA (smallest size is only 13 1/2 inches wide), completely assembled, wired and Installation Tested\* at the factory. Seven sizes, from 50,000 to 200,000 Btuh input. A.G.A. approved models for 1-inch or zero clearance installations. Models with belt-driven or direct-drive blowers available.

**GAS COUNTERFLOW.** New, more compact Model GCA for perimeter heating installations in modern, slab type homes. Permits 1-inch clearance at sides, zero clearance at rear; can be installed on combustible flooring if optional sub-base is used. Three sizes—75,000, 100,000 and 125,000 Btuh input—completely assembled, wired and Installation Tested\* at the factory.

**GAS HORIZONTAL.** Unit can be suspended from ceiling, in crawl space or placed on attic joists. Five sizes, from 60,000 to 140,000 Btuh input, all completely assembled, wired and Installation Tested\* at the factory. Models available with vertical or horizontal flue outlet.

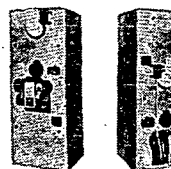
\* Installation Testing of completely assembled unit at factory includes actual gas firing and operation of blower and controls.

### AMERICAN-STANDARD OIL-FIRED FURNACES



1307-OB

1310-OB



1200-OB

1400-OB



HS

**OIL BASEMENT.** Models 1307-OB and 1310-OB for small and medium size homes are approved for installation on combustible flooring. Convertible to gas with American-Standard GP package. Six sizes, from 67,000 to 167,000 Btu capacity at register.

**OIL UTILITY.** Model 1200-OB units are designed for small homes and individual apartments. Standard and zero clearance models available. Three sizes—79,000, 96,000 and 102,000 Btu output at bonnet. Convertible to gas.

**OIL COUNTERFLOW.** Model 1400-OB units for basementless and slab construction houses, are approved for zero clearance installations; convertible to gas. Three sizes—79,000, 96,000 and 102,000 Btu output at bonnet.

**OIL HORIZONTAL.** Model HS units can be placed on attic joists, suspended from ceiling or installed in crawl space; are applicable either to perimeter or conventional heating systems. Three sizes—93,900 and 102,000 Btu output at bonnet.

### AMERICAN-STANDARD ELECTROSTATIC AIR CLEANER



EF

**MAGNE-FILTER.** Model EF is a dry type electronic air filter, easily installed in the return air duct of warm air furnace or summer air conditioner. Traps even smallest particles; remove pollen, bacteria, dust and smoke from the air. Made in 7 sizes; to meet the requirements of any installation. No water connection required.



# Armstrong Furnace Company

Columbus, Ohio



## WARM AIR HEATING EQUIPMENT

Domestic Winter Air Conditioning Furnaces



**Basement Models**—Gas, oil, or coal; 17 basic sizes; ideal for all types of new homes; widely used to replace obsolete furnaces. Gas-fired: 7 sizes, 85,000 to 250,000 Btu/hr input. Oil-fired: 6 sizes, 80,000 to 200,000 Btu/hr output. Coal-fired: 4 sizes, 20 to 27 inch.



**Counterflow Models**—Warm air delivered at bottom to ducts in slab floor or crawl space. Fits into closet or utility room corner. Gas-fired: 3 sizes, 65,000 to 105,000 Btu/hr input. Oil-fired: 2 sizes, 80,000 and 110,000 Btu/hr output.



**Hi-Boy Models**—Designed for modern basementless homes and homes with basements. Approved for operation in close quarters. Quiet, compact, attractive. Gas-fired: 6 sizes, 65,000 to 125,000 Btu/hr input. Oil-fired: 2 sizes, 80,000 to 110,000 Btu/hr output.



**Horizontal Models**—Lies flat in crawl space or attic, or suspended from ceiling anywhere. Occupies no floor space. Gas-fired: 4 sizes, 70,000 to 135,000 Btu/hr input. Oil-fired: 4 sizes, 80,000 to 165,000 Btu/hr output.

## DOMESTIC GRAVITY FURNACES

All furnaces listed above are forced air furnaces. For homes suited to gravity heating, Armstrong has models for basement installations, to burn oil, coal or gas. 10 sizes.

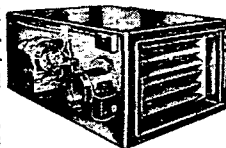
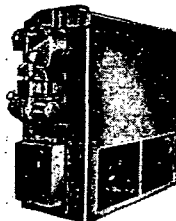


## HEAVY DUTY INDUSTRIAL FURNACES

Seven sizes, either gas or oil-fired.

Standard models, 350,000 and 450,000 Btu/hr gas or oil-fired. Stainless steel heat exchanger. Two blowers. Induced draft. Units may be installed vertically (as illustrated) for air delivery upward or suspended for air delivery downward or horizontal. Factory assembled, wired and fire-tested.

Suspended units, oil-fired only, 225,000, 275,000, and 350,000 Btu/hr. Stainless steel combustion chamber, aluminized steel secondary tubes. Factory assembled, wired, and fire-tested.



# Armstrong Furnace Company

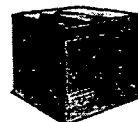
Columbus, Ohio



## COOLING EQUIPMENT

### Air Cooled

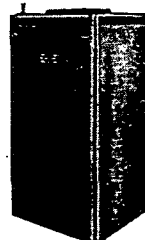
Air-cooled summer air conditioners designed for convenient installation. Evaporator unit, including only those elements which must be located close to the cooling coil is installed inside. Other parts are incorporated in the condensing unit, which is usually installed outside. Evaporator unit is connected to the condensing unit by two copper lines—a liquid refrigerant line and a suction line. Motor-compressor unit guaranteed in writing 5 years. Up-flow, down-flow, horizontal-flow, and independent unit cooling coils, 2, 3, 5-ton capacities.



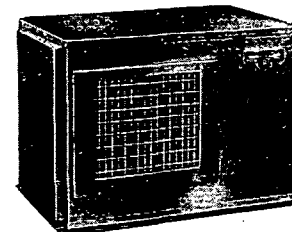
Up-Flow Coil



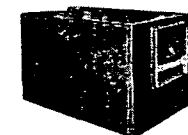
Down-Flow Coil



Vertical Companion Model



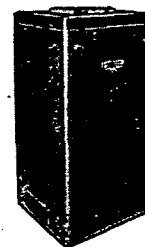
Motor-Compressor Unit



Horizontal Independent Coil



Horizontal-Flow Coil



Vertical Companion Model

### Water Cooled Residential Models

Vertical or horizontal companion units to harmonize with Armstrong winter air conditioners. Entire refrigeration unit hermetically sealed. Five year written guaranty. Water-cooled. Vertical units: 2, 3, 5-ton capacities. Horizontal units; 2 and 3 ton capacity.



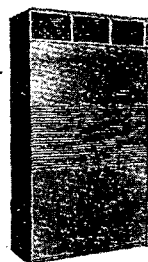
Duct Cooler

Write for the Armstrong consolidated catalog, a useful reference book on heating and cooling. Includes detailed specifications, dimensions, illustrations and descriptions of all Armstrong furnaces and air conditioners. Please address Department G-5 at the plant nearest you.

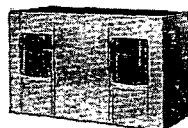


Dayton 1, Ohio

AIR CONDITIONING • HEATING FOR HOMES, BUSINESS, INDUSTRY



**WATER-COOLED "PACKAGED" AIR CONDITIONING** ... 2, 3, 5, 7½, 10, 15 hp Complete—assembly and tested at the factory. Cools, dehumidifies, filters and circulates air. Free air discharge or duct distribution. Heating coil for year 'round service optional. Compact—entire unit is enclosed in "Bond-erized" steel cabinet of modern, FUNCTIONAL design. Occupies very little floor space. Easily Installed—Needs only electric, water and drain connections. Flexible—can be installed singly or in multiple to meet virtually every requirement. 5-year warranty on entire refrigeration cycle.



**WATERLESS COMMERCIAL AIR CONDITIONING** ... 2, 3, 5, 7½ hp. Uses no water, needs no plumbing, all-electric operation. Flexibility of installation. Low cost of operation. 5-year warranty on entire refrigeration cycle.



**"SPACESAVER"—GAS OR OIL-FIRED FURNACES** ... 67,000 to 240,000 Btu output. Hi-Boy and Lo-Boy models heat, humidify, filter and circulate the air. "Bond-erized" and insulated cabinets. Burners start, stop and operate quietly, have many features for high-efficiency heating. Gas models approved by A.G.A.; oil models approved by Underwriters' Laboratories.



**"HORIZONTAL"—GAS OR OIL-FIRED FURNACES** ... gas—48,000 to 120,000 Btu output, oil—84,000 to 168,000 Btu output. May be installed in attic, under floor, or hung from ceiling. Gas models have dual flue outlets and draft diverter mounts on either side. Completely automatic controls fully enclosed.



**COUNTERFLOW—GAS OR OIL-FIRED FURNACES** ... 65,000 to 100,000 Btu output. May be installed in closet. Fully automatic. Quiet rubber-mounted blower. Front flue outlet. Factory-assembled, easy to install.



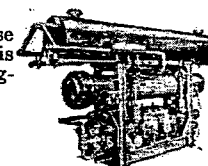
**RADIAL COMPRESSOR UNITS** ... 10 to 125 hp. These heavy-duty units, for use with Freon, are especially designed for air conditioning or refrigeration. Radial compressors are direct connected and have force-feed lubrication. Automatic capacity-reduction. Light weight, economical to operate.



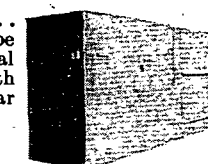
Dayton 1, Ohio

AIR CONDITIONING • HEATING FOR HOMES, BUSINESS, INDUSTRY

**"PACKAGED" LIQUID COOLERS** ... 3 to 250 hp for use with Freon refrigerants. A completely assembled unit that is piped, pressure tested, dehydrated and supplied with a refrigerant holding charge. Starters and control panels optional.



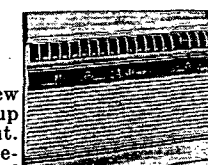
**CENTRAL DUCT "PACKAGED" AIR CONDITIONING** ... 20, 25, 30, 40, 60, 75, and 100 hp. Self-Contained Central Type "Packaged" Air Conditioners. Utilizes the Airtemp Radial Compressor with its exclusive features. Units available with evaporative condenser or for use with cooling tower. 5-year compressor warranty on 20, 25, 30 hp sizes.



**INDIVIDUAL—ROOM AIR CONDITIONING UNIT** ... For year 'round cooling and heating when used with central cold and hot water systems. Ideal for hotels, motels, offices. Three types—floor, wall and ceiling. Built-in controls make each unit independently operated. Two centrifugal fans provide circulation.



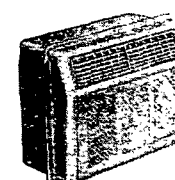
**CONVENTIONAL—ROOM AIR CONDITIONING** ... new window models available in ½, ¾, 1, 1½ hp. Flush mounts up to 3½ in. from sash line or can be installed half in and half out. Full directional control of discharge air. Cools, filters, dehumidifies, exhausts, and ventilates. Thermostatic control of temperature.



**CASEMENT—ROOM AIR CONDITIONING** ... Window models in ½ and ¾ hp. Easy inside installation without cutting or removing glass—nothing projects outside or interferes with opening, closing or locking of window.



**IMPERIAL—ROOM AIR CONDITIONING** ... In-The-Wall Installation for individual Room Air Conditioning—in ½, ¾ and 1 hp. Ideal for homes, offices, motels and hotels. Filters, dehumidifies, cools, and gently circulates the air. Only 18½ in. deep, fits flush on outside of building with minimum projection on inside. Thermostatic control of temperature. **IMPERIAL—WINDOW MOUNT**—in ½, ¾ and 1 hp. Fits all windows 28 in. and larger.



## Combustion Engineering, Inc.

Home Equipment Division

911 West Main Street, Chattanooga, Tennessee

Heatmaster  
Home Heating  
and Cooling



The simple way  
to heat and cool  
a home

Heatmaster Home Heating and Cooling System is pre-engineered and factory assembled

This "wet" system is assembled at the factory, ready to install on the job. The C-E units are approved by A.G.A., built and inspected in accordance with ASME code and backed by the C-E warranty. Designed to meet FHA Minimum Property Requirements for financing.

Take just 4 sq ft of floor space

The C-E Heatmaster Home Heating and Cooling System uses only standard piping and wiring practices. Compact room conditioners are recessed between standard studding.

### C-E HOME HEATING UNIT

Model 110GHB-88 LM

Height—36" Inlet—1" I.P.S.  
Width—24" Outlet—1" I.P.S.  
Depth—24 3/4" Gas Supply—3/4" I.P.S.  
Flue Dia.—6" Drain—1/2" I.P.S.

Weight of Complete unit—Approx. 250 lbs (including controls and circulator)

FURNISHED AS STANDARD WITH: Circulator, Gas Regulator, Gas Automatic Pilot and Safety Valve, Gas Flue Diverter (Draft Hood), Control Relay, Complete wiring and piping for simple hook-up, Three Way Control Valve, Fan Control Switch, Drain Valve, Gas Control Valve (Solenoid) Temperature, Pressure and Altitude Gauge.

### CAPACITY AT A.G.A. CONDITIONS

|                             | SEA LEVEL TO 2,000' |            | 2,000 to 5,000' |            |
|-----------------------------|---------------------|------------|-----------------|------------|
|                             | INPUT Btu           | OUTPUT Btu | INPUT Btu       | OUTPUT Btu |
| Nat'l. Mfd. and Mixed Gases | 110,000             | 88,000     | 88,000          | 70,400     |
| Liq. Pet. Gases             | 105,000             | 84,000     | 84,000          | 67,200     |

Electrical Supply  
Unit Service 110 v., a-c., 60 Cy., 1 Phase  
Thermostat Serv. 24 v., a-c.

### SPECIFICATIONS AND DIMENSIONS—ROOM CONDITIONERS

|                                  | Recessed Model 10-R | Recessed Model 22-R | Free Standing Model 10-RFS | Free Standing Model 22-RFS |
|----------------------------------|---------------------|---------------------|----------------------------|----------------------------|
| Heating Btu/hr, 200F Water Temp. | 10,000              | 22,000              | 10,000                     | 22,000                     |
| Cooling Btu/hr, 42F Water Temp.  | 4,000               | 9,000               | 4,000                      | 9,000                      |
| Water Flow gpm                   | 1.5                 | 3.0                 | 1.5                        | 3.0                        |
| Box Height                       | 18 3/4"             | 18 3/4"             | 18 3/4"                    | 29 3/4"                    |
| Box Width                        | 14"                 | 29 3/4"             | 14"                        | 29 3/4"                    |
| Box Depth                        | 6"                  | 6"                  | 6"                         | 6"                         |
| Cover Height                     | 20 1/2"             | 20 1/2"             | 20 1/2"                    | 20 1/2"                    |
| Cover Width                      | 16 3/4"             | 31 3/4"             | 16 3/4"                    | 31 3/4"                    |
| Filter Size                      | 9 3/4" x 14"        | 9 3/4" x 29 1/2"    | 9 3/4" x 14"               | 9 3/4" x 29 1/2"           |
| Cover Depth                      | 2 3/4"              | 2 3/4"              | 6 3/4"                     | 6 3/4"                     |

Fittings are adaptable for 3/4" or 1/2" I.D. Copper Water Tubing—Type "L."

Specifications are Subject to Change Without Notice.

## Hydraline Products

Division Borg-Warner Corporation

General Sales Office: 18538 Mack Avenue • Detroit 36, Michigan

District Engineers in Principal Cities of the United States



**Hydraline** YEAR 'ROUND  
RECESSED ROOM AIR CONDITIONERS

Hydraline combines in one central forced-water heating and cooling system the desirable features of two separate systems—gentle forced-water heating or cooling to the room, filtered air circulation in the room.

The basic Hydraline units measure only 17 3/4 in. x 14 in. x 4 3/4 in. and may be fully recessed between standard studs or under floor between joists.

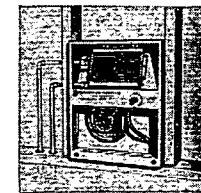
A manual blower speed control with each unit provides individual room control. Automatic Control Kits also provide thermostatic control of individual room temperatures.

Balanced heating or cooling is no problem even in the most rambling type of structure because Hydraline units are controlled independently of the central system.

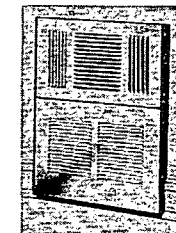
As many thermostatically controlled zones can be specified as are needed without the need of a separate circulator for each zone.

With modulating controls, Hydraline units can be economically combined with Radiant Panel Heating, such as snow melting, where such combinations are specified.

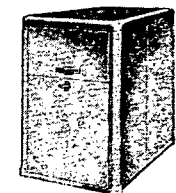
Mechanical specifications, system designs and technical data available upon request.



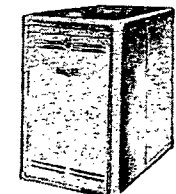
Model HAC-155  
Basic unit in wall (before plaster). Up to 155 cfm  
9M-Btu, heating—4M-Btu, cooling.



Model HAC-155  
Completed in-wall installation with grille attached.



Hydraline Chiller Package  
(May be added later)



Hydraline Boiler Package  
(Gas or Oil Fired)



## Hayes Furnace Mfg. & Supply Co.

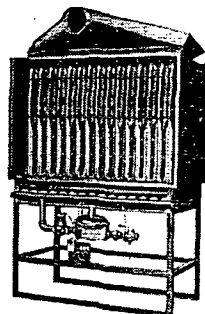
2929 South Fairfax Ave., Los Angeles 16, Calif.

(Telephone Texas 0-3734)

Contact Nearest Representative

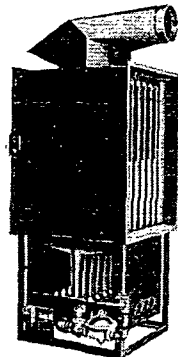
Associated Refrigeration Engrs., Montgomery, Ala.  
M. Blazer & Son, Passaic, N. J.  
Blue Flame Supply Co., Atlanta, Ga.  
Eugene Bolstad, Edmonton, Alberta, Canada  
E. B. Bomar, Phoenix, Arizona  
Boyd Engineering Co., Albuquerque, New Mex.  
and El Paso, Texas  
Dealers Supply Co., Atlanta, Ga.  
Reube O. Emery, Nashville, Tenn.  
Jewell & Co., Hot Springs, Ark.

Leudecke Engineering Co., Austin, Texas  
Homer Maxey & Co., Lubbock, Texas  
McCombs Supply Co., Denver, Colo.  
Noland & Co., Newport News, Va.  
O'Connor-Oklahoma Co., Oklahoma City, Tulsa,  
Okla., and Wichita, Kansas  
Smith Steam Specialty Co., Kansas City, Mo.  
Tay-Holbrook, Inc., San Francisco, Calif.  
F. R. Young, Houston, Texas



### DUCT FURNACES

Constructed of Type 321 Stabilized Stainless Steel. Non-corrosive property of heat exchanger permits installation downstream of cooling coils or washer. Heat exchanger will not corrode when subjected to continuous ventilation during the summer season. Designed for continuous blower operation for offices, theaters, schools, churches, factories. Air throughput in either direction. Draft Hood and Vent Manifold reversible, adjustable for both horizontal and vertical connection. 14 sizes, 80,000 to 600,000 Btu per hr input in 40,000 Btu increments. A.G.A. certified for all gases.



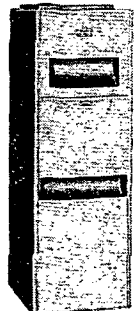
### MODEL SED-E

Non-corrosives type 321 stainless steel heat exchanger. Permits installation downstream of cooling equipment, for continuous blower operation. Air throughput in either direction. 80,000 to 600,000 Btu input.

### MODEL SED-S

Same as SED-E except controls are at the side, instead of at the end where accessibility requires. SED-S is available in sizes from 80,000 to 600,000 Btu input in increments of 40,000 Btu.

Both SED-E and SED-S can be used for industrial applications for drying.



### FORCED AIR FURNACE MODEL SEC

Heat exchanger constructed of identical die formed sections of type 321 stabilized stainless steel. Sections are seam and arc welded. One piece cast iron burners with drilled ports. Oversize double inlet blower. Long hour motor. Equipped with glass filters. Can furnish permanent filters at extra cost. Finished in baked silver grey. 6 sizes 70,000 to 245,000 Btu per hr input in 35,000 Btu increments. For natural, manufactured and L.P. gases. Can be used for 0 clearance

ALL HAYES FURNACES ARE A.G.A. APPROVED

1252

### DUCT FURNACE MODEL SED-VF

Tested and approved as a DUCT FURNACE—Constructed of type 321 stabilized stainless steel. Re-circulated or fresh air is introduced through bottom, sides or back of furnace. Equipped with air bypass. Handles large cfm per Btu input. Vent in front of furnace. Made in 6 sizes from 70,000 to 245,000 Btu per hr input in increments of 35,000 Btu. For natural, manufactured and L.P. gases.

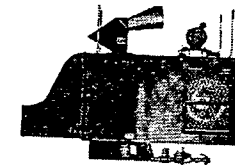
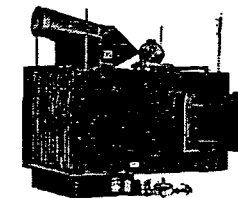


### FORCED AIR SUSPENDED FURNACE, MODEL SES

Equipped to install in a suspended duct system. Inlet and outlet designed for sheet metal duct connection.

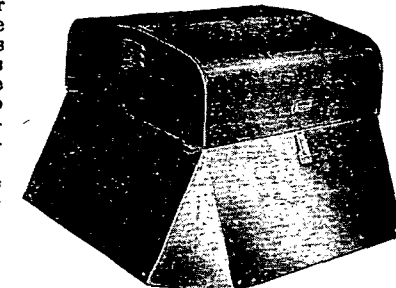
### UNIT HEATER MODEL SEU

Used where room air is to be recirculated. Diffuser outlet with adjustable vertical and horizontal vanes. Both types of Suspended units are designed for factories, commercial and other large Btu requirements — equipped with brackets for suspension, save floor space. Double inlet forward curve blower. Continuous duty variable pitch drives; cast iron, raised port, precision machined burners. Made in sizes 80,000 to 600,000 Btu per hr input in 40,000 Btu increments. For natural, manufactured and L.P. Gas.



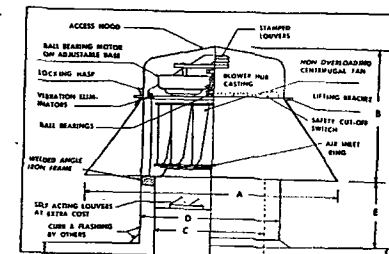
### EJECTAIR Power Roof Ventilator by HAYES

Centrifugal backwardly curved blower type . . . the blower wheel cannot be overloaded regardless of length or curves in the duct or variation in design. It is belt driven to provide flexibility. The ventilator is mounted on a built up curb on the roof. Special features include low profile with streamlined design and a corrosion resistant housing. The motor and fan bearings are grease packed ball bearings and are out of the air stream. A manually operated safety cutoff switch is provided.



### DIMENSIONS

| UNIT<br>SIZE | A      | B      | C      | D      | E  | APPROX.<br>SHIP.<br>WT. |
|--------------|--------|--------|--------|--------|----|-------------------------|
| 1000         | 24 1/4 | 15 1/4 | 11 1/4 | 19 1/4 | 16 | 130                     |
| 1200         | 28     | 17 1/4 | 13     | 21     | 16 | 137                     |
| 1300         | 29     | 24 1/4 | 13 1/4 | 21     | 16 | 180                     |
| 1600         | 35 1/4 | 25 1/4 | 16 1/4 | 24 1/4 | 16 | 275                     |
| 1800         | 39 1/4 | 27 1/4 | 20     | 28     | 16 | 300                     |
| 2000         | 43     | 30     | 20     | 28     | 16 | 325                     |
| 2200         | 46 1/4 | 30 1/4 | 22 1/4 | 30 1/4 | 16 | 350                     |
| 2400         | 49 1/4 | 32 1/4 | 25     | 33     | 16 | 500                     |
| 2700         | 55 1/4 | 34 1/4 | 28     | 36     | 16 | 590                     |
| 3000         | 60 1/4 | 36 1/4 | 31     | 39     | 16 | 630                     |
| 3200         | 66     | 40     | 33 1/4 | 41     | 16 | 700                     |
| 3600         | 75     | 42 1/4 | 40 1/4 | 48 1/4 | 16 | 795                     |
| 4000         | 83     | 45 1/4 | 40     | 52     | 16 | 875                     |
| 4400         | 90 1/4 | 49     | 44 1/4 | 56     | 16 | 1120                    |
| 4900         | 98 3/4 | 54     | 50     | 62     | 16 | 1500                    |
| 5400         | 108    | 57 1/4 | 55     | 67     | 16 | 1900                    |



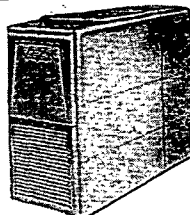
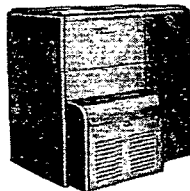
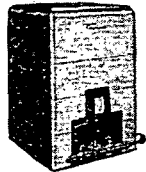
1253

HEATING

# Mueller Climatrol

COOLING

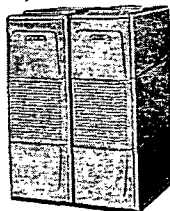
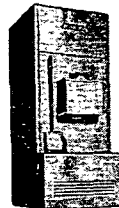
Division of Worthington Corporation  
Milwaukee 15, Wisconsin



Type 101 (Gas)—201 (Oil) Gas or oil, steel, gravity furnace, convertible. Modular design. Available in three sizes: 135-, 160-, 180,000 Btu. (Type 120-220 also available in 90,000 Btu inputs.)

Type 105 (Gas) 202 (Oil) Gas or oil, steel, winter air conditioners. Convertible. Available in eight sizes with input ratings of 150,000 to 675,000 per hour.

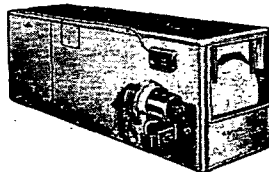
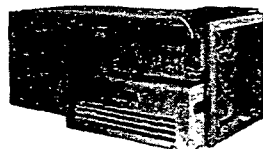
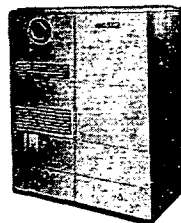
Type 116 (Gas) 216 (Oil) Gas or oil, lowboy winter air conditioners. Four sizes—90,000 to 150,000 Btu input. Convertible. Types 119 (Gas) 219 (Oil) also available.



Type 117 (Gas) 217 (Oil) Versatile unit that meets the requirements of either a low-boy or highboy. Available in four sizes—80,000, 100,000 and 125,000 and 150,000 Btu input. Shipped assembled, pre-wired. Enclosed burner.

Type 118 (Gas) 218 (Oil) Counterflow winter air conditioners. For perimeter heating, slab or crawl-space homes. One size only—100,000 Btu input. Types 115 (Gas) and 215 (Oil) available in 150,000 Btu input.

Type 124 (Gas) 224 (Oil) 906 Highboy winter air conditioners. Four sizes; 80-, 100-, 125-, 150,000 Btu input. Compact. Shipped assembled and pre-wired. Type 906 companion cooling unit available.

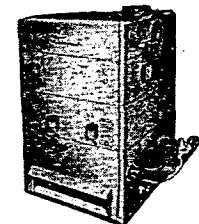
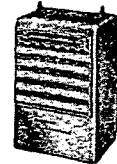


Type 123 (Gas) 223 (Oil) 928 Versatile combination heating and cooling unit. Casing has integral compartment for cooling cycle. One size only, 100,000 Btu.

Type 165 Gas-fired horizontal winter air conditioners. Available in two sizes with A.G.A. rating of 100,000 and 120,000 Btu. Shipped assembled and pre-wired. Large size centrifugal blower.

Type 253 Oil-fired horizontal winter air conditioner, or blower heater. Up-draft design. All welded steel heat exchanger. Convertible to gas firing. Available in five sizes, 110,000 to 350,000 Btu input.

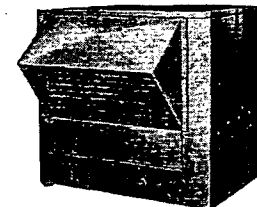
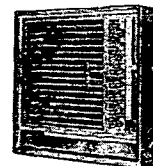
## Mueller Climatrol



Type 160 Gas, direct fired, steel, suspended unit heater. Horizontal air tube design; propeller type fan. Available in nine sizes, with A.G.A. ratings of 25,000 to 225,000 Btu input.

Type 10 Gas-fired, cast iron boiler for residential heating, and hot water supply. A.G.A. approved for all types of gas. Sizes range from a 3-section, 54,000 Btu input to a 15-section, 378,000 Btu input. Controls enclosed. (Also with controls exposed, Type 11).

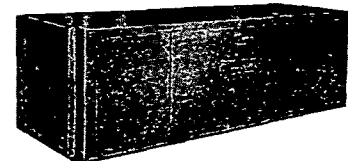
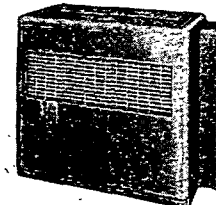
Type 21 Gas-fired, cast-iron boiler for larger installations. Sectional construction, (sizes increase in increments of 70,000 Btu). A.G.A. rated in sizes from 6-section, 350,000 to a twin 31-section, 4,200,000 Btu unit.



Type 900- 912- 914 Summer air conditioning coil units; for operation with remote air- or water-cooled condensing units. Type 900- installs vertically with any forced air unit. Available in 2, 3, 5 and 7½ ton sizes. Type 912- installs horizontally. Available in 2 and 3 ton sizes. Type 914- Counter-flow. Available in 2-3 ton sizes.

Type 903 Self-contained cooling unit for installation with any warm air system, new or existing. Refrigeration cycle is factory-assembled, charged. 2, 3 and 5 hp sizes. Water cooled.

Condensing Units Remote Type 908, air-cooled, (illustrated). Water-cooled Type 902 also available. Both in 2, 3, 5 and 7½ hp sizes. Type 907 remote condenser, for converting water cooled units. Available in 2, 3, and 5 hp sizes.



Type 904 Self-contained cooling unit for stores, restaurants; or used with duct systems in homes with steam or hot water heat. Built-in blowers and filters. 2, 3, 5, 7½, 10 and 15 hp sizes.

Type 920 For heating and cooling in hotels and commercial buildings. Cooling is self-contained—air cooled. Heating through central system with steam or hot water coil. Operates with 370 cfm. Cooling is 1 hp.

Type 911 Self-contained, air-cooled summer air conditioner. May be installed singly or as multiple units in conjunction with existing duct system, or with its own duct system. Available in 1 hp size.

## Lamneck Division

Clayton & Lambert Mfg. Co.

1026 Lamneck Street,  
Middletown, Ohio

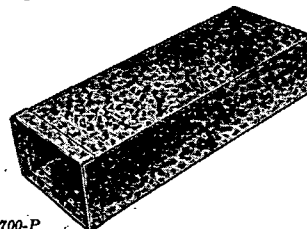
Phone 2-6304.

DISTRIBUTORS IN PRINCIPAL CITIES



Fittings and duct work illustrated are selected to indicate range of design and construction of the Lamneck line of air distribution pipe and fittings for heating and cooling. This line is designed with full-throated elbows and angles for full efficiency to simplify later air cooling demands. Line includes complete range of perimeter heating fittings. *New catalog 5529 available.*

No. 700-P standard L-shaped corner seam duct. Manufactured in 8 in. depth, 16 in. and 32 in. length, in widths from 4 in. to 26 in. Also available as No. 700-T, standard U-shaped center-seam duct. Duct sections furnished complete with No. 737-T Snap-lock connector.



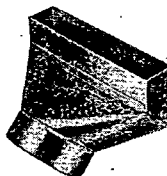
No. 700-P



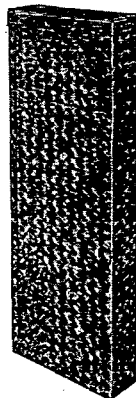
No. 794

No. 794 combination top and side takeoff (adjustable collar). Available in 4 in., 5 in., 6 in., 7 in. and 8 in. sizes.

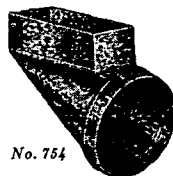
No. 753 45 degree angle boot available in register sizes  $2\frac{1}{4}$  in. x 12 in. and  $2\frac{1}{4}$  in. x 14 in. for 6 in. systems and  $2\frac{1}{4}$  in. x 10 in. for 4 in. systems.



No. 753



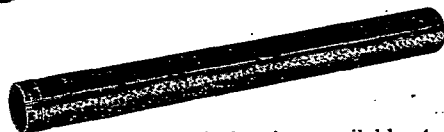
No. 700



No. 754

No. 754 center end register boot available for register sizes from  $2\frac{1}{4}$  in. x 12 in. to 6 in. x 10 in.

5 ft Snap-lock pipe



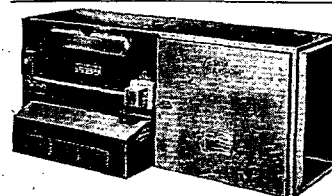
5 ft Snap-lock pipe available 4 in through 8 in.

No. 700 wall stack. Complete with No. 737 connector attached to each half. Available in  $3\frac{1}{4}$  in. depth, 10 in. to 14 in. width, and 15 in. to 60 in. length.

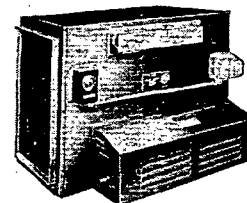
## Norman Products Company

1150 Chesapeake Avenue,  
Columbus 12, Ohio

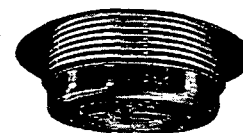
MANUFACTURERS OF A COMPLETE LINE OF GAS HEATING AND AIR CONDITIONING EQUIPMENT. FOR INFORMATION CONTACT FACTORY REPRESENTATIVE AT COLUMBUS HEADQUARTERS SALES OFFICE.



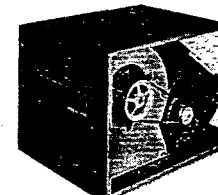
Norman Southerner—Horizontal forced air gas furnace for compact home installation. Factory assembled and tested. Right or left-hand unit. Newly designed heat exchanger provides more efficient heat transfer. Five sizes: 70-85-100-120-140 thousand Btu input.



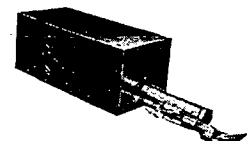
Norman Duct Furnace—for Commercial and Industrial Heating—in combination with air conditioning. Installed in ducts of warm air and air conditioning system where air is circulated by remote blower. 70-85-100-120-140 thousand Btu input.



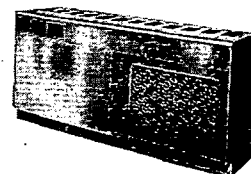
Norman '360'—Gas fired overhead forced convection heater. "Circular" heat distribution eliminates hot blasts and cold corners. Streamlined design. UL listed. 100,000 Btu input.



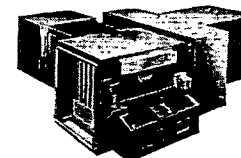
Norman Blower-Filter Unit... a compact blower, motor, and filter package for handling air requirements of heating and cooling systems up to 5 tons capacity. Entire unit is housed in a heavy gauge steel cabinet. Doors on either side for easy access to filters and blower.



Norman Gas Conversion Burners—Commercial-Industrial in 4 sizes with ratings from 300,000 to 2,000,000 Btu. Converts apartment, commercial and industrial heating plants. Residential burners, ratings 50,000 to 300,000 Btu.



Norman Direct Gas-Fired Unit Ventilator for schoolrooms, offices, stores. Low-cost, self-contained central heating and ventilation system. No piping, or expensive outside ventilating system needed. Easy to install... saves space. 85,000 Btu input.



Norman Winter-Summer Air Conditioner—Horizontal year round air conditioner combining Norman Duct Furnace with independent cooling and blower assembly in one package. Damper compartment operated by single thermostat control. Cooling only in Separate Package for Existing Furnace. Cooling available in 2 or 3 ton unit, heating in capacity of 70-85-100-120-140 Btu input.

DESCRIPTIVE LITERATURE on all items listed above is available from manufacturer. Write for detailed specifications.



## Pennsylvania Furnace & Iron Company

316 North Pine St., Warren, Pennsylvania

Representatives are in principal gas using centers. Pennsylvania Gas Furnaces, Floor Furnaces, Conversion Burners, Pennco Gas Fired Boilers for steam, vapor and water, for residences, schools, hospitals, hotels, stores, and any other type of building that requires a heating plant. A full and complete line of sizes.

### SERIES 6 PENNCO BOILER

The Series 6 Pennco boiler is a large capacity type boiler. It is a cast iron sectional type with all sections having hollow projections which add to the heating surface. The sections are assembled on a specially designed steel base. The design of this base greatly reduces assembling time and reduces installation costs.

The Series 6 boiler sections are hydro-statically tested to 150 psi. All boilers are constructed in accordance with the ASME code. They are also approved by the A.G.A. Testing Laboratory. Twenty-seven different sizes are available from 400,000 Btu per hr input to 4,400,000 Btu per hr input. All Series 6 Pennco boilers are furnished with completely automatic controls.

### SERIES 2 & 3 PENNCO BOILERS

Series 2 & 3 Pennco boilers are the cast iron sectional type with all sections having hollow projections to add to the heating surface and efficiency. Both the Series 2 & 3 are made in either Standard or Deluxe type. The Series 2 is made for water only in four sizes from 175 sq ft EDR to 350 sq ft EDR.

The Series 3 is made for steam, vapor or water and is made in eight sizes from 96,000 Btu per hr input to 400,000 Btu per hr input.

### SERIES 10A PENNSYLVANIA FURNACES

The Series 10A Pennsylvania Forced Air Furnace is constructed with an all steel combustion chamber and corrugated steel radiator. All joints and seams are continuous welded assuring gas tightness. A two-tone blue baked enamel casing contributes to the beauty of the Series 10A Pennsylvania furnace. This Series furnace is made in seven sizes, ranging from 75,000 Btu per hr input to 225,000 Btu per hr input.

### SERIES 10-V VERTICAL TYPE PENNSYLVANIA FURNACE

The Series 10-V vertical type furnace is constructed with the same type combustion chamber and radiator as the Series 10 horizontal. This unit is compact and made in three sizes; 60,000, 90,000 and 120,000 Btu per hr input.

### SERIES 11 AND SERIES 11 ULTRA

The Series 11 and Series 11 Ultra are newly designed forced air furnaces. The Series 11 Ultra is constructed of 12 gauge steel to comply with SUR and for burning fuel oil and gas. Both series are available in three sizes—75,000, 100,000 and 125,000 Btu per hr input.

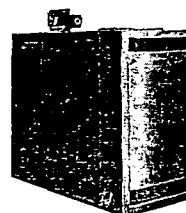
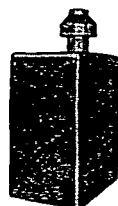
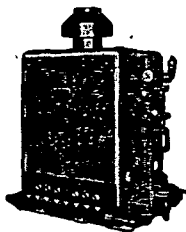
### SERIES 55 PENNSYLVANIA GRAVITY FURNACES

This new line of Pennsylvania Gravity Furnaces is made in six sizes—75,000 to 250,000 Btu per hr input. A two-tone blue enamel finish casing and special designed lining which forms a dead air space contribute to the high efficiency of this unit.

### PENNSYLVANIA CONVERSION GAS BURNERS

The Pennsylvania Conversion Gas Burner is made in three sizes and ranges in size from 75,000 Btu per hr input to 350,000 Btu per hr input.

1258

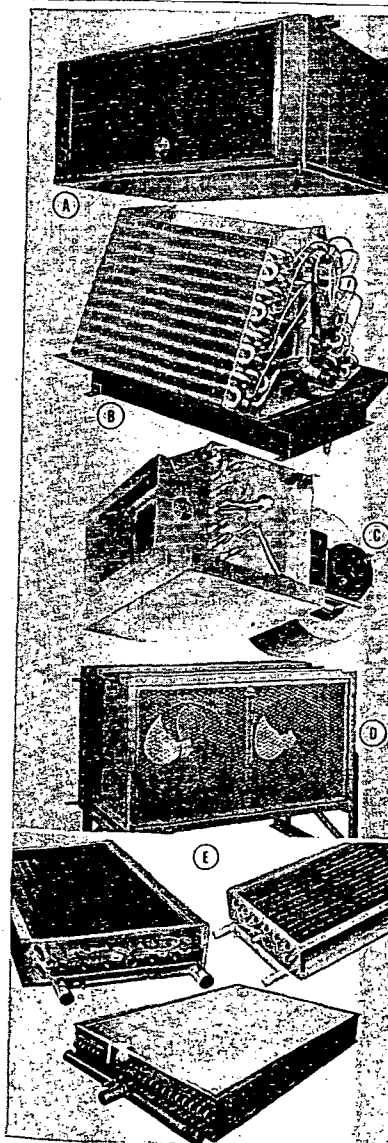


## Refrigeration Appliances, Inc.

909 West Lake Street, Chicago 7, Illinois

MAKERS OF

AIR CONDITIONING AND REFRIGERATION EQUIPMENT  
SINCE 1931



### A—New Krack Komfort Masters

Quiet remote type air conditioners. Models adaptable to practically all remote comfort cooling and heating uses. Designed for ceiling or floor mounting, use with or without ducts. Can be supplied without cabinets for furred-in installation. Volume control dampers and 3-speed control on fan motors give wide range of air velocity modulation. Wide choice of coil arrangements for direct expansion, water, steam, or combinations. Sizes: 2, 3, and 5 ton. Removable filters.

### B—New Krack Furnace Bonnet Koils

Convert new or existing forced air furnace duct systems to summer cooling service with minimum installation problems. Compact V-bank arrangement of air-conditioning coils. Three models have 24,000, 36,000, and 60,000 Btu per hour nominal capacities.

### C—New Krack Transom Komfort Conditioners

Quiet remote type cooler and heater for multi-room offices and commercial, institutional, and private housing. Direct expansion, chilled water, hot water. Optional 3-speed fan control. Two models handle 410 and 480 cfm.

### D—Krack Air Kooled Kondensers

Eliminate all water problems. Easy, inexpensive installation and maintenance. Five models, 1 to 7.5 ton certified nominal capacities based on 110 F condensing temperature and 90 F ambient.

### E—Krack Koils

Air-E-Fex series air conditioning coils . . .  $\frac{3}{8}$  in.,  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in. tube surfaces, for all sizes of installations, old or new. Patented construction features give increased strength, reduce static resistance.

### Evaporative Condensers & Cooling Towers

Floor types for indoor and outdoor applications. Nine sizes 5 to 50 ton.

Write for new detailed bulletins

1259



## Rheem Manufacturing Company

Chicago, 29, Illinois

### REGIONAL OFFICES

SPARROWS POINT 19, MD. 4361 FIRESTONE BLVD., SOUTH GATE, CALIF.  
7600 S. KEDZIE AVE., CHICAGO 29, ILL. 3693 E. MARGINAL WAY, SEATTLE, WASH.  
1025 LOCKWOOD DRIVE, HOUSTON 20, TEX.  
EXPORT SALES OFFICE: 477 MADISON AVE., NEW YORK 22, N. Y.

Every Rheem Furnace is "Fire-Tested" with pilot and burners ignited, Automatic controls, safety checks, operational and construction details must pass rigid tests.



### WARM-AIR HEATING EQUIPMENT GAS-FIRED

Fully automatic, factory-assembled, forced-air furnaces of all-steel, electrically welded construction. "Flame-shaped" combustion chambers (in all but horizontal models) and multiple channel heat exchanger prevent expansion-contraction noise, and provide high heat transfer in limited space. All models feature built-in draft diverters, except for 3302 gravity model and 1603 B floor furnace, and enclosed controls. A.G.A.-approved for natural, mixed, manufactured and LP gases.



**Imperial Highboy—Model 3202**—for first-floor utility room or small basement installation. Top rear flue outlet. Side or bottom filter frames. Knockout plates on casing sides for optional cold-air return. Eight sizes—from 85,000 through 300,000 Btu/hr input—assure a tailored-heat-loss installation for small to largest residences, commercial buildings, churches and stores. 2-tone grey and green baked enamel finish.

**Imperial Lowboy—Model 3402**—for basement installation. Top rear flue outlet with built-in draft diverter. Four sizes from 85,000 through 150,000 Btu/hr input. Completely insulated jacket, finished in attractive grey and green baked enamel for safe, exposed recreation room placement.



**Standard Highboy—Model 3203S**—"File cabinet" styled for compact utility room, hall, closet or small basement installation. Top front flue outlet. Six sizes from 60,000 through 150,000 Btu/hr input finished in pearl-grey baked enamel. All models approved for zero clearance.

**Standard Lowboy—Model 3402S**—designed for even limited overhead clearance basement installation. Top rear flue outlet with built-in draft diverter. Four sizes from 85,000 through 150,000 Btu/hr input. Poly-chromatic, baked-on grey enamel finish. Oversized glass fibre filters assure high dust removal efficiency.



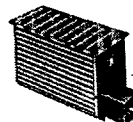
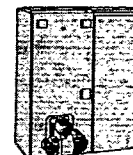
**Horizontal Furnace—Model 2400**—for "perimeter" heating or conventional duct systems. Suitable for attic, attached garage or basementless home crawl space installation. May be suspended from roof rafters or ceiling joists, or rigid support brackets can be placed on bottom of unit for base setting. Five sizes from 60,000 through 140,000 Btu/hr input.

**Counterflow Furnace—Model 3205**—for "perimeter" heating applications. 80,000 and 100,000 Btu/hr input sizes, both A.G.A.-approved for zero clearance installation. Readily accessible blower-filter assembly in top of unit. Ample space in bottom for dehumidifier placement.

**Gravity Furnace—Model 3302**—designed for low cost installation in basements of smaller, compact houses. Four sizes from 77,000 through 150,000 Btu/hr input. Piping and controls fully enclosed in insulated, grey baked enamel-finished jacket. Optional side gas connection.

### RHEEM OIL-FIRED HEATING EQUIPMENT

Highboy—Model 2448, Lowboy—Model 2446, and Counterflow—Model 2444, are pressure atomizing oil-fired. 90,000 and 112,000 Btu/hr bonnet output sizes in all three models. Additional 140,000 Btu/hr bonnet output size available in Lowboy. "Air-foil" design in convoluted heat exchanger assures rapid heat transfer, and expansion and contraction without noise. Factory-assembled burner and support for easy, accurate positioning during installation. All models readily convert to gas-fired furnaces.



### RHEEM SPACE HEATING EQUIPMENT

Four types of space heaters for small homes, "hard-to-heat" rooms and small commercial applications. All are A.G.A.-approved for natural, manufactured, mixed or LP gases.

Flat floor and dual wall (series 1603B) registers in 25,000, 35,000 and 50,000 Btu/hr input sizes. Only 25½ in. overall depth. 2-way adjustable head on dual wall model for easy installation in walls of varying thickness. Console heaters (model 1703) in similar input sizes with minimum space requirements. Tailored design in golden tone finish. Available with automatic or manual controls.

Recessed wall heaters (model 1801) in 28,000 Btu/hr input single wall unit and 50,000 Btu/hr input dual wall units. Both models 60 in. high, 17 in. wide, in neutral ivory casing. Thermostat or manual controls.



### RHEEM AIR CONDITIONING EQUIPMENT

**Year 'Rounder—Model 3103**—offers forced warm-air heating and summer air conditioning controlled by a single thermostat. Summer-winter changeover damper leaves control circuits energized during transfer. Burner operates quietly, efficiently on all gases. Models available with water or air cooled refrigeration condensers. Water cooled refrigeration circuits hermetically sealed for life. Remote air cooled condenser field installation work involves only two refrigeration lines. Wide selection of furnace and cooling capacities.

**Add-on Conditioner—Model 3150**—provides year 'round air conditioning when installed beside any Rheem warm-air heating furnace. For economical summer air conditioning, unit may be combined with existing warm air, or wet heat systems, or used in houses without heating systems. 2 and 3 ton water or air cooled models. Thermostat available, including "off-on" switch. Completely automatic controls. Water cooled refrigeration circuits hermetically sealed for life. Only work required for field-installed air cooled units involves two refrigeration lines.

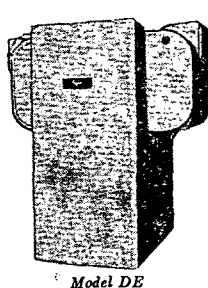




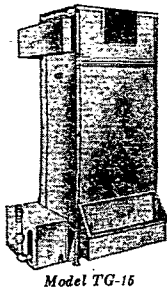
# Servel

**Air Conditioning Division**  
Servel, Inc.  
Evansville 20, Indiana

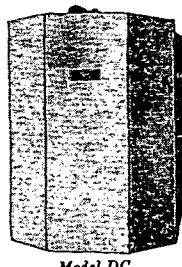
## SERVEL All-Year® GAS AIR CONDITIONERS



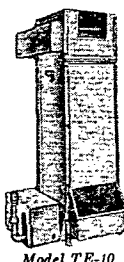
Model DE



Model TG-15



Model DC



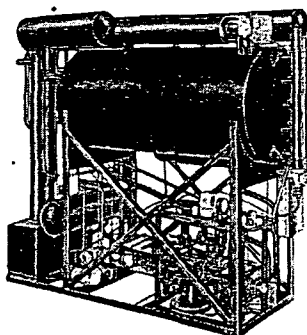
Model TE-10

### 5.4-TON MODEL AND COOLING TOWER

Complete year-round air conditioning. Delivers 5.4 tons of refrigeration, and 96,000 or 144,000 Btuh of heating output depending on model. Fully automatic. Induced draft type tower with capacity to match model DE unit.

### 3.3-TON MODEL AND COOLING TOWER

Deluxe unit for medium-size homes. Supplies 3.3 tons of refrigeration, and 96,000 Btuh of heating output. Fully automatic. Induced draft type tower with capacity to match model DC unit.

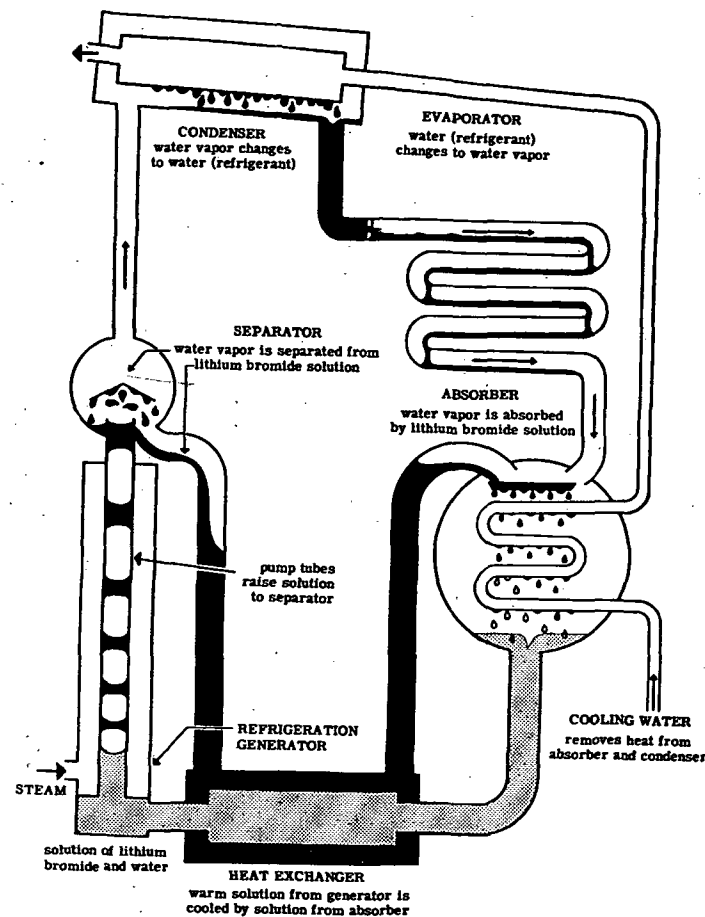


Model DYCS

### SERVEL 25-TON WATER CHILLER (Steam Operated)

Completely "packaged." Requires only simple plumbing connections plus 115-volt line to operate controls. Steam controls built in. Provides chilled water at minimum temperature of 40 F for wide range of applications—from industrial processing to comfort air conditioning. Chilled water circuit operates under normal pump pressure—is not a part of absorption vacuum system.

## SERVEL ABSORPTION REFRIGERATION CYCLE



In these Servel Air Conditioners an absorption refrigeration unit takes the place of the usual electric compressor refrigeration system. It is a compact factory-sealed unit that is actuated by heat. Gas-operated, self-contained steam generators supply the heat in DE and DC models.

The 25-ton Water Chiller does not incorporate its own steam generator.

In all models, water is the refrigerant and lithium bromide the absorbent.

Five-Year Factory Warranty is provided for all models—one year on the complete unit and four additional years on the absorption refrigeration unit. In DE and DC models, the steam generator and heating coil are also covered for five years.

## Utility Fan Corporation

A Division of Utility Appliance Corp.  
911 East 59th Street, Los Angeles 1, Calif.

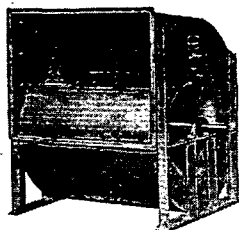
Cable Address: UTILIFAN, Los Angeles

Manufacturers of heavy and standard duty blowers for heating, air conditioning and ventilating installations. Producers of blowers and blower parts for original equipment manufacturers.

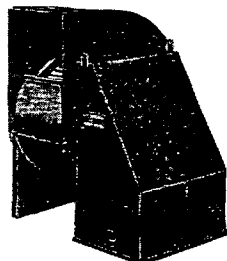
Built, tested and rated in accordance with ASHVE and NAFM codes.

Sizes 6 inches to 60 inches.

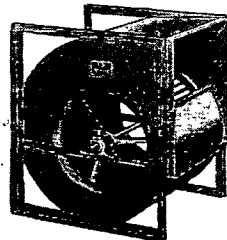
Write for catalog data.



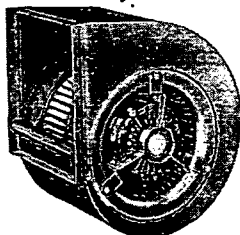
Heavy duty blower, Type "B" backward curved DWDI.



Enclosed Drive Blower



Four-Way Blower



Silent Direct Drive Blower

**HEAVY DUTY BLOWERS**, Double Inlet Double Width and Single Inlet Single Width, Forward and Backward Curved Wheels. Wheel diameters range in size from 12 inches to 60 inches. These blowers are of Class I construction, in any of ten drive arrangements and eight discharge positions.

**NEW ENCLOSED DRIVE BLOWERS**, sizes 10 inches to 36 inches, with fully enclosed drive compartment. Ideal for roof installation. The ED blowers are of the forward curved slow speed type, built for ease of installation and a minimum of maintenance.

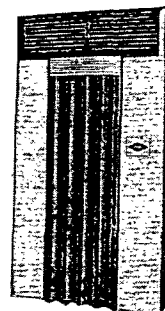
**UTILITY'S FAMOUS "FOUR WAY" BLOWERS**, designed by Utility, available in single width single inlet as well as double width double inlet. A simple change in bearing position makes it possible to obtain discharges in any of four directions. An economy unit for medium duty use, rigidly constructed and factory guaranteed.

**NEW SILENT DIRECT DRIVE BLOWER**. By using vibration-absorbing Neoprene in the basic hub design, the blower wheel is isolated from the motor shaft. This unique development produces a very quiet blower. The direct drive blower is available in three wheel sizes providing a varied range of capacities, depending on motor horsepower selected.

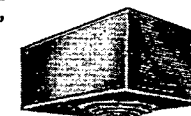


## Union Asbestos & Rubber Company

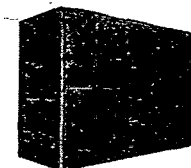
332 S. Michigan Ave., Chicago 4, Illinois  
HEATING AND COOLING PRODUCTS



The UNARCO  **ROYAL-AIRE** (CU series) provides full comfort cooling range. Refrigerant flow through vertical coil is thermostatically controlled, utilizing UNARCO "pump-down" control system. Oversize vari-flow blower and oversize condenser, plus large "fin area" cooling coil, insure full-rated capacity.



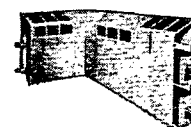
The UNARCO  **CEILING SUSPENDED UNIT** (CS series) is a completely self-contained unit available in 2-, 3-, 5- and 7½-ton capacities.



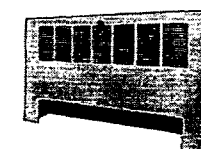
The UNARCO  **COMPLETE AIR CONDITIONING PACKAGE** for stores and industrial plants (series AEC) is available in capacities from 5 to 60 tons. It is of single cabinet construction, with packaged condensing unit, blower coil section and evaporative condenser.



UNARCO  **HORIZONTAL AND DOWNBLOW UNIT HEATERS** (down-blow shown) include die-formed cabinets of not less than 20 gauge steel. Casings are phosphatized and finished in hammer enamel, baked on for permanence.



UNARCO  **WALL RADIATION**. Covers are of 14, 16 and 18 gauge steel in sloping top, flat top and expanded metal styles. Available in 2 ft to 10 ft lengths in 6 in. increments. Elements range from 2 ft to 12 ft in 6 in. increments. Accessories available.



UNARCO  **CONVECTOR RADIATORS**. Cabinets are phosphatized, finished in prime gray paint, and constructed of furniture quality steel. Also available in other models. Elements consist of cast brass headers, aluminum fins, copper tubes and 20 gauge side plates.

## American Foundry and Furnace Co.

General Offices: Bloomington, Illinois, P. O. Box 904

### Sales Offices

|                       |                           |                   |                            |
|-----------------------|---------------------------|-------------------|----------------------------|
| ATLANTA 6, GA.        | Boynton Cole              | PHILADELPHIA 2,   | Am. Heating & Ventilating  |
| BOSTON, MASS.         | Foulds Associates         | PA.               | Co.                        |
| BUFFALO 2, N. Y.      | Arnold R. Kamman Co.      | RICHMOND 25, VA.  | Richmond Air Equipment     |
| CHICAGO, ILL.         | D. P. Gladish Co.         |                   | Co., Inc.                  |
| (Glenview)            |                           | ROCHESTER 7,      | Wm. H. Stell Co.           |
| CINCINNATI 2, O.      | Walter A. Juergens        | N. Y.             |                            |
| CLEVELAND 7, O.       | Am. Warming & Ventilating | ST. LOUIS 17, MO. | M. F. Carlock              |
|                       | Co.                       | SALT LAKE CITY 1, | Williams, Gritton & Wilde  |
| DES MOINES 14, IA.    | C. H. McGuinness Co.      | UTAH              |                            |
| ELMIRA, N. Y.         | Am. Warming & Ventilating | SAN ANTONIO 6,    | Langhammer-Rummel Co.      |
|                       | Co.                       | TEX.              |                            |
| INDIANAPOLIS 18, IND. | Elliott-Williams Co.      | SAN LEANDRO,      | Aladdin Heating Corp.      |
| KANSAS CITY 11, MO.   | John H. Kitchen & Co.     | CALIF.            |                            |
| LOS ANGELES 7,        | Harry F. Haldeman, Inc.   | SEATTLE 9, WASH.  | McPherson Furnace & Equip- |
| CALIF.                |                           |                   | ment Co.                   |
| MILWAUKEE 2,          | Am. Foundry & Furnace     | SYRACUSE 3, N. Y. | F. W. Chadwick Co., Inc.   |
| WIS.                  | Co.                       | TOLEDO 4, O.      | Am. Warming & Ventilating  |
| NASHVILLE 6, TENN.    | James H. Winters Co.      |                   | Co.                        |
| NEW ORLEANS 15,       | R. K. Rothrock            | TORONTO,          | Michael Stuart Co., Ltd.   |
| LA.                   |                           | CANADA            |                            |
| NEW YORK 68,          | The Demuth Co.            |                   |                            |
| N. Y.                 |                           |                   |                            |

### HEAVY DUTY FORCED WARM AIR HEATERS

Heavy Cast Iron Construction—Integrally Cast Fins.  
Shipped Knocked Down—Assemble Inside Building.  
Tight Bolted Joints.  
Long Fire Travel—Ample Heating Surface.  
Design Relieves Internal Stresses When Expanding.  
Horizontal Flues With Access Doors Facilitate Cleaning.

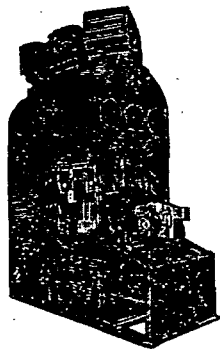
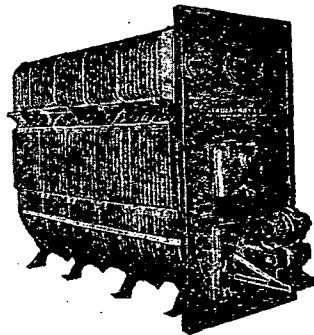
#### CENTRAL TYPE

"June-Aire" conditioning for schools, public and commercial buildings. Heats and ventilates with same system. Outside air and recirculated air used in any desired proportion. Air filters—Germ killing means. Atomist humidifier—Humidistat control. Individual room temperature control with constant ventilation. Time clock program control of plant. Oil, Gas, Coal (hand or stoker fired) and convertible models. Capacity for buildings of any size. Warm floors (air tubes in slab) combined with window sill air supply, optional application method. Summer cooling by adding compressor and coil.

#### UNIT HEATER TYPE

"Superfin" (Cast Iron\*) and "Dyne-Aire" (Stainless Steel) for factories, industrial buildings, warehouses, etc. Complete heating plant in one package. Use for heating and ventilating or tempering outside air supply. Main blower, burner, and induced draft fan driven by separate motors. \*Cast iron units with built-in refractories recommended for heavy oil.

RESIDENTIAL UNITS: "June-Aire" cast iron—oil and gas fired. Complete information available at nearest sales office or factory.

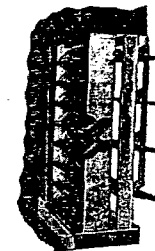


### "AFFCO" VENTILATING SPECIALTIES

"Affco" Specialties Comprise A Full Line Of Fresh Air Intakes, Outside Wall Adjustable Louvers, Dampers (Single and Multiple Blade—Parallel and Opposed Blade), Automatic Fire Dampers, Fan Outlet Louvers, Fan Pent Houses, Low Profile Roof Ventilators, Et Cetera. Used in Public, Commercial, Factory, and Industrial Buildings Including Power Plants. Inquiries Invited On Standard Or Special Constructions In Any Size, Any Metal, Any Quantity.

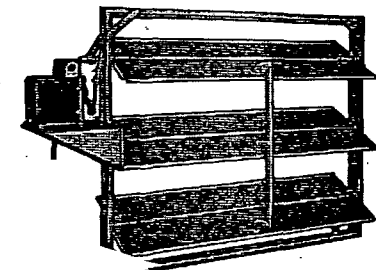
#### S-454-F COMBINATION STORMPROOF LOUVER AND DAMPER

Frame: 20 gauge galvanized steel. Stationary Stormproof Louvers: 26 gauge galvanized riveted to frame—apron extends over sill.  
Insect Screen: 16 mesh, rust-proofed, in removable "U" type frame, back of stationary louvers.  
Louver Control Damper: 16 gauge galvanized steel multiple blades in 2 x 1/2 x 1/2 galvanized steel channel frame. Manual or motor operation means available.  
Wall Thickness: 8 in. minimum.



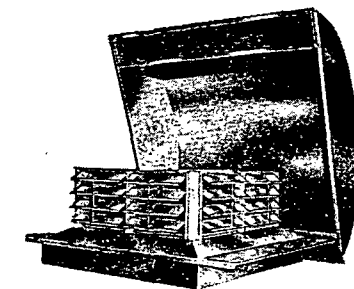
#### F-12 LOUVER DAMPER

Frame: 2 x 1/2 x 1/2 steel channel, 2 x 1/2 bar iron optional, heavier frames for large sizes.  
Blades: 16 gauge steel.  
Bearings: Oilite, ball, or brass trunnions.  
Position Installed: Vertical or horizontal.  
Maximum Blade Length: 48 in. Longer dampers are made in sections with all blades arranged to operate in unison.  
Motor Mounting Brackets: Internal or external—at extra charge.  
Motors and Connecting Linkage: By others, or from us at extra charge.  
Finish: Prime coat—galvanized steel optional.



#### "LO-VENT" ROOF VENTILATOR

Designed to hug roof and be inconspicuous. For buildings with pressurizing ventilating systems—propeller fans may be added.  
Body: galvanized steel—cover hinged.  
Back Pressure Dampers: aluminum blade.  
Bird Screen: over exhaust openings on four sides.  
Louver Control Damper: optional for inside curb.  
Vent Grille: By others if desired—may be placed under curb.  
Sizes: 8 to 42 in. square standard—special sizes optional.



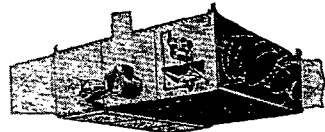
## Campbell Heating Co.

3121 Dean, Des Moines 17, Iowa

### WINTER-CHASER AIR CONDITIONING SYSTEMS

EASTERN REPRESENTATIVE: Neil Adams, 22 Jefferson St., Lambertville, N. J. Tel. No. 2-0655

HORIZONTAL UNIT HEATER Oil & Gas



### HEAVY DUTY HEATERS

For Large Churches, Schools,  
(Up to 3,000,000 Btu)

Commercial & Industrial  
Buildings

### 75 F Heating Guarantee

If the heating plant design is approved by our Engineering Department or designed by a Registered Engineer and the heater and blower are furnished by us and are in accordance with our ratings, we will guarantee the heating of all rooms to which warm air is delivered to 75 F in the coldest and windiest weather.

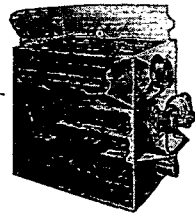
### 10 Year Durability Guarantee

All Campbell Heaters installed as described above are guaranteed for 10 years against repairs from any cause, parts to be furnished free f.o.b. the factory. Motor, humidifier, automatic burner and controls and other parts not manufactured by us carry their manufacturers' guarantee of one year against defects.

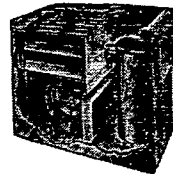
### Engineering Service

Our Engineering Department will be glad to help the consulting engineer or architect solve any heating, ventilating or air conditioning problems or help with layouts and specifications for any large building. Our Engineering Department consists of trained graduate engineers backed by 60 years of practical experience.

HI-BOY UNIT HEATER Oil & Gas



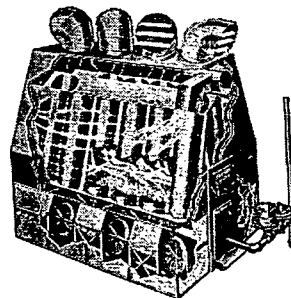
LO-BOY Oil & Gas Fired



8000 SERIES For All Fuels



8000 UNIT HEATER For all Fuels



### SPECIFICATIONS and DIMENSIONS

| HEATER     |                            |                       |                                                                          | BLOWER†                           |          |         | MAX. FUEL RATE‡  |            |                  |       | DIMENSIONS |       |  |
|------------|----------------------------|-----------------------|--------------------------------------------------------------------------|-----------------------------------|----------|---------|------------------|------------|------------------|-------|------------|-------|--|
| Unit No. * | Output Capacity BTU/ Hr. † | Heating Surface Sq Ft | Btu per Sq Ft Heating Surface<br><small>Normal of 33° Dia. Temp.</small> | Assumed External Static In. Water | Motor hp | Oil gph | 1000 Btu Gas cfh | LP Gas gph | Coal Lbs Per Hr. | H in. | L in.      | W in. |  |

#### Hi Boy & Horizontal Unit Heater—Oil & Gas for Churches, Schools, Commercial & Industrial Buildings

|        |           |     |      |       |     |     |      |      |  |     |     |    |
|--------|-----------|-----|------|-------|-----|-----|------|------|--|-----|-----|----|
| HU200  | 200,000   | 83  | 2410 | 2600  | 1/4 | 1.8 | 250  | 2.5  |  | 66  | 48  | 23 |
| HU250  | 250,000   | 83  | 3000 | 3300  | 1/4 | 2.2 | 312  | 3.1  |  | 66  | 48  | 23 |
| HU300  | 300,000   | 119 | 2520 | 4000  | 1/4 | 2.7 | 375  | 3.8  |  | 72  | 54  | 29 |
| HU350  | 350,000   | 119 | 2930 | 4600  | 1/4 | 3.1 | 437  | 4.4  |  | 72  | 54  | 29 |
| HU400  | 400,000   | 180 | 2220 | 5300  | 1/2 | 3.6 | 500  | 5.0  |  | 84  | 60  | 34 |
| HU500  | 500,000   | 180 | 2790 | 6600  | 1/2 | 4.5 | 625  | 6.3  |  | 84  | 60  | 34 |
| HU600  | 600,000   | 244 | 2460 | 8000  | 1/2 | 5.4 | 750  | 7.5  |  | 99  | 78  | 40 |
| HU700  | 700,000   | 244 | 2870 | 9200  | 1/2 | 6.3 | 875  | 8.8  |  | 99  | 78  | 40 |
| HU850  | 850,000   | 333 | 2540 | 11000 | 1/2 | 7.6 | 1060 | 10.6 |  | 108 | 106 | 48 |
| HU1000 | 1,000,000 | 333 | 3000 | 13000 | 1/2 | 9.0 | 1250 | 12.5 |  | 108 | 106 | 48 |

#### Lo Boy Oil & Gas Fired for Large Residences, Small Churches, Schools, etc.

|      |         |     |      |      |     |     |     |     |  |    |     |    |
|------|---------|-----|------|------|-----|-----|-----|-----|--|----|-----|----|
| H200 | 200,000 | 100 | 2000 | 2600 | 1/4 | 1.8 | 250 | 2.5 |  | 52 | 75  | 41 |
| H250 | 250,000 | 125 | 2000 | 3300 | 1/4 | 2.2 | 312 | 3.1 |  | 57 | 85  | 41 |
| H300 | 300,000 | 136 | 2200 | 4000 | 1/4 | 2.7 | 375 | 3.8 |  | 61 | 87  | 50 |
| H350 | 350,000 | 152 | 2300 | 4600 | 1/4 | 3.1 | 437 | 4.4 |  | 61 | 87  | 50 |
| H400 | 400,000 | 187 | 2400 | 5300 | 1/4 | 3.6 | 500 | 5.0 |  | 61 | 87  | 50 |
| H500 | 500,000 | 200 | 2500 | 6600 | 1/2 | 4.5 | 625 | 6.3 |  | 74 | 91  | 60 |
| H600 | 600,000 | 240 | 2500 | 8000 | 1/2 | 5.4 | 750 | 7.5 |  | 76 | 97  | 60 |
| H700 | 700,000 | 280 | 2500 | 9200 | 1/2 | 6.3 | 875 | 8.8 |  | 72 | 104 | 80 |

#### 8000 Series Oil, Gas, Stoker or Hand Fired For Large Schools, Churches, etc.

|      |           |      |      |        |     |      |      |      |     |     |     |     |
|------|-----------|------|------|--------|-----|------|------|------|-----|-----|-----|-----|
| 8075 | 840,000   | 280  | 3000 | 11,000 | 3/4 | 7.6  | 1050 | 10.5 | 100 | 93  | 134 | 76  |
| 8100 | 960,000   | 320  | 3000 | 12,500 | 3/4 | 8.6  | 1200 | 12.0 | 114 | 95  | 153 | 76  |
| 8125 | 1,080,000 | 360  | 3000 | 14,100 | 3/4 | 9.7  | 1350 | 13.5 | 129 | 97  | 171 | 76  |
| 8150 | 1,320,000 | 440  | 3000 | 17,300 | 3/4 | 11.8 | 1650 | 16.5 | 157 | 98  | 195 | 76  |
| 8175 | 1,440,000 | 480  | 3000 | 18,900 | 3/4 | 12.9 | 1800 | 18.0 | 171 | 99  | 202 | 76  |
| 8200 | 1,800,000 | 600  | 3000 | 23,600 | 3/4 | 16.1 | 2250 | 22.5 | 214 | 120 | 216 | 94  |
| 8250 | 2,250,000 | 750  | 3000 | 29,500 | 3/4 | 20.1 | 2810 | 28.0 | 268 | 120 | 243 | 94  |
| 8300 | 2,700,000 | 900  | 3000 | 35,400 | 3/4 | 24.1 | 3380 | 33.8 | 320 | 132 | 251 | 104 |
| 8350 | 3,150,000 | 1050 | 3000 | 41,300 | 3/4 | 28.1 | 3940 | 39.4 | 375 | 150 | 251 | 114 |

#### 8000 Series Unit Heater—Oil, Gas, Stoker or Hand Fired—For Large Industrial Buildings

|       |           |      |      |        |                  |         |      |      |      |     |     |     |     |
|-------|-----------|------|------|--------|------------------|---------|------|------|------|-----|-----|-----|-----|
| U8125 | 1,080,000 | 360  | 3000 | 14,100 | Consult          | 2-1     | 9.7  | 1350 | 13.5 | 129 | 97  | 105 | 76  |
| U8150 | 1,320,000 | 440  | 3000 | 17,300 | our Engineers if | 2-1 1/2 | 11.8 | 1650 | 16.5 | 157 | 98  | 118 | 76  |
| U8175 | 1,440,000 | 480  | 3000 | 18,900 |                  | 2-1 1/2 | 12.9 | 1800 | 18.0 | 171 | 99  | 130 | 76  |
| U8200 | 1,800,000 | 600  | 3000 | 23,600 | duct system      | 2-2     | 16.1 | 2250 | 22.5 | 214 | 120 | 137 | 94  |
| U8250 | 2,250,000 | 750  | 3000 | 29,500 | is to be         | 2-3     | 20.1 | 2800 | 28.0 | 268 | 120 | 157 | 94  |
| U8300 | 2,700,000 | 900  | 3000 | 35,400 | used.            | 2-3     | 24.1 | 3380 | 33.8 | 320 | 132 | 157 | 104 |
| U8350 | 3,150,000 | 1050 | 3000 | 41,300 |                  | 2-5     | 28.1 | 3940 | 39.4 | 375 | 150 | 157 | 114 |

\* Type A units include Special Oil or Gas Heater, Casing, Blower, Motor, Drive, Filters, Humidifier, and Blower Control but less Burner, Controls and Built-in Combustion Chamber.  
Type B units include same as Type A plus Oil or Gas Burner and built-in Combustion Chamber and Standard Controls.

† Based on 80% thermal efficiency for oil and gas and 70% for coal. Add 10% to 35% over calculated heat loss for pick-up load and 10% to 15% for duct radiation losses. The higher figure is preferable for best operating economy and life of the equipment.

‡ For other air volumes and static pressures consult our Engineering Department.

§ An induced draft blower can be furnished if a stack or chimney is not available. The gas passages of the heaters are adequate so an induced draft blower is not ordinarily needed.

For Complete Specifications, See Sweet's Catalog Service



## E. K. Campbell Company

Manchester at 18th Street, Kansas City 26, Missouri

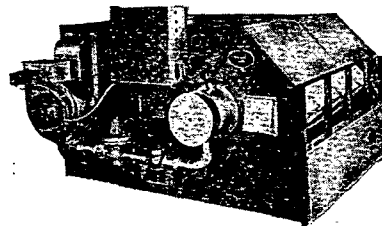
Since 1910 Manufacturers of Heavy Duty Furnaces

Unit capacities up to 8,000,000 Btu per hour

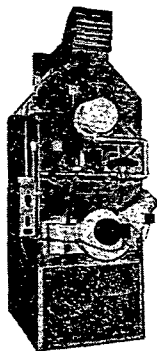
District Offices: NEW YORK CITY, ST. LOUIS, MO., DENVER, COLO., KANSAS CITY, MO.  
Representatives: MINNEAPOLIS, MINN., SALT LAKE CITY, UTAH, MEMPHIS, TENN.

### "THERMIDAIRE" DESIGN 20 TYPE H-D FURNACE

Standard equipment for engineered application—available for installation in any position in capacities from 400,000 to 3,000,000 Btu per hour output—requires separate blower equipment—highly compact heavy duty furnace of high operating efficiency up to 84 per cent—available in any fuel except coal—normally shipped assembled. Available for special air volumes if required.



"Thermidaire" Design 20



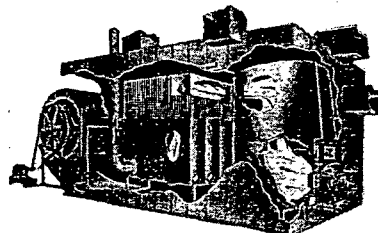
### "THERMIDAIRE" DESIGN 30 TYPE H-D FURNACE

Standard equipment, industrial type direct fired heater—available from 400,000 to 2,000,000 Btu per hour output—available in vertical, horizontal and inverted models—provides maximum compactness—available for single or multiple unit installations—equipped with burner, induced draft fan, and controls mounted and wired at the factory.

"Thermidaire" Design 30

### "THERMIDAIRE" DESIGN 10 TYPE H-D FURNACE

Custom equipment for engineered applications—units from 400,000 to 8,000,000 Btu per hour output—any required duct-outlet arrangement—equipment component arrangements extremely flexible—balanced job design, blower and furnace sized separately—available in any fuel, oil fired model illustrated—large air volumes at low temp. rises up to 84 per cent operating efficiencies—normally shipped K-D.



"Thermidaire" Design 10

"THERMIDAIRE" TYPE H-D FURNACES are all heavy-duty high-quality equipment—extra heavy, welded steel construction—induced draft fan on all models—baked enamel exterior finish—low internal resistance of flue gases—low static pressure-drop across equipment—permanently smoke and gas tight—true counterflow heat transfer—operating efficiencies up to 84 per cent. Outstanding for schools, churches, auditoriums, factories, hangars, warehouses, etc.

For further information ..... E. K. CAMPBELL COMPANY  
Kansas City 26, Missouri

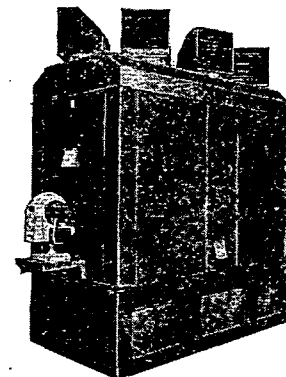
1270

## Chicago Steel Furnace Co.

9326 S. Anthony Ave., Chicago 17, Ill.

Manufacturers of Heating & Cooling Products

### DIRECT-FIRED SPACE HEATERS OIL-GAS OR COMBINATION FIRING



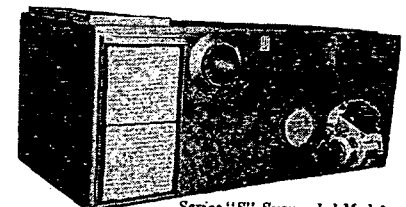
Series "A" Floor Model

#### PERFORMANCE DATA MODEL "A"

| Model No. | BTU Output | Firing Rate—GPH | Air Delivery CFM @ 1/2" SP | HP Motor | Stack |
|-----------|------------|-----------------|----------------------------|----------|-------|
| A-560     | 448,000    | 4.0             | 5,850                      | 1 1/2    | 10"   |
| A-700     | 560,000    | 5.0             | 7,300                      | 2        | 12"   |
| A-840     | 672,000    | 6.0             | 8,750                      | 2        | 12"   |
| A-980     | 784,000    | 7.0             | 10,250                     | 3        | 12"   |
| A-1260    | 1,008,000  | 9.0             | 13,100                     | 5        | 14"   |
| A-1610    | 1,344,000  | 11.5            | 16,700                     | 5        | 14"   |
| A-1960    | 1,568,000  | 14.0            | 20,500                     | 7 1/2    | 16"   |
| A-2240    | 1,792,000  | 16.0            | 23,500                     | 7 1/2    | 16"   |
| A-2520    | 2,016,000  | 18.0            | 26,500                     | 10       | 18"   |

Designed to provide uniform heat at low cost, eliminating the need for boiler rooms, costly chimneys or extensive duct work. All CSF equipment is constructed for durability, utilizing heavy gauge steel heat exchangers, high temperature refractories, and heavy duty fans. All models supplied with approved firing equipment. All heat exchangers are warranted for ten years.

There is a CSF model designed to meet any application, requiring either light oil, heavy oil, or gas.



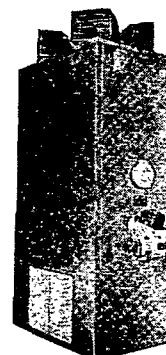
Series "S" Suspended Model

#### PERFORMANCE DATA MODEL "S"

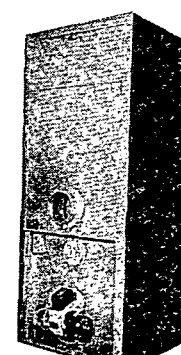
| Com-mercial | BTU-Output | CFM at 1/2" SP | Stack | GPH   | Weight |
|-------------|------------|----------------|-------|-------|--------|
| S-210       | 168,000    | 2,200          | 8     | 1.5   | 870    |
| S-280       | 224,000    | 2,900          | 9     | 2.00  | 1,160  |
| S-350       | 280,000    | 3,600          | 9     | 2.50  | 1,450  |
| Indus-trial |            |                |       |       |        |
| S-490       | 392,000    | 4,900          | 10    | 3.50  | 2,100  |
| S-560       | 448,000    | 5,600          | 10    | 4.00  | 2,650  |
| S-700       | 560,000    | 6,600          | 12    | 5.00  | 2,850  |
| S-1050      | 840,000    | 9,600          | 12    | 7.50  | 4,200  |
| S-1260      | 1,008,000  | 15,400         | 14    | 9.00  | 5,300  |
| S-1610      | 1,344,000  | 18,000         | 14    | 11.50 | 5,600  |
| S-1960      | 1,568,000  | 22,000         | 16    | 14.00 | 6,100  |

#### PERFORMANCE DATA MODEL "H" & "C"

| Model No. | BTU Output | Firing Rate—GPH | Air Delivery CFM @ 1/2" SP | HP Motor | Stack |
|-----------|------------|-----------------|----------------------------|----------|-------|
| C-210     | 168,000    | 1.5             | 2,200                      | 1/2      | 8"    |
| H-210     | 168,000    | 1.5             | 2,200                      | 1/2      | 8"    |
| C-280     | 224,000    | 2.0             | 2,900                      | 3/4      | 9"    |
| H-280     | 224,000    | 2.0             | 2,900                      | 3/4      | 9"    |
| C-350     | 280,000    | 2.5             | 3,650                      | 3/4      | 9"    |
| H-350     | 280,000    | 2.5             | 3,650                      | 3/4      | 9"    |
| C-420     | 336,000    | 3.0             | 4,400                      | 1        | 10"   |
| H-420     | 336,000    | 3.0             | 4,400                      | 1        | 10"   |
| C-490     | 392,000    | 3.5             | 5,100                      | 1 1/2    | 10"   |
| H-490     | 392,000    | 3.5             | 5,100                      | 1 1/2    | 10"   |



Model "H" Highboy



Model "C" Counterflow

1271



## Dravo Corporation

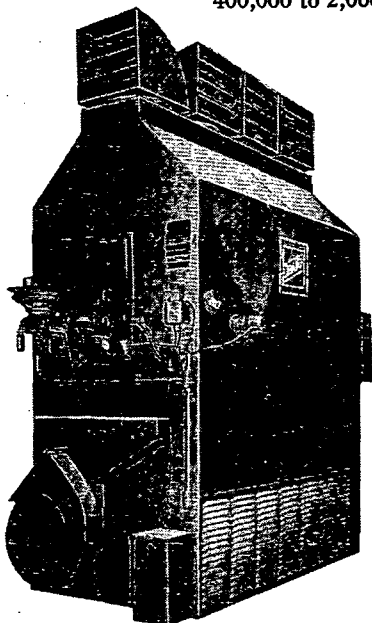
Machinery Division  
Dravo Building, Fifth & Liberty Avenues,  
Pittsburgh 22, Penna.

ATLANTA, BALTIMORE, BOSTON, CHICAGO, CINCINNATI, CLEVELAND, DETROIT,  
HOUSTON, INDIANAPOLIS, NEW YORK, PHILADELPHIA, PITTSBURGH,  
SAN FRANCISCO, ST. LOUIS

Sales Representatives in Principal Cities

### Dravo Counterflo SPACE HEATERS

400,000 to 2,000,000 Btu/hr output



- **ECONOMICAL**—Low initial cost—30-70 percent less than standard wet-type equipment to install. 80-85 percent efficient at bonnet . . . burns gas or oil, readily convertible from one to the other.
- **EASY INSTALLATION**—Just hook up fuel, electric and exhaust connections—no ductwork required.
- **STAINLESS STEEL COMBUSTION CHAMBER**—Rugged mill-type construction . . . top quality engineering. Exhaust whirl-cooled through two sets of economizer tubes.
- **SAFETY-TESTED**—Approved by A.G.A. and listed by Underwriter's Laboratories, Inc. Dravo Safety Control Circuit is accepted by Factory Mutual Engineering Division and Factory Insurance Association.
- **10-YEAR GUARANTEE**—All standard model Counterflo heaters carry a fully bonded 10-year guarantee on all parts in direct contact with flame or flue gases.

Dravo Counterflo Space Heaters in addition to comfort heating are easily adapted to heat curing and process drying, tempering of replacement air and

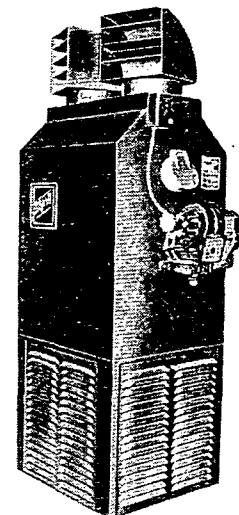
summertime ventilation. Dravo Counterflo Space Heaters can also be tied in with air conditioning systems.

#### COUNTERFLO

| Htr. No. | Output Btu/hr | CFM at 70°F | Temp. Rise | Efficiency | Fan Mtr. hp | Nozzles | Approx. Shpg. Wt. | Dimensions |      |        |
|----------|---------------|-------------|------------|------------|-------------|---------|-------------------|------------|------|--------|
|          |               |             |            |            |             |         |                   | L          | W    | H*     |
| 40       | 400,000       | 4500        | 82°        | 80%        | 1½          | 3       | 1400              | 5'3"       | 2'7" | 8'3"   |
| 50       | 500,000       | 5500        | 84°        | 80%        | 2           | 3       | 1500              | 5'3"       | 2'7" | 8'3"   |
| 75       | 750,000       | 8500        | 82°        | 80%        | 3           | 4       | 2500              | 7'7"       | 3'7" | 10'0"  |
| 100      | 1,000,000     | 11,000      | 84°        | 80%        | 5           | 4       | 2600              | 7'7"       | 3'7" | 10'0"  |
| 125      | 1,250,000     | 14,000      | 83°        | 80%        | 7½          | 4       | 3400              | 9'2"       | 4'3" | 11'2"  |
| 150      | 1,500,000     | 17,000      | 82°        | 80%        | 10          | 4       | 3600              | 9'2"       | 4'3" | 11'2"  |
| 175      | 1,750,000     | 19,000      | 85°        | 80%        | 10          | 4       | 4200              | 9'9"       | 4'9" | 12'10" |
| 200      | 2,000,000     | 22,000      | 84°        | 80%        | 15          | 4       | 4400              | 9'9"       | 4'9" | 12'10" |

### Dravo Paraflo SPACE HEATERS

200,000 to 250,000 Btu/hr output



- **POWER AND FUEL**—Heater operates on 220 volt 60 cycle current. 220 or low voltage operation can be supplied if desired. Unit can be equipped with a self-contained gun-type oil or gas burner depending upon the fuel available.
- **FAST TRANSFER OF HEAT**—Stainless steel combustion chamber allows faster heat transfer from fuel to air and guarantees longer heater life and sustained efficiency. Equipped with UL approved gun-type oil burner or A.G.A. approved gas burner.
- **FLOATING COMBUSTION CHAMBER**—Supporting straps hold stainless steel chamber in place for inverted or horizontal mounting. One end floats freely relieving stresses and strains due to normal expansion of chamber.
- **HEAT ANY DIRECTION**—Warms areas up to 3600 sq ft. Directional nozzle can be rotated 360 deg heating any desired location, high velocity discharge assures good distribution up to 90 ft from the unit without the use of ductwork.

This new Dravo heater is ideal for garages, service stations, construction offices, recreation centers, agriculture buildings, warehouses, stores, offices and

showrooms. The heater fan can be used for summer ventilation. Heaters can be adapted to air conditioning systems.

#### PARAFLO

| Htr. No. | Output Btu/hr | CFM at 70°F | Temp. Rise | Efficiency | Fan Mtr. hp | Nozzles | Approx. Shpg. Wt. | Dimensions |      |       |
|----------|---------------|-------------|------------|------------|-------------|---------|-------------------|------------|------|-------|
|          |               |             |            |            |             |         |                   | L          | W    | H     |
| 20       | 200,000       | 2200        | 84°        | 80%        | ¼           | 2       | 785               | 4'2"       | 2'5" | 7'10" |
| 25       | 250,000       | 2700        | 84°        | 80%        | ¾           | 2       | 795               | 4'2"       | 2'5" | 7'10" |

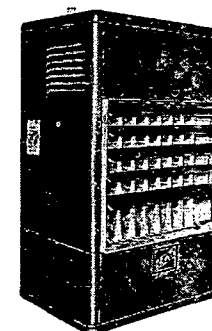
### Dravo Gas Fired SUSPENDED TYPE UNIT HEATERS

68,000 to 180,000 Btu/hr output

- **COMPLETE RANGE OF SIZES**—Heaters are available in a wide range of capacities in various model sizes with outputs from 68,000 to 180,000 Btu/hr.

- **FLEXIBILITY OF GAS FUELS**—Heaters can operate on natural, manufactured, mixed, butane, sewer, or propane gas and liquefied petroleum.

- **LOW COST HEATING**—These heaters are ideal for economically heating small unit areas in commercial or industrial buildings such as garages, stores, machine shops, warehouses, amusement centers and other similar type buildings.





## Johnson Heater Corp.

1 Winnisimmet St. Chelsea, Mass.  
DESIGNERS MANUFACTURERS

15 Models, single heater capacities to 5,000,000 Btu fired by light or heavy oil, gas or combination gas and oil burner.



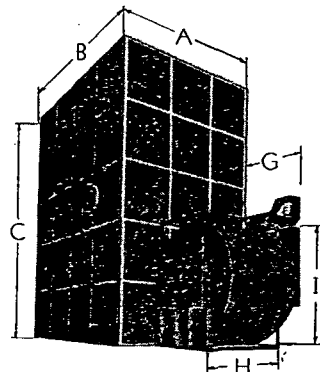
Multiple criss-cross air tube heating surfaces over the combustion chamber.

**DIRECT FIRED "AIR ROTATION" HEATING UNITS (PATENTS PENDING)  
FOR INDUSTRIAL AND COMMERCIAL APPLICATIONS  
LOW INITIAL INSTALLATION—FUEL AND MAINTENANCE COST**

Simplified heating for large open buildings such as Warehouses—Machine Shops—Garages—Airplane Hangars—Fabricating plants, etc.

Our exclusive method of "air rotation" heating (Patents Pending) uniformly blankets with warm air all areas of an open building. All duct work, piping spotting, and throwing of the heated air is eliminated. One Johnson Heater can successfully heat in excess of 1,500,000 cubic feet of building space.

- TUBULAR DESIGN
- FULLY AUTOMATIC
- HIGH EFFICIENCY
- CONSERVATIVELY RATED
- PRACTICALLY SELF CLEANING
- ALL STANDARD PARTS



DIMENSIONAL DATA

| MODEL | BTU OUTPUT AT PLENUM | AVER'G CFM | MAX. BTU INPUT | APPROX. SHIP- PING WEIGHT | A     | B      | C     | G     | H    | I     | SMOKE- PIPE DIA |
|-------|----------------------|------------|----------------|---------------------------|-------|--------|-------|-------|------|-------|-----------------|
| JA-3  | 330,000              | 4600       | 420,000        | 1850                      | 3'6"  | 4'3"   | 6'3"  | 2'5"  | 2'3" | 3'0"  | 9"              |
| JA-4  | 425,000              | 6000       | 560,000        | 2300                      | 3'8"  | 5'4"   | 6'8"  | 2'10" | 2'7" | 3'5"  | 10"             |
| JA-5  | 550,000              | 7800       | 700,000        | 3100                      | 4'2"  | 5'8"   | 7'8"  | 3'3"  | 3'0" | 3'10" | 12"             |
| JA-6  | 650,000              | 9200       | 815,000        | 3500                      | 4'8"  | 5'8"   | 8'0"  | 3'3"  | 3'0" | 3'10" | 12"             |
| JA-7  | 750,000              | 10,500     | 950,000        | 4000                      | 4'10" | 6'2"   | 8'4"  | 3'7"  | 3'0" | 4'1"  | 12"             |
| JA-8  | 850,000              | 12,000     | 1,080,000      | 4500                      | 5'0"  | 6'10"  | 8'8"  | 3'7"  | 3'3" | 4'6"  | 14"             |
| JA-10 | 1,000,000            | 14,000     | 1,260,000      | 5200                      | 5'8"  | 7'6"   | 9'6"  | 3'11" | 3'3" | 4'8"  | 14"             |
| JA-12 | 1,250,000            | 17,500     | 1,580,000      | 6100                      | 6'0"  | 8'2"   | 10'3" | 4'5"  | 3'9" | 5'0"  | 16"             |
| JA-15 | 1,500,000            | 21,000     | 1,900,000      | 7100                      | 6'6"  | 8'8"   | 11'1" | 4'9"  | 4'2" | 5'5"  | 16"             |
| JA-20 | 2,000,000            | 28,000     | 2,500,000      | 10,750                    | 7'6"  | 9'8"   | 12'8" | 5'2"  | 4'0" | 5'10" | 18"             |
| JA-25 | 2,500,000            | 36,000     | 3,150,000      | 12,500                    | 8'7"  | 10'11" | 13'5" | 5'5"  | 4'6" | 5'2"  | 20"             |
| JA-30 | 3,000,000            | 42,000     | 3,750,000      | 14,000                    | 9'6"  | 11'10" | 14'4" | 5'5"  | 4'6" | 6'2"  | 22"             |
| JA-35 | 3,500,000            | 49,000     | 4,375,000      | 16,500                    | 9'10" | 13'2"  | 15'2" | 5'10" | 5'0" | 6'8"  | 24"             |
| JA-40 | 4,000,000            | 55,000     | 5,000,000      | 21,000                    | 10'7" | 13'6"  | 16'4" | 6'8"  | 5'5" | 7'6"  | 24"             |
| JA-50 | 5,000,000            | 68,000     | 6,250,000      | 24,500                    | 11'0" | 14'10" | 17'8" | 6'8"  | 5'5" | 7'6"  | 26"             |

The Johnson Heater Corp. reserves the right to change any dimensions contained herein without notice.

Models JA-3 thru JA-15 can be supplied with blower enclosures with or without filters.

All models of Johnson Heaters are designed for use with a conventional duct system where required.

## Johnson Heater Corp.

1 Winnisimmet St. Chelsea, Mass.  
DESIGNERS MANUFACTURERS

9 Models, single heater capacities to 500,000 Btu. Fired by light fuel oil or gas. Stock sizes.



Practically self cleaning multiple air tube heating surfaces.

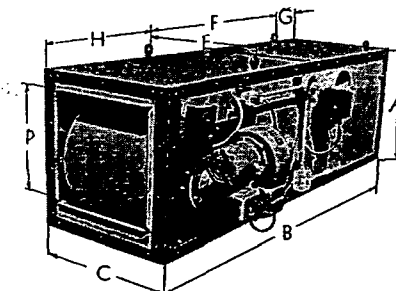
**SUSPENDED TYPE MULTI-TUBE DIRECT FIRED HEATERS**

Low cost heating for Service Stations—Garages—Warehouses—Machine Shops—Residences and other types of commercial and domestic installations.

Larger single heater models up to 1,000,000 Btu.

Heaters fired by oil, gas or combination burners.

- COMPLETELY ASSEMBLED
- NO FLOOR SPACE REQUIRED
- FULLY AUTOMATIC
- ALL STANDARD PARTS
- CONSERVATIVELY RATED



DIMENSIONAL DATA

| MODEL   | BTU OUTPUT AT PLENUM | AVER'G CFM | MAX. BTU INPUT | APPROX. SHIP- PING WEIGHT | SMOKE PIPE DIA | A  | B   | C  | E  | F  | G  | H  | P     |
|---------|----------------------|------------|----------------|---------------------------|----------------|----|-----|----|----|----|----|----|-------|
| JAS-1   | 138,000              | 1800       | 175,000        | 800                       | 8              | 28 | 85  | 26 | 23 | 48 | 12 | 25 | 20x20 |
| JAS-1E  | 152,000              | 2000       | 190,000        | 850                       | 8              | 28 | 85  | 26 | 23 | 48 | 12 | 25 | 20x20 |
| JAS-1.5 | 170,000              | 2400       | 210,000        | 925                       | 9              | 31 | 88  | 28 | 25 | 48 | 15 | 25 | 22x22 |
| JAS-2   | 220,000              | 3000       | 280,000        | 1025                      | 9              | 36 | 96  | 32 | 29 | 48 | 23 | 25 | 26x26 |
| JAS-2E  | 280,000              | 3600       | 350,000        | 1050                      | 9              | 36 | 96  | 32 | 29 | 48 | 23 | 25 | 26x26 |
| JAS-3   | 335,000              | 4300       | 420,000        | 1450                      | 10             | 46 | 109 | 36 | 33 | 60 | 19 | 30 | 30x30 |
| JAS-3E  | 390,000              | 5000       | 490,000        | 1550                      | 10             | 46 | 109 | 36 | 33 | 60 | 19 | 30 | 30x30 |
| JAS-4   | 450,000              | 6000       | 560,000        | 2000                      | 12             | 48 | 115 | 43 | 40 | 60 | 25 | 30 | 38x38 |
| JAS-5   | 500,000              | 6500       | 630,000        | 2025                      | 12             | 48 | 115 | 43 | 40 | 60 | 25 | 30 | 38x38 |

The Johnson Heater Corp. reserves the right to change any dimensions herein without notice.

### SMALLER JOHNSON FLOOR MODEL HEATERS

Five models of horizontal extended casing units: 110,000-138,000-165,000-210,000-275,000 Btu.

Five models of vertical Hi-Boy units: 110,000-138,000-165,000-210,000-275,000 Btu.

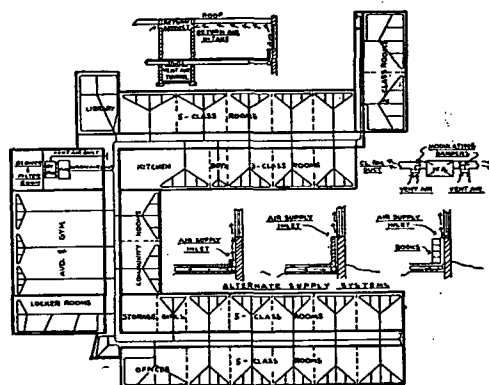
## Jackson & Church

Furnace Division

Saginaw, Michigan

**J-C**

"Work well done since '81"

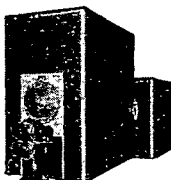


The school building heating system shown incorporates all the advantages of perimeter heating... plus seven complete air changes per hour; constant blower operation, and individual room temperature control. A J-C furnace provides both heat and ventilation. A blending of desired proportions of fresh outside air and room air is heated to proper temperature and delivered through floor ducts in tunnels used for wiring and piping. Air may be introduced through floor registers, elevated registers or book-shelf-register combinations. High inside wall returns are used.



**SUSPENSION FURNACES**—the line of horizontal units. Available in wide range, 80,000 to 1,000,000 Btu output. Oil and gas fired... with UL and A.G.A. approval.

**POWERAIRE FURNACES**—for most commercial and large residential jobs. Air conditioning units can be added to system. Outputs from 152,000 to 320,000 Btu. Oil and gas fired.



**POWERATED FURNACES**—for industrial heating and industrial ventilating where outside air is introduced. Outputs from 380,000 to 3,800,000 Btu. Oil, gas and coal fired.

J-C Direct-fired units now available with outputs from 400,000 to 2,000,000 Btu/hr.

## Lee Corporation

Foot of Madison Street, P. O. Box 1801 Wilmington, Delaware

BALTIMORE, Md.

NEW YORK, N. Y.

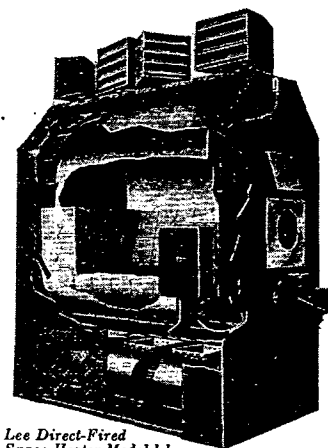
CHICAGO, ILL.

Representatives in all Principal Cities

Manufacturers and Designers of Complete Line of Industrial and Commercial Warm Air Heaters

MODEL HD—750,000 to 2,000,000 Btu  
MODEL VTH—2,000,000 to 6,000,000 Btu

MODEL TSE—2,000,000 to 8,000,000 Btu  
MODEL BST—2,000,000 to 10,000,000 Btu



Lee Direct-Fired Space Heater Model hd 750,000 to 2,000,000 Btu

### LEE HEAVY DUTY HEATERS

LEE HEATERS have been in continuous operation since 1918. Lee Heater installations have been made in most of the States of the United States, in Canada, Alaska, Yukon Territory, Northwest Territory, Labrador, Iceland, Norway, Mexico and South America.

Firing Equipment manufactured specially for us by leading Companies with International service organization. There is a Service man near you if and when you require assistance. In addition Lee maintains a competent field serving staff.

Replacement and Spare Parts Service is maintained. Most items are carried in stock.

### VERSATILE

#### Types of Fuel

- Light Oil (#3 or Lighter)
- Medium Oil (#5 or Lighter)
- Heavy Oil (#6 or Lighter)
- Gas (Natural, Manufactured Propane Coke Oven.)
- Combination Light Oil & Gas
- Combination Heavy Oil & Gas

#### Mount in any Position

- Floor Mounted
- Horizontally Mounted (& Suspended)
- Vertically Mounted (& Suspended)
- Use with Ducts for Central Heating System
- Use without Ducts as Self Contained Heating System

|                                                            | HD-750  | HD-1000   | HD-1250   | HD-1500   | HD-1750   | HD-2000   |
|------------------------------------------------------------|---------|-----------|-----------|-----------|-----------|-----------|
| Output Capacity (Btu per hr)                               | 750,000 | 1,000,000 | 1,250,000 | 1,500,000 | 1,750,000 | 2,000,000 |
| Total Heating Surface in Sq Ft                             | 175     | 192       | 218       | 260       | 328       | 383       |
| Cu Ft of Air per Min. (Approx.)*                           | 8,500   | 11,000    | 14,000    | 17,000    | 20,000    | 22,000    |
| Air Fan Motor h.p.                                         | 5       | 5         | 7½        | 7½        | 10        | 15        |
| Induced Draft Fan Motor h.p.                               | ¼       | ¼         | ¼         | ¼         | ¼         | ¾         |
| External Static Pressure (Std.)                            | ¼"      | ¼"        | ¼"        | ¼"        | ¼"        | ¼"        |
| Maximum External Static Pressure Available for Duct Work** | 1"      | 1"        | 1"        | 1"        | ¾"        | ¾"        |
| Temperature Rise-Degrees F.                                | 82°     | 80°       | 83°       | 82°       | 81°       | 84°       |
| Fuel Consumption***                                        |         |           |           |           |           |           |
| Gas (cu ft per hr)                                         | 940     | 1250      | 1560      | 1880      | 2190      | 2500      |
| Oil (gal per hr)                                           | 6.5     | 8.6       | 10.8      | 13.0      | 15.0      | 17.2      |
| Shipping Weight-lbs                                        |         |           |           |           |           |           |
| Refractory Comb. Chamber                                   | 5000    | 5300      | 5800      | 7000      | 8600      | 9400      |
| Stainless Steel Comb. Chamber                              | 3100    | 3400      | 3800      | 4700      | 6300      | 7000      |
| Heater Length                                              | 6'-4½"  | 7'-1½"    | 8'3"      | 8'-4½"    | 8'-4½"    | 9'-4½"    |
| Heater Width                                               | 4'0"    | 4'0"      | 4'0"      | 4'4"      | 4'4"      | 4'4"      |
| Heater Height                                              | 9'11"   | 9'11"     | 9'11"     | 11'-3½"   | 11'11"    | 11'11"    |
| Number of Outlets                                          | 3       | 4         | 4         | 4         | 4         | 4         |
| Number of Blowing Fans                                     | 2       | 2         | 3         | 2         | 2         | 2         |

\* Based on Standard Air at 70 F Free Delivery

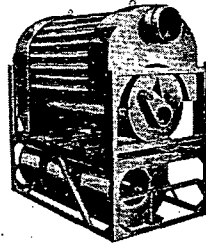
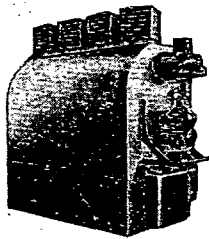
\*\* Requires large Air Fan Motor

\*\*\* Fuel consumption based on 1000 Btu per cu. ft of Gas, 145,000 Btu per gal of Oil and on 80 per cent efficiency for the heater.

## Mammoth Furnace Company

509 Vandalia Street St. Paul, Minnesota

Commercial-Aire



Strong—built for rugged service and safe shipment.

Quiet Fan Operation—a rigid tubular fan shaft supported by two self aligning bearings eliminates shaft and bearing problems.

Retractable Burner Tray—allows complete service to burner. Permits removal from unit with no disassembly and minimum handling.

Central Control Cabinet—provides controls, fusing and wiring in an accessible dust-tight enclosure.

Direct Driven Induced Draft—trouble-free, vortex cooled motor shaft connection to blower wheel. No belts and additional bearings to service.

Variety Of Controls And Power Supplies—units may be "off-on" thermostat controlled, hi-low fire or modulated control.

Wiring and controls can be provided for all power supplies.

Integrated Burner Applications—burners by reputable manufacturers are tailored to produce the most effective flame configuration for the heater design.

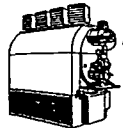
Combustion Safety And Draft Controls—MH-Electronic flame control system, pre-ignition draft purge timing and draft sensing give a high degree of operation safety.

Series "F" Floor mount with discharge heads for industrial plants, foundries, etc.

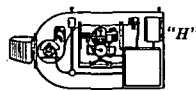
Series "H" Horizontally suspended unit for use where floor space is unavailable.

Series "FD" For duct distribution. For churches, schools, auditoriums, etc.

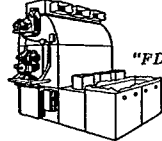
Series "U" Suspended inverted unit for make-up air applications in plants, foundries, etc.



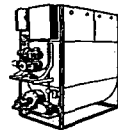
"F"



"H"



"FD"



"U"

### SPECIFICATIONS

| Model | Btu Output | Sq ft Htg. Surface E.D.T. | Oil @ 1/2" S.P. 33° RISE | Blower DIDW | Motor hp | Approx. Fan rpm | Max Firing Rate |         | Length | Height† | Width | Plenum Opening | Mech. Exhaust Discharge | Approx. Shipping Weight |
|-------|------------|---------------------------|--------------------------|-------------|----------|-----------------|-----------------|---------|--------|---------|-------|----------------|-------------------------|-------------------------|
|       |            |                           |                          |             |          |                 | Oil gph         | Gas cfh |        |         |       |                |                         |                         |
| 300   | 300,000    | 135.3                     | 4,000                    | 14" twin    | 3/4      | 675             | 3.0             | 375     | 60"    | 80"     | 32"   | 18x60          | 8" dia.                 | 1,590                   |
| 400   | 400,000    | 135.3                     | 5,500                    | 14" twin    | 1        | 640             | 4.0             | 500     | 60"    | 80"     | 32"   | 18x60          | 8" dia.                 | 1,690                   |
| 550   | 550,000    | 183.6                     | 7,000                    | 14" triple  | 1 1/2    | 750             | 5.0             | 658     | 80"    | 80"     | 32"   | 18x80          | 8" dia.                 | 1,950                   |
| 700   | 700,000    | 183.6                     | 8,700                    | 14" triple  | 2        | 820             | 7.0             | 875     | 80"    | 80"     | 32"   | 18x80          | 8" dia.                 | 2,150                   |
| 800   | 800,000    | 276.8                     | 10,000                   | 16" triple  | 3        | 710             | 7.5             | 1,000   | 80"    | 83"     | 48"   | 22x80          | 10" dia.                | 2,775                   |
| 1000  | 1,000,000  | 276.8                     | 13,000                   | 16" triple  | 5        | 790             | 9.5             | 1,250   | 80"    | 83"     | 48"   | 22x80          | 10" dia.                | 2,850                   |
| 1250  | 1,250,000  | 431.0                     | 16,000                   | 18" triple  | 5        | 755             | 11.5            | 1,563   | 100"   | 96"     | 54"   | 26x100         | 10" dia.                | 3,850                   |
| 1500  | 1,500,000  | 431.0                     | 19,000                   | 18" triple  | 7 1/2    | 830             | 14.0            | 1,875   | 100"   | 96"     | 54"   | 26x100         | 10" dia.                | 4,010                   |
| 1750  | 1,750,000  | 574.1                     | 23,000                   | 21" triple  | 7 1/2    | 680             | 16.5            | 2,188   | 120"   | 96"     | 60"   | 30x120         | 12" dia.                | 4,750                   |
| 2000  | 2,000,000  | 574.1                     | 26,000                   | 21" triple  | 10       | 740             | 18.5            | 2,500   | 120"   | 96"     | 60"   | 30x120         | 12" dia.                | 4,910                   |

\* Equivalent Direct Transfer. Head Projection Not Included.

\*\* Adjustable.

† Burner Projections Not Included.

‡ Discharge

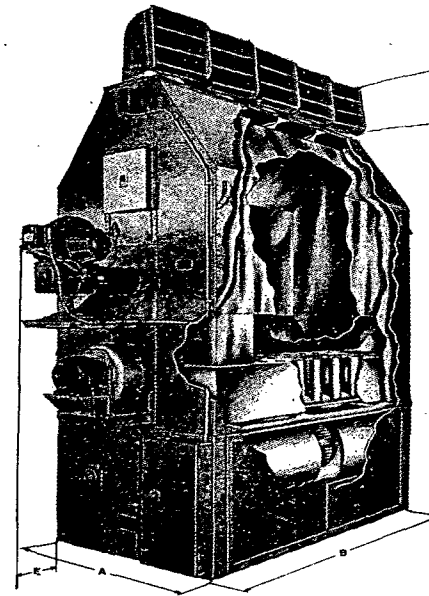
## Arthur A. Olson & Company

Canfield, Ohio

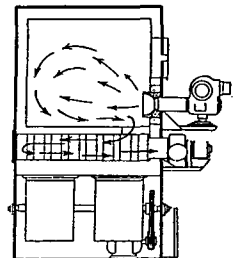
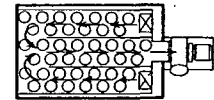
Manufacturers of Direct Fired Heaters

Olson

A completely automatic direct-fired unit heater. Olson heaters operate on gas, oil, dual gas-oil or coal. These units may be hung, suspended horizontally or inverted. All heaters can be adapted to filtering, humidifying and air conditioning. Use of standard accessories and easy access to bearings and other vital parts simplify maintenance. Also special adaptations for make-up air, drying, high-temperature and process work.



- Austinitic Stabilized Stainless Steel Combustion Chamber with floating design and a multiple battery of 10 gauge boiler tube economizer section.
- Heavy Duty Fans and Shaft.
- Inlet Screens or Frame for Filter Box.
- Adjustable, Deflecting Outlets.
- Separate Induced Draft Fan.
- Bearings Outside Heater at End of Shaft.



Four Pass Gas Travel-Counter Current.

### Engineering Data—Gas, Oil, or Dual Gas-Oil Heaters

| Heater Model Number | Btu/Hr Output Capacity | Cfm Blowing Fans | General Dimensions |           |        |       |       | No. of Blowing Fans | Motor Hp Blowing Fans | Stack Dia. | No. of Nozzle Outlets |
|---------------------|------------------------|------------------|--------------------|-----------|--------|-------|-------|---------------------|-----------------------|------------|-----------------------|
|                     |                        |                  | A                  | B         | C      | D     | E     |                     |                       |            |                       |
| S-300               | 300,000                | 3,500            | 3'-0"              | 3'-3"     | 7'-6"  | 1'-3" | 2'-3" | 1                   | 1                     | 8"         | 2                     |
| S-400               | 400,000                | 4,500            | 3'-0"              | 3'-3"     | 7'-6"  | 1'-3" | 2'-3" | 1                   | 1 1/2                 | 8"         | 2                     |
| S-500               | 500,000                | 5,500            | 3'-0"              | 4'-7 1/2" | 8'-0"  | 1'-3" | 2'-3" | 2                   | 2                     | 8"         | 3                     |
| S-600               | 600,000                | 7,000            | 3'-0"              | 4'-7 1/2" | 8'-0"  | 1'-3" | 2'-3" | 2                   | 3                     | 8"         | 3                     |
| S-750               | 750,000                | 8,500            | 3'-8"              | 5'-11"    | 8'-4"  | 1'-3" | 2'-7" | 2                   | 3                     | 10"        | 4                     |
| S-1000              | 1,000,000              | 11,000           | 3'-8"              | 5'-11"    | 8'-4"  | 1'-3" | 2'-7" | 2                   | 5                     | 10"        | 4                     |
| S-1250              | 1,250,000              | 14,000           | 4'-4"              | 7'-6"     | 9'-10" | 1'-5" | 2'-7" | 2                   | 7 1/2                 | 10"        | 4                     |
| S-1500              | 1,500,000              | 17,000           | 4'-4"              | 7'-6"     | 9'-10" | 1'-5" | 2'-7" | 2                   | 10                    | 12"        | 4                     |
| S-1750              | 1,750,000              | 20,000           | 4'-10"             | 8'-6"     | 10'-9" | 1'-5" | 2'-9" | 2                   | 15                    | 12"        | 5                     |
| S-2000              | 2,000,000              | 22,000           | 4'-10"             | 8'-6"     | 10'-9" | 1'-5" | 2'-9" | 2                   | 15                    | 12"        | 5                     |

Write for complete data on stoker fired units and large central systems.

## National Heater Company

**NATIONAL**  
*Champion*  
DIRECT FIRED

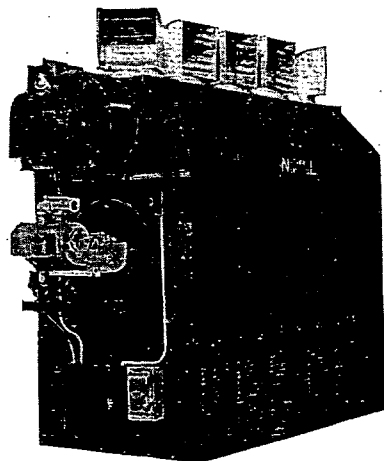
2180 Cleora Avenue St. Paul 4, Minnesota

### NATIONAL CHAMPION HEATERS

200,000 to 2,000,000 Btu

Direct fired for oil, gas, or combination units

Engineered for industry—space heating, tempering make up air, and drying



MODEL H Available in ceiling suspended, inverted and portable units

- **GUARANTEED 80 PER CENT OPERATING EFFICIENCY** — in factories, foundries, warehouses, garages, hangars, terminals and many other installations.
- **SAVE ON OPERATION** — National Champion Heaters circulate warm air at working levels, keep roof heat loss at a minimum. Low initial cost—no boiler house or power piping required. Low operating cost—standby losses eliminated, no licensed attendant needed!
- **SAVE ON FUEL**—National Champion Heaters burn fuel only when zone thermostats call for heat. Burner shuts off when temperature is attained. No fuel wasted to overcome transmission losses. No wasteful recycling to maintain steam pressure or water temperature.
- **SAVE ON MAINTENANCE**—National Champion Heaters feature simplified burner and controls and easily accessible clean-out plates—no problem to maintenance personnel. Spare parts are readily available.

**TESTED CONSTRUCTION** — Features high chrome nickel stainless steel combustion chamber, in efficient teardrop design. Structure welded into rugged, one-piece steel unit with baked enamel exterior finish. Engineered for dependable, enduring service. Underwriter's laboratories listed.

- **SAVE ON INSTALLATION**—National Champion Heaters save 30 per cent to 70 per cent over systems requiring expensive ductwork, piping, condensate lines, traps, pumps, etc. Units are shipped completely wired, assembled and flame-tested at the factory to guarantee peak performance.

1280

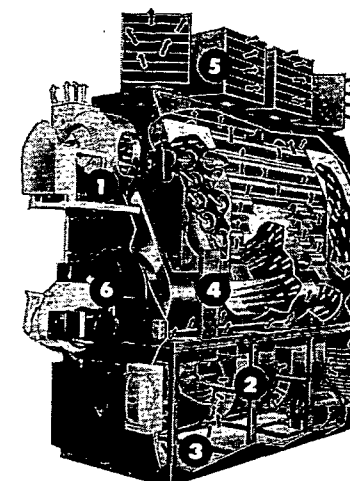
## National Heater Company

2180 Cleora Avenue

St. Paul 4, Minnesota

Efficient heat exchange, high velocity discharge develop truly economical space heating.

1. When thermostat calls for heat, induced draft blower starts first to purge combustion chamber and establish draft before burner is fired.
2. Main blowers—separate from induced draft blowers—start only when proper bonnet temperature is attained.
3. Cool air is drawn through louvered panels at floor level.
4. Air passes over National's stainless steel teardrop combustion chamber and then around multiple banks of economizer tubes.
5. After this full uniform heating, air discharges at high velocity from adjustable heads atop the heater.
6. Separate blower integral with burner, and separate induced draft blower, are independently adjustable for maximum combustion efficiency.



Cutaway view of the National Champion Model H shows air flow from floor intake to adjustable discharge heads.

**RESULT:** No "cold blasts" on start-up; proper, uniform heating of air; high velocity discharge keeps warmed air at working levels; minimum temperature differential between floor and roof.

Underwriters' Laboratories Listed

WRITE FOR DESCRIPTIVE BROCHURE!

| Heater Number | Btu Output Capacity | CFM at ½ in. S.P. | HP Blower Motor | Overall Dimensions |        |        | Shipping Weight |
|---------------|---------------------|-------------------|-----------------|--------------------|--------|--------|-----------------|
|               |                     |                   |                 | Width              | Length | Height |                 |
| TD-20         | 200,000             | 2,400             | ¼               | 28                 | 52     | 66     | 950             |
| TD-25         | 250,000             | 3,200             | ¾               | 28                 | 52     | 66     | 1020            |
| TD-30         | 300,000             | 4,000             | ¾               | 32                 | 60     | 81     | 1400            |
| TD-40         | 400,000             | 5,400             | 1               | 32                 | 60     | 81     | 1500            |
| TD-50         | 500,000             | 6,600             | 1½              | 32                 | 80     | 81     | 1750            |
| TD-70         | 750,000             | 8,800             | 2               | 32                 | 80     | 81     | 1900            |
| TD-80         | 800,000             | 10,200            | 3               | 48                 | 80     | 81     | 2400            |
| TD-100        | 1,000,000           | 12,500            | 5               | 48                 | 80     | 81     | 2600            |
| TD-125        | 1,250,000           | 15,300            | 5               | 54                 | 100    | 98     | 3200            |
| TD-150        | 1,500,000           | 19,400            | 7½              | 54                 | 100    | 98     | 3450            |
| TD-175        | 1,750,000           | 22,000            | 7½              | 60                 | 120    | 98     | 4150            |
| TD-200        | 2,000,000           | 26,000            | 10              | 60                 | 120    | 98     | 4300            |

1281

## Reznor Manufacturing Company

66 Union Street, Mercer, Pa.

Gas Unit Heaters—nine sizes: 25,000 to 250,000 Btu; Console-Type Room Heaters—25, 50, 65 and 75,000 Btu; Duct Furnaces—50,000 to several million Btu; Gas Horizontal Furnaces—75,000, 100,000 and 125,000 Btu.

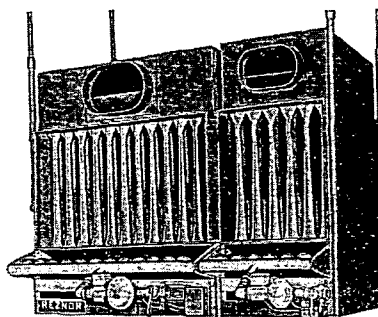
### Reznor Series DS Sectional Duct Furnaces 150,000 to Several Million Btu

Sectional assembly simplifies installation. Capacities totaling 2,000,000 Btu and above can be installed in custom engineered heating systems from sections weighing no more than 315 pounds. Unlimited number of sizes in steps of 50,000 Btu from 150,000 to several million Btu. All assembled from four basic sections—150, 200, 250 and 300,000 Btu.

Units are compact, highly efficient, lightweight heat exchangers, each with a full complement of combustion controls. For assembly with components for air-moving, cooling, cleaning and humidification selected to meet the exact requirements of each job. May also be used as booster units to supplement other warm air heating equipment.

Designed for installation as an integral part of the ductwork, all sections are equipped for either suspended or base mounting. Because air flow through the heater may be in either direction, sections can always be turned to provide easy access to controls and burners. To provide for seasonal operation of less than the total capacity, each section is complete with controls and built-in draft diverter.

The unit shown above is a 450,000 Btu duct furnace (one 150,000 and one 300,000 Btu section mounted side-by-side). Because sections can be mounted in a single bank or in a double bank, overall dimensions



sions depend on the manner of installation. All sections are 37 in. high and 24 in. deep. Width varies according to capacity.

Gas and electrical controls are normally installed on the front of the heater, but can be relocated to the side if preferred. Controls include main and pilot shut-off valves, electric valve, pressure regulator, safety pilot and adjustable limit control. All controls supplied by leading manufacturers. All electrical components Underwriters' Laboratory approved.

Aluminized steel is the standard heat exchanger material; stainless steel heat exchangers are also available.

Built-in draft diverter is reversible so that flue connection may face in either direction. Flue collar on snap-out plate for easy adaption to vertical or horizontal discharge.

#### Specifications—DS Duct Furnace Sections

| Section | Btu Input | Btu Output | EDR  | Thruput-cfm |       | High | Deep* | Wide**  | Weight  |
|---------|-----------|------------|------|-------------|-------|------|-------|---------|---------|
|         |           |            |      | Mini-       | Maxi- |      |       |         |         |
| DS-150  | 150,000   | 120,000    | 519  | 1200        | 1900  | 37"  | 24"   | 21 1/2" | 190 lbs |
| DS-200  | 200,000   | 160,000    | 692  | 1600        | 2400  | 37"  | 24"   | 27 1/4" | 235 lbs |
| DS-250  | 250,000   | 200,000    | 884  | 2000        | 3000  | 37"  | 24"   | 35 3/8" | 275 lbs |
| DS-300  | 300,000   | 240,000    | 1033 | 2400        | 3600  | 37"  | 24"   | 40 7/8" | 315 lbs |

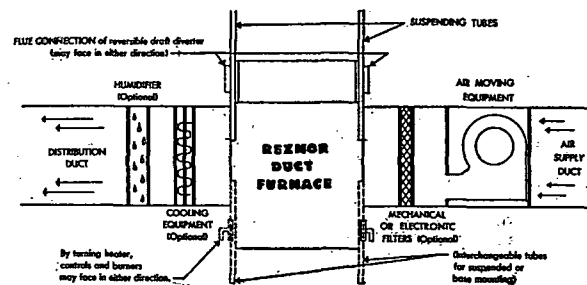
\* 90° rise || 60° rise.  
\* For total depth of multiple banks, add depths of sections, then add 12" if sections will be installed back-to-back, or add enough space to allow for removal of burners if units are to be installed front-to-front or front-to-back.  
\*\* For total width of multiple sections, add widths of sections. For total width of duct on multiple sections subtract 2 1/4" from total overall width.

## Reznor Manufacturing Company

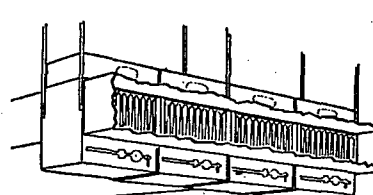
66 Union Street, Mercer, Pa.

Check your local phone directory for your nearest Reznor distributor or district office

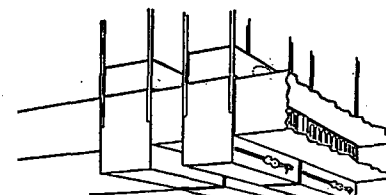
### Methods of Installation—DS Series Duct Furnaces



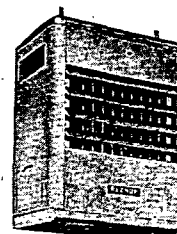
This schematic diagram shows how Reznor Series DS Duct Furnaces may be combined in the duct system with other components. All components shown (except the blower or other air-impelling equipment) are optional, to be used only as required by the specific job to be done. It is recommended that cooling and humidifying equipment be installed downstream.



Multiple-section single bank installation with common air supply and distribution ducts.



Multiple-section, double-bank installation with common air supply and distribution ducts.

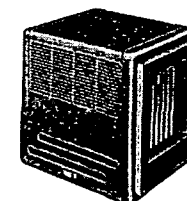


### Reznor Gas Unit Heaters

Completely automatic heating for all commercial and industrial buildings... as the basic system or to supplement other types of equipment. Eight sizes—25,000 to 200,000 Btu with choice of propeller fan or centrifugal blower plus 250,000 Btu twin-fan model. Aluminized steel heat exchangers. Cast iron universal burners. Built-in draft diverter. For complete details, dimensions and specifications write for Bulletin B-55-UH.

### Reznor Series D Duct Furnaces

For residential and small commercial applications requiring a heat exchanger for use in a custom engineered system. Four sizes: 50, 75, 100 and 125,000 Btu. For installation with any combination of equipment for air moving, cooling, cleaning and humidification. Burner access and controls completely enclosed on same side of handsomely-styled cabinet. All models 22 in. wide by 23 in. high; depth varies with capacity. Complete with combustion controls and built-in draft diverter. For suspended or base mounting. Bulletin B-55-D.



# THERMOBLOC

Division of PRAT-DANIEL CORPORATION

Meadow Street



South Norwalk, Conn.

**THERMOBLOC DIRECT-FIRED INDUSTRIAL HEATERS**  
The Thermobloc heater is a direct-fired, self-contained heating unit designed to provide high efficiencies for all commercial and industrial heating applications.

The Thermobloc Heater is a product of a firm with over 30 years of experience in the industrial heating field. It represents up-to-date proven design and engineering principles to assure a minimum of installation and operating costs and dependable comfort conditions.

Thermobloc Heaters are sold in 28 countries. They are available in a complete range of sizes from 100,000 Btu/hr to 2,250,000 Btu/hr output to cover any industrial or commercial application.

All heaters are factory assembled, tested, and shipped complete—requiring only connection of fuel, power and vent for immediate operation in the field. Range of sizes available offers a versatile unit or a combination of units for any industrial or commercial job regardless of size. They may be located directly in the area to be heated or may be full ducted and placed where desirable.

Units are available for all commercial fuels; oil—number two or four; gas; combination gas and oil; combination gas and LP gas.

**PORTABLE THERMOBLOC HEATERS.** Designed for temporary or emergency heating in industrial construction, agriculture or personnel applications. The Industrial Model P 420 is oil-fired, has a capacity of 4,500 cfm and may be used in open areas or ducted, as required. Maximum output is 420,000 Btu/hr vented and 560,000 Btu/hr unvented. Unit may be easily moved to location.

The personnel heater Model P 190 provides radiant heat with an output 175,000 Btu/hr. It is oil-fired and completely self-contained including fuel tank, and may be easily moved by one man.

**PANELBLOC GAS-FIRED INFRA RADIANT INDUSTRIAL HEATERS.** The overhead Panelbloc (formerly the Overhead Panelray) offers an entirely new design for industrial heating. Proven for the past seven years in over 15,000 installations, the Panelbloc has demonstrated its advantages as a heater for personnel or equipment. The Overhead Panelbloc is available in two sizes, 62,500 and 125,000 Btu/hr input and it is available for all commercial gas fuels. All models are A.G.A. approved.

Operating on the radiant heat principal, the Overhead Panelbloc requires no fans, blowers or electrical energy for operation. The absence of moving parts make maintenance negligible.

The sun-like radiant heat output from the Overhead Panelbloc is not affected by drafts from open doors or windows, assuring a deposit of heat on the objects and floor in the area being heated. The Overhead Panelbloc, makes it possible to properly heat spots or areas within large unheated buildings,

# Tjernlund Manufacturing Co.

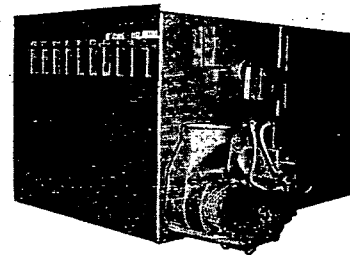
2140 Kasota Avenue • St. Paul 14, Minnesota

TJERNLUND  
"Quick Heat"

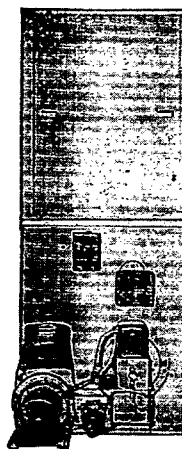
Manufacturers of DOMESTIC, INDUSTRIAL, and COMMERCIAL WARM AIR HEATING EQUIPMENT, OIL and GAS BURNERS, BLOWERS and DRAFT INDUCERS

7 MODELS

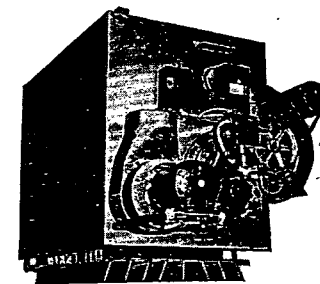
134,000-896,000 BTU OUTPUT



Style "A" Suspended or Lo-Boy



Style "E" Counterflow



Style "D" Suspended Units

## HEAT EXCHANGER

Features well known Tjernlund Counterflow flue system coupled with direct firing into high heat resistant stainless steel combustion area. No internal baffles or restrictions.

## FIRING EQUIPMENT

Oil fired units utilize Tjernlund high pressure integral draft inducing oil unit for #2 or #3 oil. Single motor operation of inducer and oil burner. Two stage fuel units—standard equipment.

## GAS FIRED UNITS

Feature Tjernlund jet fire power type gas units. Models 150, 200, 280 incorporate integral draft inducing equipment identical to that shown on oil units with electric ignition, prepurge timing electronic safety control.

## DUCT HEATERS

All Tjernlund units available less blower equipment for use in conjunction with air conditioning units or as replacement heaters where existing blower equipment can be utilized.

## BLOWER EQUIPMENT

Properly sized DWDI blower wheels with correctly designed scrolls. Blowers made by Tjernlund for correct application to each piece of equipment. Extra capacities available for higher air delivery and external static pressure.

## Engineering Data

| Model | Btu Output | Cfm 3/4" S.p. | Input Oil Gph | Nat Gas Cfh | Blower Phase |      |     | No. Wheels | Wheel Size | Filters |         |
|-------|------------|---------------|---------------|-------------|--------------|------|-----|------------|------------|---------|---------|
|       |            |               |               |             | h.p.         | Volt | Rpm |            |            | Quan.   | Size    |
| 35    | 134,000    | 1600          | 1:20          | 160         | 3/4          | 110  | 680 | 1          | 12 x 12    | 2       | 16 x 25 |
| 50    | 184,000    | 2300          | 1:55          | 230         | 1 1/4        | 110  | 560 | 1          | 14 x 12    | 4       | 16 x 20 |
| 70    | 224,000    | 2800          | 2:00          | 280         | 1 1/4        | 110  | 600 | 1          | 14 x 14    | 4       | 20 x 20 |
| 100   | 336,000    | 4200          | 3:00          | 400         | 3/4          | 120  | 520 | 1          | 16 x 16    | 4       | 20 x 25 |
| 150   | 500,000    | 6300          | 4:50          | 600         | 1            | 120  | 500 | 2          | 16 x 14    | 6       | 20 x 25 |
| 200   | 670,000    | 8400          | 6:00          | 800         | 1 1/4        | 120  | 450 | 2          | 18 x 16    | 8       | 16 x 25 |
| 280   | 896,000    | 10000         | 8:00          | 1000        | 2            | 120  | 480 | 2          | 18 x 18    | 8       | 20 x 25 |

For cfm and s.p. other than stated request additional information from factory.

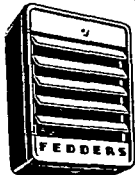
## Fedders-Quigan Corporation

Heating Division

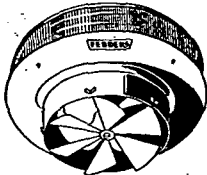
Lalor & Hancock Sts., Trenton 7, N. J.

### FEDDERS

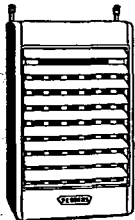
Manufacturers of Convactor-Radiators, Wall Radiation, Baseboard Radiation, Unit Air Conditioners, Unit Heaters, Railroad Car Convectors, Unit Coolers, Refrigeration Coils, Air-Cooled Fin and Tube Condensers, Clip-on Thermometers, Room Air Conditioners, Automotive Radiators, Car Heater Cores, Dehumidifiers.



Fedders Series 17 Horizontal Unit Heaters made in capacities from 83-1225 EDR.



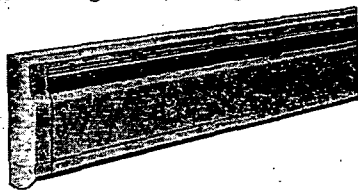
Fedders Series 16 Down-blow Unit Heaters for high or low ceilings and spot locations. Capacities from 165-2050 EDR.



Fedders Series 18 Gas-Fired Unit Heaters in eight sizes—185-667 EDR.

#### FEDDERS UNIT HEATERS

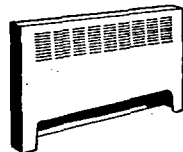
Made in horizontal and down-blow types. Well graduated range of capacities to fit requirements. Quick response to manual and thermostatic controls assures comfort and fuel economy. Complete data given in catalogs.



#### FEDDERS BASEBOARD RADIATION

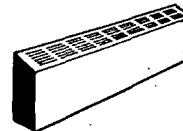
Provides uniform around-the-room comfort. Delivers radiant and convected heat at floor level. No interference with furniture arrangement, draperies or wall-to-wall carpeting. Packaged units factory assembled in 4, 6 and 8 ft lengths. Aluminum-finned, copper tube heating elements. Also steel-finned steel tube. Full length, built-in deflectors serve as adjustable dampers for individual control. I-B-R Approved. Write for catalog.

#### FEDDERS CONVECTOR-RADIATORS



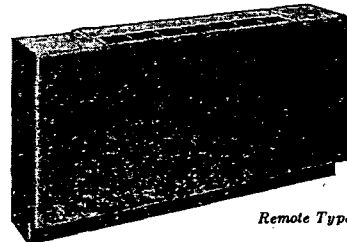
Cabinets are attractively designed for free standing, semi-recessed and flush installations. Heating elements have copper tubes and aluminum fins. Types F, FE and FB available with Fedders slide-in front panels. Code-approved in accordance with Commercial Standard CS140-47. Write for catalog.

#### FEDDERS WALL RADIATION



For industrial, commercial and institutional uses. Available with aluminum-finned copper tube elements or steel-finned steel tubes. Flat or sloping top covers. Also expanded metal covers. Write for catalog.

#### FEDAIR AIR CONDITIONERS



Remote Type

For multiple room installations using circulating hot and cold water supplied from a remote source. Individual room control, quiet operation, no duct work. 3 sizes. Free standing, semi-recessed, concealed and overhead models. Write for catalog.



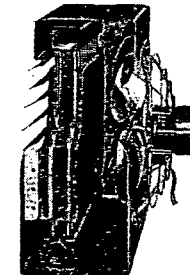
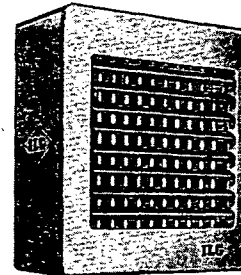
## ILG Electric Ventilating Co.

2880 North Crawford Ave., Chicago 41, Ill.

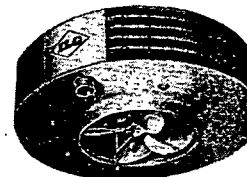
Offices in more than 40 Principal Cities

ILG UNIT HEATERS—STEAM, HOT WATER, ELECTRIC OR GAS

Tested and rated by IUHA and ASHVE codes. "One-name-plate" guarantee.



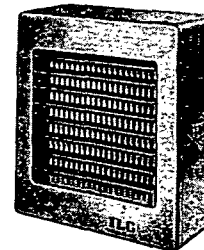
**HORIZONTAL TYPE UNIT HEATERS**—New design. Four side pipe connections for simplified piping. Copper tubes hydraulically expanded for permanent mechanical union with aluminum fins, brazed to one-piece cast iron headers. Suitable for hot water and steam to 150 lbs pressure . . . tubes hydrostatically tested to 500 lbs. Motor totally enclosed, continuous duty type with oil lubricated bearings. 16 capacity sizes.



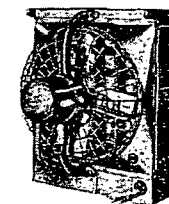
**VERTICAL TYPE UNIT HEATERS**—New design. Ball bearing motors shielded from radiant heat. Heating surface features similar to Horizontal Type above. Type V for standard outlet temperatures, Type VL for low outlet temperatures. 12 capacity sizes.



**ILGDUALGAS UNIT HEATERS**—Use natural, manufactured, mixed, Butane-air mixtures, Propane, or Butane gas. Safety pilot, automatic control valve, electric limit switch. Motor has thermal overload protection.



**TEXTILE TYPE UNIT HEATERS**—More tubes, no fins—for applications where lint, etc. normally adheres to fin surfaces. Other features same as Horizontal Type above.



**HEAVY DUTY ELECTRIC UNIT HEATERS**—Non-glow heating coil. Ideal for heating isolated buildings and for completely automatic heating, periodic, temporary, and auxiliary heating. Capacities 1½ to 15 kw . . . all sizes available for 110, 230, 440 and 550 volts.



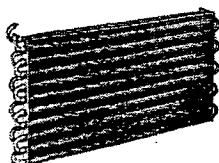


**McQuay Inc.**

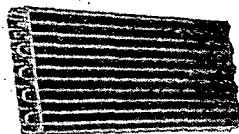
• Heating • Air Conditioning • Refrigeration

1602 Broadway, N. E., Minneapolis 13, Minn.

SALES OFFICES IN PRINCIPAL CITIES



3/8" Tube Evaporator



3/8" Tube Condenser

#### McQUAY RIPPLE-FIN COILS

McQuay now makes the famous Ripple Fin coils in three tube diameters, 3/8 in., 1/2 in. and 3/4 in.; in a wide variety of styles and sizes; for steam, hot water, cold water, direct expansion and refrigerant condensing.

"Custom Engineered" coils are readily obtained as McQuay's manufacturing methods provide a wide variety of fin spacings, fin heights, finned lengths, rows deep, and circuiting; thereby both space and capacity requirements can be met.

Ripple-Fin coils have all tubes mechanically pressure bonded into the wide smooth fin collars providing a permanent bond and high heat transfer

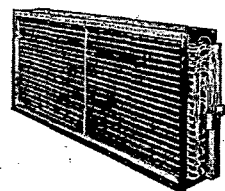
efficiency. McQuay coils are pneumatically tested under water at 300 psig.

Ripple-Fin coils have a staggered tube pattern which combined with the ripple fin produces a turbulent air flow and reduces air "by-pass."

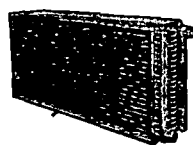
In addition to the ripples across the air flow the fins of McQuay coils have rippled edges to give strength and a pleasing appearance.

McQuay Evaporators and Condensers are dried to minus 40°F. dew point to assure moisture free coils.

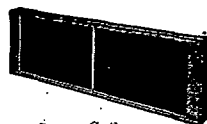
McQuay Ripple Fin coils have been approved by *Underwriters' Laboratories* for use as evaporators or condensers with either Freon 12 or Freon 22.



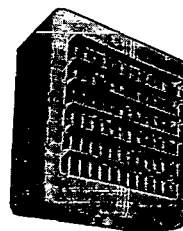
Direct Expansion Coil



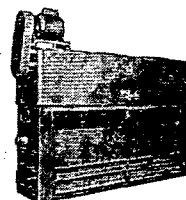
Water Coil



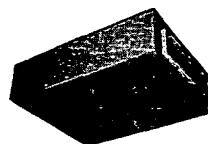
Steam Coil



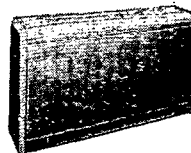
Horizontal Unit Heater



Heating and Ventilating Unit



Seasonmaker (Ceiling Type)



Seasonmaker (Floor Type)

#### HORIZONTAL UNIT HEATERS

Two basic types available—Standard and High cfm. 13 Standard models ranging in size from 21,600 to 360,000 Btu; 11 High cfm models 20,300 to 248,000 Btu. Write for *Catalog 322*.

#### DOWN FLOW UNIT HEATERS

Two basic types available—Standard and High cfm. 11 Standard models ranging in size from 39,300 to 500,000 Btu; 11 High cfm models 25,400 to 289,000 Btu. Write for *Catalog 762*.

#### "RH" AIR CONDITIONER

(For Small Commercial Jobs)

Deluxe units with attractive appearance. Four basic sizes: 1000, 1500, 2000, and 3000 cfm. Nominal capacities range from 2 to 10 tons. Freon and water cooling coils—steam and water heating coils—condenser reheat coils. Write for *Bulletin 88*.

#### HEATING AND VENTILATING UNIT

Horizontal, vertical, wall and inverted types. Covers the entire range from 1280 cfm and 26,000 Btu to 32,000 cfm and 2,227,000 Btu. Filters, face and by-pass dampers, mixing boxes, humidifiers, discharge plenums, and nozzles are available. Write for *Catalog 344*.

#### SEASONMASTER

(Central Station Air Conditioner)

Horizontal and Vertical types. Cools, dehumidifies, filters, and circulates air in summer; heats, humidifies, filters, and circulates air in winter. Freon and water cooling coils—steam and water heating coils. Cooling capacities from 1 to 100 tons, cfm from 640 to 21,000 in both suspended and floor type. Write for *Catalog 505*.

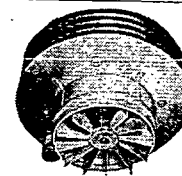
#### SEASONMAKERS

(For Multi-Room Buildings)

Room air conditioner, four types: floor, hideaway, basic, and ceiling. Cooling and heating medium supplied from central plant. Cools, dehumidifies, and filters in summer; heats and filters in winter. Three basic sizes: 200, 400, and 600 cfm (up to 25 per cent of cfm may be fresh air). The Seasonmaker's compactness, attractiveness, quiet operation, and ease of installation make it ideal for hotels, apartment buildings, hospitals, motels, etc. Write for *Bulletin 704*.

#### ICY-FLO ACCUMULATORS

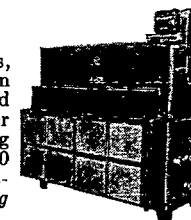
The practical "Storage-Battery" for refrigeration effect is now available for handling heavy loads of short duration. Ideal for churches, lodges, mortuaries, noon cafeterias, and many industrial applications. Write for *Bulletin 109*.



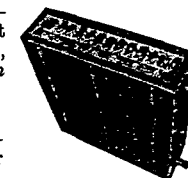
Down Flow Unit Heater



Air Conditioner  
(Year-Round)



Seasonmaster  
Air Conditioner  
(Year-Round)



Accumulator

## Modine Manufacturing Company

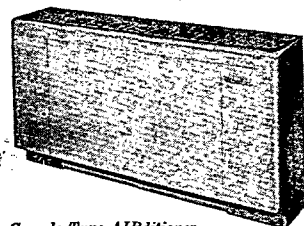
Heating and Air Conditioning Division

General Offices: 1515 Dekoven Ave., Racine, Wis.

Factories at Racine, Wis., LaPorte, Ind., Paducah, Ky., and Whittier, Calif.

Sales Representatives in all Principal Cities

### NEW MODINE AIRditioner\*



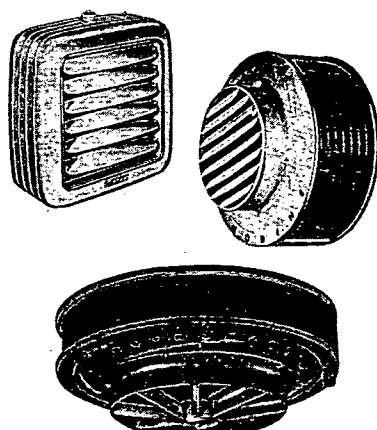
Console Type AIRditioner

Four types available: The Console (illustrated) for exposed and partially recessed installation . . . the Concealed . . . the Ceiling . . . and the Overhead Models, with or without casings. Each is available in three sizes rated at  $\frac{3}{4}$ ,  $1\frac{1}{2}$  and 2 tons of refrigeration (220, 440 and 640 cfm respectively).

All Modine AIRditioners are designed and engineered for fast, easy installation and quick access to all connections and parts. Casings are Parker-Bonderized and finished in a semi-gloss Marine Green primer.

### MODINE UNIT HEATERS FOR WATER AND STEAM

A fully coordinated line of Modine Unit Heaters offers greatly expanded opportunities for correct unit heater application. Individually or in combination, they meet the exacting engineering demands of any space heating application.



For steam, Modine builds 26 sizes of vertical (includes 13 low outlet temperature models), 19 sizes of horizontal (includes 9 low outlet temperature models), and 10 sizes of power throw units. For hot water, Modine builds 13 sizes of vertical and 15 sizes of horizontal units.

\* Trademark

The modern room unit for cooling and heating hotels, apartments, motels, offices, hospitals, schools and homes. Ideal for new construction and modernization. Provides cooling with chilled water and heating with hot water—from a central source. Filters and dehumidifies while introducing and circulating fresh air. Four-speed motor control for maximum adaptability to conditions.

**Rugged Condenser**—Tubes and headers are cylindrical and brazed at the joints for greater pressure-resisting strength. Individual expansion bends of horizontal models absorb differential stresses.

**One-Piece Construction**—Tubes, header, inlet and outlet connections are brazed into a rugged, pressure-resisting unit.

**Safety Fan Guard**—On all Horizontal models, a built-in fan guard offers constant protection from exposed fan.

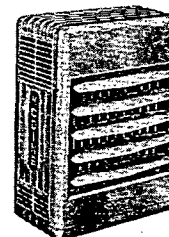
**Bonderite-Treated Casings**—All unit heater casings are Bonderite-treated to prevent rust and bond paint to steel.

**Efficient Motors**—Nationally known makes of continuous-duty, totally enclosed fan type. Rubber mounted to prevent vibration noise.

**Easy Installation**—Direct-from-pipe line suspension for low cost, fast installation of all Horizontal types. Accurately rated in strict accordance with the Standard Test Code for Unit Heaters.

### MODINE GAS-FIRED UNIT HEATERS

Half the weight . . . half the size . . . of the average of 7 other leading gas units of comparable capacity.



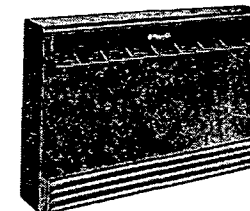
Gas-fired unit heater

Modine Gas-Fired Units are made with both stainless steel burners and a choice of stainless or aluminized steel heat exchangers. Lighter weight means easier, less expensive installation plus faster heat delivery . . . within five seconds after thermostat calls for it. Individually fired tubes provide higher heat transfer. Elongated ports—four times free area of conventional drilled ports—minimize clogging and simplify cleaning.

Seven sizes—from 25,000 to 220,000 Btu. A.G.A. and CGA approved for natural, mixed, manufactured LP and LP-air gases.

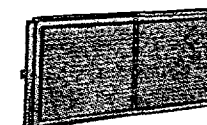
### MODINE CONVECTOR RADIATION

Modine Convectors combine exceptional beauty with outstanding performance. Available in Deluxe and Standard enclosure styles, they are also obtainable in heavy-duty Institutional models. Floor, wall, sloping wall, concealed, fully recessed and partially recessed styles offer a wide selection to meet any requirement.



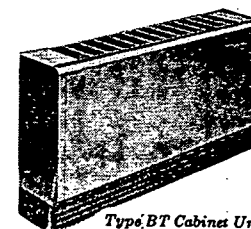
Deluxe Floor Convector—for recessed or free-standing installation.

**MODINE HEATING COILS** The extensive line of Modine Heating Coils is engineered to meet the diversified requirements of modern air-handling systems. In addition to more than 1200 cataloged heating coils for use with steam and hot water, Modine produces many custom built coils for installation in air-handling equipment produced by other firms. Types include standard and non-freeze heating and booster coils, and hot water heating coils.



Standard Heating Coil

**MODINE CABINET UNITS** The Modine Cabinet Unit line provides economical heating, cooling and ventilating where the expense of air conditioners or unit ventilators is not warranted. A single Cabinet Unit can provide quick, positive, quiet distribution of heated or cooled air—with or without ducts. Addition of inexpensive accessories permits introduction, filtering, heating and distribution of fresh outside air for ventilating.



Type BT Cabinet Unit

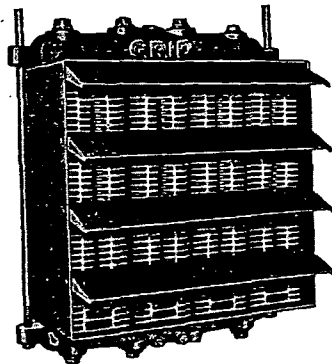
Five different models provide (1) heating with steam or hot water and (2) cooling with chilled water in addition to heating. Various combinations, with or without optional equipment, permit free-standing, recessed and concealed installations—floor, wall or ceiling mounting.



## D. J. Murray Manufacturing Co.

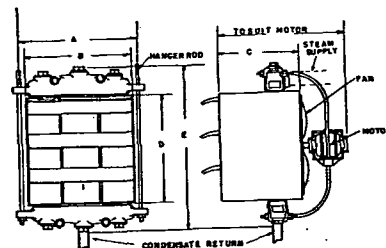
Wausau, Wisconsin  
Offices in Principal Cities

MANUFACTURERS OF GRID UNIT HEATERS  
AND GRID BLAST COILS



One piece construction "fin" heating sections of high test cast iron—no soldered, brazed, welded or expanded connections. Patented.

Designed and tested to operate with steam or hot water systems—for steam pressures from 2 lbs to 250 lbs. GRID Unit Heaters are "Put up to stay up" without repairs or other maintenance... service records from all types of industry prove it.



Overall dimensions for installation of Cast Iron  
GRID Unit Heater

### CI (CAST IRON) SERIES GRID UNIT HEATER DATA

| Model No. | Dimensions |        |        |        |        | Motor |      | Vol. Fan Cfm | Capacities 5 PSI Steam 60°F Air |                | Pipe Size |        | Support Rod Dia. | Approx. Ship. Weight Lbs |
|-----------|------------|--------|--------|--------|--------|-------|------|--------------|---------------------------------|----------------|-----------|--------|------------------|--------------------------|
|           | A          | B      | C      | D      | E      | Hp    | RPM  |              | Btu/Hr                          | Final Temp. °F | Supply    | Return |                  |                          |
| CI-1000   | 11 3/4     | 10 1/4 | 12 3/4 | 10 7/8 | 17 1/4 | 1/20  | 1550 | 572          | 29,080                          | 106            | 1 1/4     | 1 1/4  | 1/4              | 150                      |
| CI-1200   | 14 1/4     | 13 1/4 | 12 3/4 | 13 3/4 | 21 1/4 | 1/12  | 1700 | 798          | 45,450                          | 112            | 1 1/4     | 1 1/4  | 1/4              | 210                      |
| CI-1500   | 17 1/4     | 15 3/4 | 11 1/2 | 16     | 23 3/4 | 3/8   | 1700 | 1500         | 76,500                          | 107            | 1 1/2     | 1 1/2  | 1/2              | 280                      |
| CI-1520   | 17 1/4     | 15 3/4 | 11 1/2 | 21     | 26 3/4 | 3/8   | 1700 | 1700         | 101,500                         | 114            | 1 1/2     | 1 1/2  | 1/2              | 300                      |
| CI-2000   | 22 1/4     | 20 3/4 | 11 1/2 | 21 1/4 | 26 3/4 | 3/8   | 1100 | 2600         | 143,000                         | 110            | 2         | 1 1/2  | 1/2              | 490                      |
| CI-2025   | 22 1/4     | 20 3/4 | 11 1/2 | 25 1/4 | 36 1/4 | 3/8   | 1100 | 2875         | 173,640                         | 115            | 2         | 1 1/2  | 1/2              | 520                      |
| CI-2504   | 27 1/4     | 25 1/4 | 13     | 25 1/4 | 36 1/4 | 3/4   | 1100 | 4350         | 224,000                         | 107            | 2         | 1 1/2  | 5/8              | 660                      |
| CI-2504   | 27 1/4     | 25 1/4 | 13     | 25 1/4 | 36 1/4 | 3/4   | 1150 | 3300         | 206,000                         | 117            | 2         | 1 1/2  | 5/8              | 700                      |
| CI-2500   | 27 1/4     | 25 1/4 | 13     | 25 1/4 | 36 1/4 | 3/4   | 1150 | 4650         | 275,800                         | 114            | 2         | 1 1/2  | 5/8              | 900                      |
| CI-2530   | 27 1/4     | 25 1/4 | 13     | 31     | 40 1/4 | 1 1/2 | 850  | 6300         | 332,000                         | 108            | 2 1/2     | 1 1/2  | 3/4              | 1020                     |
| CI-3000   | 32 3/4     | 31     | 13     | 31     | 40 1/4 | 1 1/2 | 1150 | 8000         | 380,000                         | 103            | 2 1/2     | 1 1/2  | 3/4              | 1070                     |

### NO ELECTROLYSIS TO CAUSE CORROSION

Low maintenance expense.  
More air changes per hour.  
Positive "directed" heat.  
No leaks—no breakdowns.

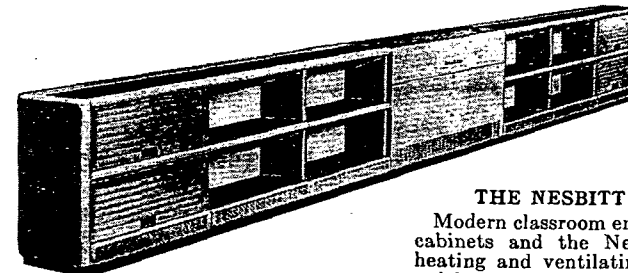
Lower outlet temperature.  
Larger air volume.  
No soldered, brazed or expanded joints.  
Open design that keeps units clean.

Send for complete Catalog information  
Send for information on Blast coils and radiation.

## JOHN J. NESBITT, INC.

Philadelphia 36, Pa.

Manufacturers of  
NESBITT SCHOOLHOUSE HEATING AND VENTILATING  
EQUIPMENT AND AUXILIARY STORAGE CABINETS



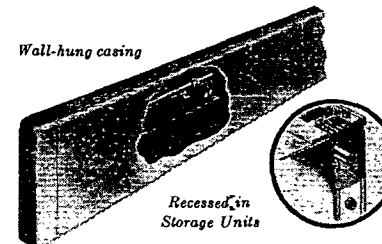
Ensemble of  
the Nesbitt  
Syncretizer and  
metal shelving.

### THE NESBITT PACKAGE

Modern classroom ensemble of storage cabinets and the Nesbitt Syncretizer heating and ventilating unit. Provides quick, economic heat without overheating; draft-free ventilation and cooling when needed; room-by-room balance. A fully automatic, quiet-operating unit adaptable to four cycles of control. Sturdy, attractive 28 in. and 32 in. high ensembles with laminated plastic hardtop, choice of 6 baked enamel finishes. Capacities from 750 to 1560 cfm anemometer rating. Publication 101.

### SERIES-WIND-O-LINE SYSTEM

A new hot water heating and ventilating system (Syncretizers and Wind o-line piped in series circuits) that reduces mechanical system costs by eliminating pipe trenches, coverings and individual runouts. Variable water temperature provides better control, ideal cold surface protection. Pub. 104.



Wall-hung casing

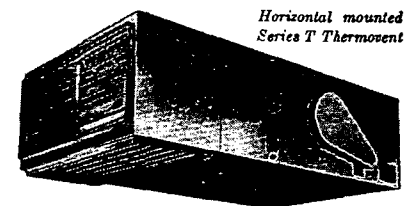
Recessed fin  
Storage Units

### WIND-O-LINE RADIATION

For integration with the Syncretizer under large glass areas with cold exposures. Consists of fin and tube radiation in a gridded wall-hung casing or recessed in components of the Nesbitt Package. Controlled in cycle with the Syncretizer to meet the heat demands of low temperature surfaces. Capacities 450, 550 and 700 Btu/lineal ft. Pub. 261, Section W.

### SERIES T THERMOVENTS

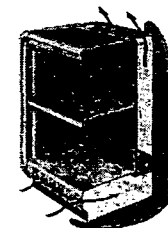
New higher capacity heating and ventilating units for large auditoriums, gyms, shop rooms, cafeterias and similar gathering places. Available for both low-pressure and high-pressure, relatively high-resistance applications. Unique acoustically treated discharge plenum assures quiet operation. Available in capacities from 1250 to 15,000 cfm. Publication 270.



Horizontal mounted  
Series T Thermovent

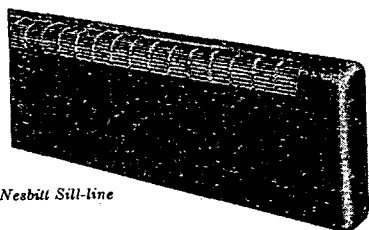
### SILL-LINE RADIATION WITH STORAGE CABINETS

For modern school and office installations which require practical storage space combined with a need for heating, this low-cost combination of high-capacity Sill-line perimeter heating with Nesbitt open and closed storage shelving is ideal. Cabinets are made in 28 in. and 32 in. heights, 2 ft, 3 ft and 4 ft lengths to form continuous ensembles. Piping Compartment and Fill-in Section conceal control valves, piping, etc. Available in choice of 6 attractive baked enamel finishes with laminated plastic hardtop for extreme durability. Steam heating capacities from 1435 to 2520 Btu per hr per lineal ft, true condensation. Publication 261, Section S.



## JOHN J. NESBITT, INC.

Philadelphia 36, Pa.



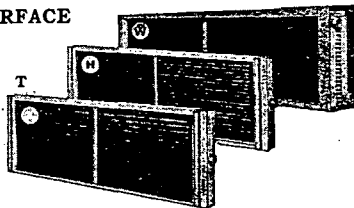
Nesbitt Sill-line

### NESBITT SILL-LINE RADIATION

High-capacity perimeter heating in an attractive 16-gauge wall-hung enclosure for use in schools, hospitals, offices, showrooms, etc. Made in five casing styles with one-piece back panel for true, rigid alignment; seven lengths from 2 ft to 8 ft; choice of finishes. Full range of accessories and sleeves eliminate on-the-job cutting. Eight heating elements with CODE approved ratings from 2.9 to 12.1 sq ft EDR. *Publication 102.*

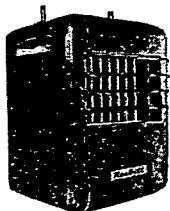
### NESBITT HEATING AND COOLING SURFACE

**SERIES W.** Water surface for air-cooling, dehumidifying or heating. Copper tubes, aluminum or copper fins. Wide range of sizes in three types: Type WD (continuous tube with exclusive freeze-proof drainability feature, and surface pitched in the casing). Pub. 246. Type WB (continuous tube sections for booster-heating or air-cooling relatively small air volumes but without drainability feature) and Type WC (standard Series W cores pitched in the casing; cast iron headers removable cover plates to permit cleaning, single or double serpentine circuits.) Pub. 255.



**SERIES T.** With Trombone-shaped steam-distributing tubes that eliminate stratification and all danger of freezing under modulated valve control. Gives uniform temperatures over the entire capacity range. Ideal for heating and ventilating and for preheating outdoor air. Copper tubes and headers, aluminum or copper fins. Type TO with steam and condensate connections at opposite ends, Type TS with connections at same end. Fin lengths from 12 in. to 120 in. *Publication 305.*

**SERIES H.** General blast coil surface for heating, ventilating, air-conditioning and drying in both high and low-pressure systems. Copper tubes, aluminum or copper fins. Seven types, full range of sizes. Pub. 248.

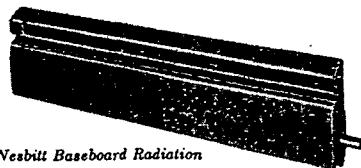


### NESBITT GAS-FIRED UNIT HEATERS

Modern, attractive direct-fired unit heaters in seven basic models ranging in capacity from 25,000 to 200,000 Btu heat input. Made of die-formed furniture steel finished in heat-resistant, baked-on enamel. Low-speed motor equipped with thermal overload protection. Quiet-operating fans; die-formed adjustable louvers. Equipped with automatic controls and safety pilot. Units are A.G.A. approved and listed by Underwriter's Laboratories. *Publication 280.*

### NESBITT BASEBOARD RADIATION

A new approach in baseboard design. Combines an enclosure of unusual beauty with a heating capacity ample to achieve true perimeter heating (4.1 sq ft EDR per lineal ft). CODE approved steam and hot water ratings. Copper tube, aluminum fin element. Furniture steel cabinet in 4, 5, 6, 8 ft lengths. Pub. 272.



Nesbitt Baseboard Radiation

## JOHN J. NESBITT, INC.

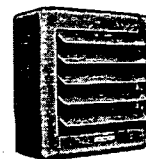
Philadelphia 36, Pa.

NESBITT UNIT HEATERS are designed to circulate large volumes of air at comparatively low temperatures, assuring quick heating.

Ratings of Nesbitt Unit Heaters are based on tests made in accordance with standard test code of Industrial Unit Heater Association and ASHVE.

### PROPELLER FAN UNIT HEATERS

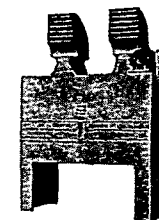
Featuring universal heating elements of continuous tube design, each size unit gives a comparable range of capacities with either steam or hot water. Made for high temperature drops, low water rates for installation economy. Small physical size for comparable Btu output *saves space*. Sturdy steel casings with baked-on gray-green hammertone finish for lifetime beauty. Flush-to-ceiling mounting permitted by male pipe connections extending through casing rear. Sealed-for-life motors in most models. Balanced aluminum fans with large blade areas assure gradual, quiet, efficient air delivery. Eight basic sizes, 24 models, capacities from 15,000 to 335,000 Btu per hour. Sound rated within lowest classifications of new Bulletin 13, I.U.H.A. Sound Test Code. Pub. 401.



Standard Propeller-Fan Type

### GIANT BLOWER-FAN UNIT HEATERS

Large capacity units for: heating and/or ventilating, free delivery or static pressure, steam or water systems. Twelve basic sizes, each with one of three standard steam coils, three distributing-tube coils, or with a single, two, three, or four-row hot water coil. Air deliveries from 2000 to 28,000 cfm. Basic steam ratings, 83,000 to 1,735,000 Btu/hr. Hot water capacities from 50,000 to 2,460,000 Btu/hr, 1800 to 3400 fpm. Control may be STANDARD—periodic fan operation; THERMADJUST—continuous fan operation with thermostat-controlled dampers; or VALVE-CONTROLLED—with thermostat controlling steam supply. Horizontal-suspended, wall, inverted or floor-mounted with wide choice of cowls, fans, dampers, filters and other accessories. Pub. 404.



Giant Blower-Fan Type

### LITTLE GIANT UNIT HEATERS

Adaptable to a wide variety of applications and field conditions. Eight basic sizes, each with a choice of two (some units three) heating elements. The three smaller sizes are of the blow-through type, having lower outlet velocities generally intended for the lower mounting heights of commercial installations. These sizes in down-blow type only. The five larger models are of the draw-through type; produce the high discharge velocities necessary to blow long distances. These five available for either horizontal or vertical down-blow.

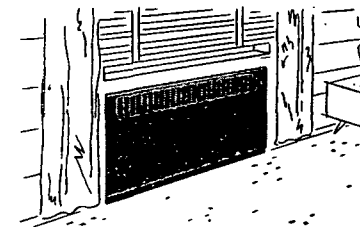
Durable lightweight Heating Elements. Extended fin-and-tube type, copper condensing tubes and plate-type aluminum fins. Steam capacities from 28,500 to 510,000 Btu. Pub. 402.



Little Giant Down-Blow Type

### SERIES "C" UNIT HEATERS

The new Series "C" permits complete flexibility of design and operation. Units are available for floor mounting, horizontal, wall or inverted applications and can be installed fully recessed, semi-recessed or free standing. The discharge or intake can be face, top or bottom—direct or with ducts. Available in five basic sizes—46 basic capacities ranging from 25,000 to 148,000 Btu per hour. For steam or hot water. Pub. 403.



Series "C" Cabinet Heater

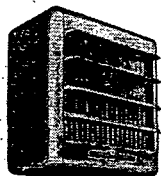


## HERMAN NELSON

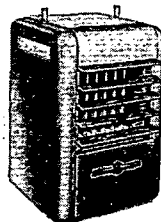
American Air Filter Company, Inc.

Office — Louisville, Ky. Factories — Louisville, Ky., and  
Moline, Ill.

Branch Offices and Product Application Engineers in Principal Cities



Horizontal Shaft Heater



Gas Fired Heater

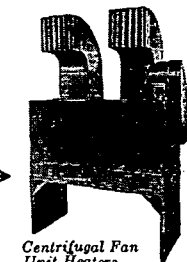
◀ **HORIZONTAL SHAFT PROPELLER-FAN TYPE UNIT HEATERS.** For ceiling or wall mounting. Use with steam or hot water. Copper heating element with patented stay tube prolongs unit life. Many models and sizes. *Bulletin 700.*

▶ **VERTICAL SHAFT PROPELLER-FAN TYPE UNIT HEATERS.** Designed for high ceiling installations. Long life copper heating element for use with either steam or hot water. Units available in range of capacities with high or low velocity discharge. *Bulletin 700.*



Vertical Shaft Heater

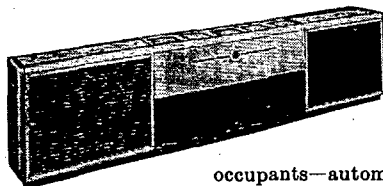
◀ **GAS FIRED UNIT HEATER.** Operates on all types of gas. Compact in design—easy to install—readily moved. Available in 7 sizes with heat output ranging from 20,000 to 160,000 Btu's per hour. *Bulletin 715.*



Centrifugal Fan Unit Heaters

▶ **CENTRIFUGAL FAN UNIT HEATERS.** Use has supplied solution to many heating and ventilating problems. Wide variety of models, sizes and speeds assure right unit for every commercial and industrial building need. *Bulletin 750.*

**CONSOLE HEATER.** Compact, quiet, economical and attractively styled. Ideal for offices, showrooms, corridors, stores, etc. May be placed on floor, wall or suspended from ceiling. 18 models and sizes. *Bulletin 727.*



Unit Ventilator

Console Heater

### DRAFT/STOP UNIT VENTILATORS.

A Unit Ventilation System that traps cold drafts before they reach classroom occupants—automatically heats, ventilates and cools. System is quiet and economical—requires little maintenance. *Bulletin 600.*

Herman Nelson Unit Heaters and Unit Ventilators are tested and rated in accordance with the Standard Test Codes adopted by the *Industrial Unit Heater Association* and *ASHVE*.

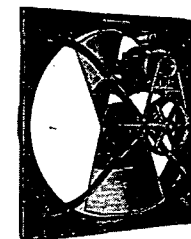
## HERMAN NELSON

American Air Filter Company, Inc.

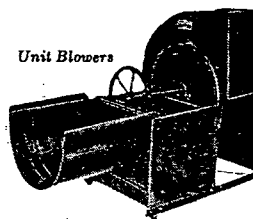
Louisville, Ky. • Moline, Ill.



▶ **PROPELLER FANS.** A complete line of belt or direct drive ventilating fans. Twenty-nine sizes with wheel diameters from 10 to 54-in. Unit capacities ranging from 655 to 36,150 cfm. *Bulletin 800.*



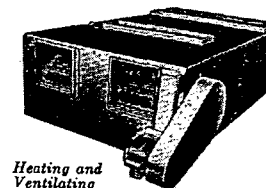
Propeller Fan



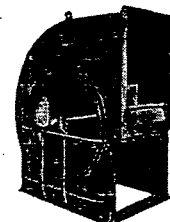
Unit Blowers

◀ **UNIT BLOWERS.** Direct or belt drive with forwardly curved or backwardly inclined wheels. Wheel diameters from 4½-in. to 30-in. and capacities from 160 to 18,303 cfm. *Bulletin 825.*

**HEATING AND VENTILATING UNIT.** Features sectionalized construction, low outlet velocities, slow fan speeds, wide selection of heating coils. Available with humidifier. Ideal for institutional or commercial use. *Bulletin 775.*



Heating and Ventilating Unit



Centrifugal fans

▶ **CENTRIFUGAL FANS.** Designed for systems requiring a Class I or II centrifugal fan. Slow speed or non-overloading type. Wheel diameters from 12¼ to 73-in., single or double width. Direct or belt drive. Any rotation or discharge. *Bulletin 850.*

### RADIATION PRODUCTS

**BASEBOARD RADIATION.** Recess and flush types for steam or hot water feature aluminum fin on copper tube and are designed to prevent "wall streaking." *Bulletin 792.*

**CONVECTOR RADIATORS.** Range of sizes for steam or hot water. Heating elements made of non-ferrous materials. Cabinets designed for free standing or semi-recessed installation. Also sloping top models. *Bulletin 791.*

**FINNED RADIATION AND COVERS.** Adaptable to any system as a primary or supplementary heating source. Range of sizes with choice of expanded metal, flat top or slant top covers. *Bulletin 790.*

Herman Nelson Propeller and Centrifugal Fans are tested and rated in accordance with the Standard Test Code adopted jointly by the *National Association of Fan Manufacturers* and *ASHVE*.

## The TRANE Company • La Crosse, Wis.

IN CANADA: TRANE COMPANY OF CANADA, LTD., TORONTO, ONTARIO—OFFICES IN 17 CANADIAN CITIES

REFRIGERATION  
AIR  
CONDITIONING

# TRANE

HEATING  
VENTILATING  
HEAT TRANSFER

### COMPLETE LINE HEATING AND CONDITIONING

88 Trane Sales Offices in U. S.

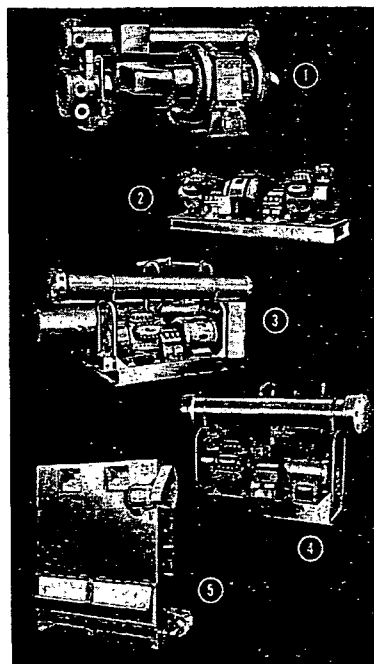
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## TRANE REFRIGERATION



### 1. CENTRAVACS

A self-contained hermetic centrifugal refrigeration unit in 19 sizes. Capacities 45 to over 800 tons.

### 2. RECIPROCATING COMPRESSORS

Two cylinder sizes in 4, 6, and 8 cylinder units. Single or duplex direct drive arrangements with capacities from 10 to 150 tons.

### 3. COLD GENERATORS

Complete refrigeration machine meets all normal requirements of chilled water systems. Models from 10 to 150 tons.

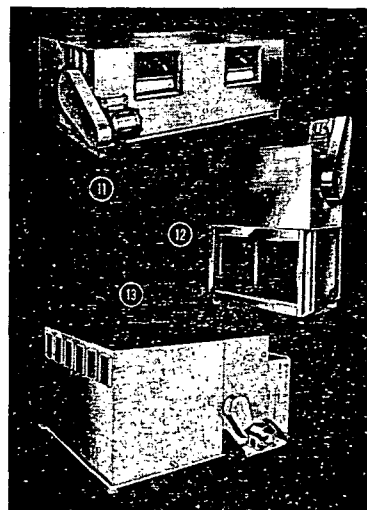
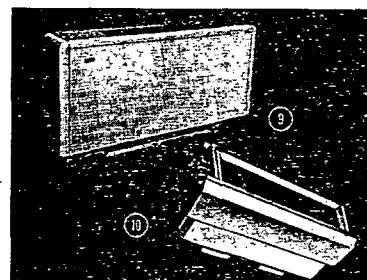
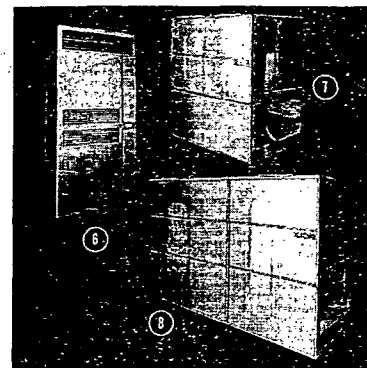
### 4. CONDENSING UNITS

Trane Reciprocating Compressor complete with water cooled condensers. Capacities 10 to 150 tons.

### 5. EVAPORATIVE CONDENSERS

Condenses Freon-12 and Freon-22 refrigerants. Uses minimum amount of water. Sizes 3 to 100 tons.

## TRANE AIR CONDITIONING



### 6-7-8. SELF-CONTAINED AIR CONDITIONERS

Packaged air conditioning units for offices, shops or home air conditioning. Available in 6 sizes—9 models ranging from 3 to 20 tons. Smaller 3, 5, and 7½-ton sizes have de luxe cabinet design to be installed in the conditioned space and blend with any surrounding. Larger 10, 15, and 20-ton sizes constitute the commercial line and are usually installed in a remote location, outside the conditioned area. De luxe units available with water cooled condenser. Commercial units may be had with either water cooled condenser or built in evaporative condenser.

### 9-10. ROOM AIR CONDITIONERS

UniTrane air conditioners heat, ventilate, filter and circulate air in the winter. In summer, they cool, ventilate, filter, control moisture content and circulate air. Two vertical and two horizontal models. Each available for 200, 300, 400 and 600 cfm delivery.

### 11-12-13. CLIMATE CHANGERS

Any or all phases of air conditioning available in one unit. Two models, horizontal and vertical, each in 12 different sizes. Capacities range from 600 cfm to 29,000 cfm for any application, comfort or process.

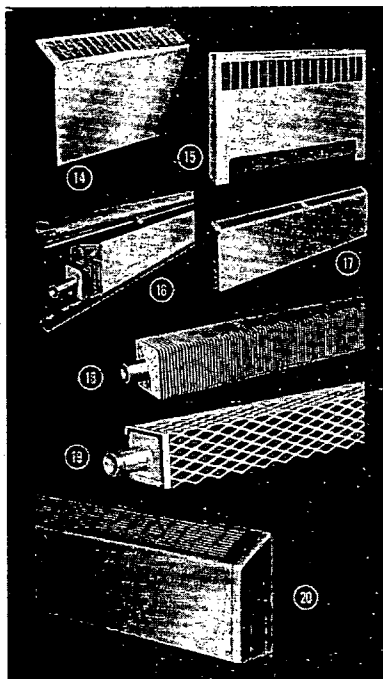
Multi-Zone Climate Changers provide a number of zones with different air conditions at the same time.

### EDUCATIONAL MATERIAL

"Trane Air Conditioning Manual" (\$6.50), an unbiased 380-page textbook for the engineering profession. New revised edition now available. Many tables and charts included for making computations. In general, text covers heat gains, psychrometry, calculations for the conditioned air supply, refrigeration for air conditioning, water for air conditioning, and ducts and fans.

"Trane Refrigeration Manual," a reference for servicing and installing all types of refrigeration systems. Also available from The Trane Company, La Crosse, Wis. Price \$1.50.



**TRANE****HEATING AND  
VENTILATING****14-15. CONVECTORS**

For all steam and hot water systems. Type C—immediately available in many standard sizes. Other units for specific application problems.

**16. BASEBOARD CONVECTORS**

Non-ferrous fin-and-tube heating element. Attractive steel cabinets, 8¼ in. or 12 in. height. Damper or valve controls, optional.

**17. WALL LINE CONVECTORS**

High capacity radiation designed to run continuously below window expanses. Cabinet depths 4 in. and 6 in., heights—14 in., 16 in., and 26 in.

**18-19-20. WALL-FIN**

Ferrous or non-ferrous finned radiation. Lengths 2 ft to 12 ft in 6 in. increments. Cabinets and expanded metal grilles available.

**21. PROJECTION UNIT HEATERS**

Model "P" taps the reservoir of ceiling heat, solves multitude of heating problems. Louver Cone diffuser, optional.

**22. HORIZONTAL UNIT HEATERS**

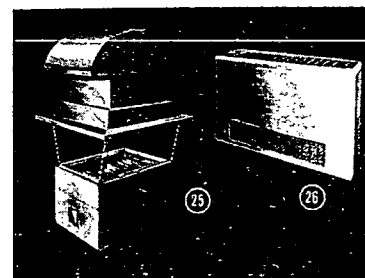
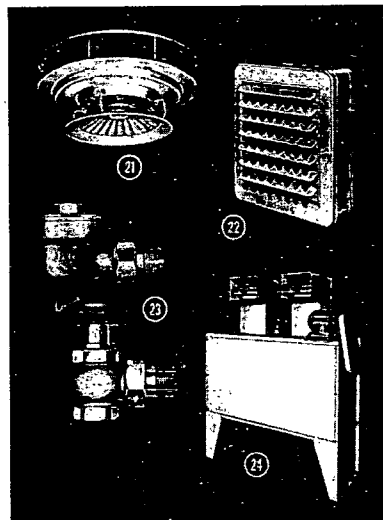
Combines Trane broad blade propeller fan and extended surface coil. In 24 sizes, 22,000 to 352,000 Btu. Louver Fin diffuser, optional.

**23. STEAM SPECIALTIES**

Complete line including thermostatic traps, valves, float traps, bucket traps, strainers, vents and temperature control valves.

**24. TORRIDORS**

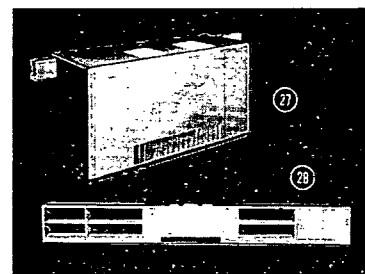
Blower type unit heaters combining Trane Centrifugal Fans and extended surface coils for heating and ventilating large spaces and for process applications.

**25. ROOF VENTILATORS**

Complete line of supply and exhaust ventilators and ventilating heaters. 355 to 25,000 cfm.

**26. FORCE-FLO HEATERS**

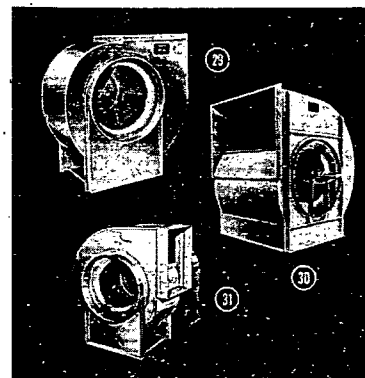
De luxe cabinet-type unit heater with centrifugal fan. Capacities: 17,700 to 105,000 Btu.

**27. UNIT VENTILATORS**

Kinetic Barrier System with lateral extensions the length of the outside wall provides constant protection against window downdrafts. Conventional discharge type units with all air being delivered from the unit itself, also available.

**28. SHELIVING**

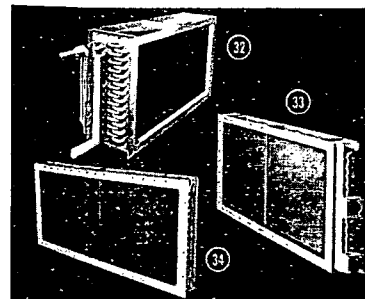
Available for Kinetic Barrier and conventional units in open or closed type. Have plain tops, or may be linoleum covered. Three sizes.

**29-30-31. FANS**

Centrifugal fans in non-overloading backwardly inclined or slow speed forward curved types. All standard arrangements in sizes from 12 in. to 108 in. Capacities 668 to 491,000 cfm.

Utility fans, both belt-driven and direct connected, in non-overloading backwardly inclined or slow speed forward curved types. All standard arrangements in sizes 4½ in. to 30 in. Capacities 110 to 15,450 cfm.

Propeller fans with direct or belt drive. Sizes 10 in. through 72 in. Capacities 475 to 58,560 cfm.

**32-33-34. EXTENDED SURFACE COILS**

Heating coils include a complete range of same and opposite end connection steam distributing tube coils, standard coils, heavy duty, high pressure steam coils, and equipment coils. Cooling coils are manufactured for direct expansion or water cooling in thousands of sizes and types. All extended surface coils have exclusive Delta-Flo Fin for greater heat transfer efficiency.



Office and Factory  
LINDEN, N. J.

**L. J. Wing Mfg. Co.**  
59 Vreeland Mills Road, Linden, N. J.

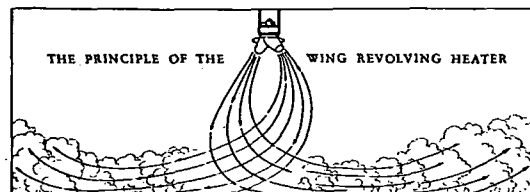
Canadian Factory:  
MONTREAL

Branch Offices in  
European Representative for Heaters:



Principal Cities  
Wanson, Haren-Nord, Brussels, Belgium

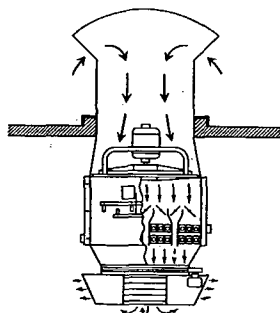
### WING REVOLVING UNIT HEATERS



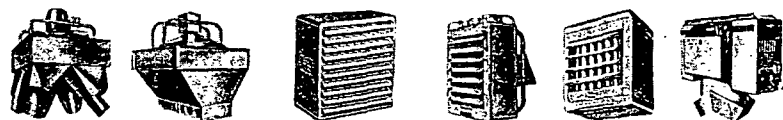
An outstanding and unique feature of WING Revolving Unit Heaters is the revolving air distributor, which slowly turns, delivering air obliquely downward, in ever changing direction, to the working floor. Warm air spreads across the floor and around obstacles creating a pleasant atmosphere. In warm weather with heat off, WING Revolving Units furnish refreshing zephyrs of cooling air. Write for *Bulletin HR-6A*.



### WING FRESH AIR SUPPLY HEATERS



Ventilating and fume exhaust systems require free admission of air into the building to balance the air exhausted. WING Fresh Air Supply Heaters provide an adequate supply of properly warmed, evenly distributed fresh air without chilling drafts. They cannot freeze, regardless of outdoor temperature, as the steam is on at full pressure all the time. Write for *Bulletin HS-4*.



### OTHER WING HEATERS (Left to Right)

WING Stationary Discharge Unit Heater. WING Door Heater. WING Utility (Horizontal Discharge) Unit Heater. WING Electric (Horizontal Discharge) Unit Heater. WING Gas-Fired Unit Heater (Horizontal). WING Gas-Fired (Vertical Discharge) Unit Heater.

Office and Factory  
LINDEN, N. J.

**L. J. Wing Mfg. Co.**  
59 Vreeland Mills Road, Linden, N. J.

Canadian Factory  
MONTREAL

Branch Offices in  
European Representative for Heaters:



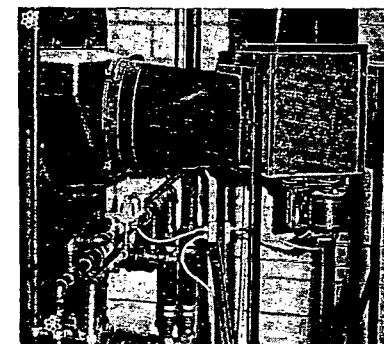
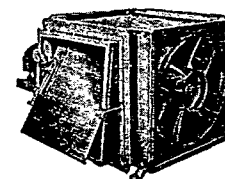
Principal Cities  
Wanson, Haren-Nord, Brussels, Belgium

### WING FANS



The Elbow Type WINGFOIL Duct Fan replaces an elbow in a run of duct. The WINGFOIL Straight Line Duct Fan is inserted in a straight run of duct. In both of these types the motor, outside the casing remains cool and clean. The WINGFOIL Vaneaxial Fan has a sealed motor within the casing. All deliver large volumes of air for size of fan, quietly, without vibration. Capacities to 95,000 cfm. Write for *Bulletin F-10A*.

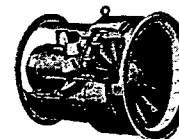
### WING DRAFT INDUCERS



WING Draft Inducers for heating boilers assure positive draft regardless of weather conditions and eliminate the need for high chimneys. New design has interchangeable inlets, automatic belt tension, sealed bearings. Fan assembly may be withdrawn from housing for inspection or servicing. Available in a wide range of capacities. WING Packaged Power Plant Draft Inducers for power

plants up to 120,000 lbs of steam per hour. Send for *Bulletin I-56*.

### WING BLOWERS



WING Motor Driven Forced Draft Blowers for statics up to 10 in.; volumes up to 50,000 cfm. Manual or automatic capacity regulation. Vertical or horizontal mounting. Voltrol vanes permit regulation to 10 per cent of maximum. *Bulletin FD-4*.

WING Turbine Driven Blowers are easily installed on burner fronts or boiler settings, providing precise draft control manually or automatically. Oil-free exhaust steam permits utilization in processes or heating. *Bulletin FD-4*.



WING STEAM TURBINES for driving pumps, fans, compressors, etc. are sturdy, dependable sources of auxiliary power. Capacities to 150 bhp. Temp. to 750F. Speeds to 4000 rpm. *Bulletin T-54*.

# YOUNG Radiator Company

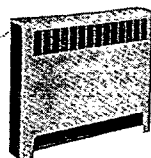
Dept. 546, Racine, Wis.

Sales & Engineering Representatives in all Principal Cities



Heating, Cooling, Air Conditioning Products for Home and Industry, Heat Transfer Products for Automotive, Agricultural, Industrial, Gas and Diesel Engine Applications

## CONVECTORS & UNIT HEATERS



Convectors are available from stock in six standard cabinet styles; also Institutional and bathroom models; for steam or hot water systems.

"Vertiflow" Unit Heaters are built in nine sizes; capacities from 52,600 to 552,000 Btu per hr; adjustable louvers, nozzles, diffusers, Anemostats.

Type "SH" Unit Heaters are built in 14 sizes; capacities from 19,000 to 325,000 Btu per hr; for steam and hot water systems.

Cabinet Type Unit Heaters are available in number of arrangements, wall hung, horizontally suspended, etc.; from 26,200 to 115,000 Btu per hr.

"Perimaheat" Baseboard Convector for hot water service; available in 6 and 8 ft lengths; capacity with 190 deg average water 822 Btu per lineal foot; available with either adjustable damper or splitter.

Gas-Fired Unit Heaters are available in seven sizes ranging in capacities from 50,000 to 230,000 Btu/hr output. Have welded corrosion-resistant aluminized steel combustion chamber and heat exchanger; other important design features.

## HEATING & COOLING COILS

Young manufactures a complete line of heating and cooling coils for central heating or cooling systems.

## AIR CONDITIONING UNITS

Young "YAC" Air Conditioning Units provide year around service for cooling, heating, filtering, circulating, humidifying and dehumidifying in any combination. Units are available in nine sizes; capacities from 400 to 22,000 cfm; vertical (right) or horizontal types;

Young "Roomaire" Cabinet Air Conditioner cools, heats, filters, circulates and dehumidifies—for use with chilled water systems. Available in 3 sizes and 4 models.

## ELECTROMODE CORPORATION

45 Crouch St., Rochester 3, N. Y.

Complete line of Electric Heating Systems

For HOME, INDUSTRY, FARM

Division of Commercial Controls Corporation

The advantages of electric heat are well known. However, there is a great difference in the safety of electric heaters. Electromode has a completely sealed-in, cast-aluminum heating element which

provides absolute protection against fire, shock, burn or explosion. This element acts as a superior heat diffuser, resulting in greater heating efficiency and economy.

For Big Rooms

For HOME and OFFICE

Bathroom  
Small Room



Fig. 1.

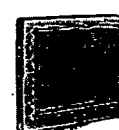


Fig. 2.



Fig. 3.



Fig. 4.

Electromode Wall-type Heaters are made in models and capacities suitable for all size rooms, ranging from 1320 to 4000 watts, with built-in thermostat or manual control. Heat is fan-circulated at floor level. All have automatic thermal safety switch. The big room heaters have silver grey hammertone finish; small room or bathroom heaters are available in gleaming chrome or white enamel. See figs. 1 and 4.

**ELECTROMODE RADIANT HEATING PANEL** combines radiant and convection heating. Modern design with silver grey hammertone finish. With or without built-in thermostat. Capacity 1100 watts. See fig. 2.

**ELECTROMODE BASEBOARD HEATERS** provide low level perimeter heat. Blank sections, endpieces, corners, for making up system to room dimensions. 600, 900, 1200 watts; 120 or 240 volts. See fig. 3.



Fig. 5.

**ELECTROMODE RADIANT CABLE HEAT.** Coils of cable hidden in ceiling radiate clean, healthful heat downward. Each room temperature controlled by separate thermostat. Cables are a measured length of specially constructed and insulated electric wires; waterproof; non-corrosive. Used in plaster or drywall ceilings, or concrete floors. Magic Seal coating prevents streaks on ceiling. See fig. 5.

## For INDUSTRY



Fig. 6—  
Suspension

**UNIT HEATERS** available in Suspension-type and Combination Portable and Suspension models. Capacities from 1500 to 45,000 watts. Ideal for auxiliary warmth in hard-to-heat areas and for complete heating in outlying buildings. Adjustable louvers for directing fan-circulated heat into working zone. Thermostat control available on all models. See fig. 6 and 7.



Fig. 7—  
Portable &  
Suspension

**EXPLOSION-PROOF HEATERS** for areas charged with inflammable vapors. Listed by Underwriters' Laboratories for Class 1-Group D Hazardous Industries. Convection type. Three models range from 2000 to 6000 watts. See Fig. 8.

**ELECTROMODE BLAST COILS** consist of a bank of Electromode cast-aluminum heating elements mounted in a 16 gauge formed steel frame having a 1 1/2 in. wide



Fig. 8



Fig. 9

flange with 5/16 in. holes on approx. 6 in. centers for mounting to air ducts. Complete wiring diagrams for special applications furnished on request. See Fig. 9. All Electromode Heating Systems are approved by Underwriters' Laboratories and are fully guaranteed.

Engineering help gladly given. For more information, see your supplier or write Dept. HVG-16, Electromode Corporation.

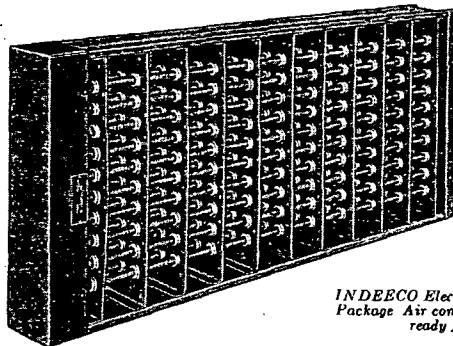
## Industrial Engineering and Equipment Co.

711 South Theresa Ave., St. Louis 3, Mo.



ELECTRIC BLAST COIL HEATERS FOR  
PACKAGE AND DUCT AIR CONDITIONERS  
AND SUPPLEMENTARY HEAT

3,487 INSTALLATIONS—150 to 15,000,000 Watts  
More than 100 Installations at Rockefeller Center



INDEECO Electric Blast Coil Heater for  
Package Air conditioners as shipped and  
ready for installation

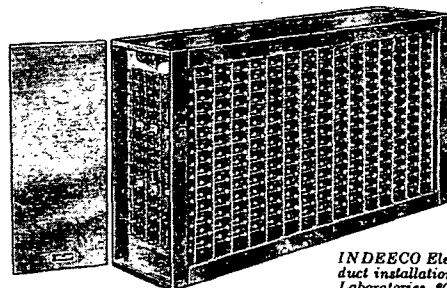
Leading commercial, industrial and governmental properties are heated by these units. They offer the following advantages:

1. COMPLETE UNIT, ready for installation, eliminating design and layout work
2. SIZED TO FIT
3. THERMAL CUT-OUTS, furnished with each unit
4. WIDE SIZE RANGE

INDEECO UNITS FOR PACKAGE AIR CONDITIONERS, are furnished in 280 sizes to fit 11 manufacturers' package units—write for *Bulletin E97P*.

INDEECO UNITS FOR DUCT-INSTALLATION are furnished in 422 sizes—write for *Bulletin E97U*.

SPECIAL UNITS in both categories furnished at no extra cost. INDEECO Blast Coil Heaters are made to suit your specifications. You are not compelled to change your plans to meet our specifications.



INDEECO Electric Blast Coil Heater for  
duct installation. Listed by Underwriters'  
Laboratories. 200,000-watt capacity. Above  
is part of installation totaling 1,880,000  
watts.

WRITE for CATALOGS

## Wesix Electric Heater Co.

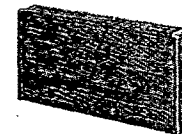
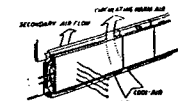
390 First Street

San Francisco 5, California



CHICAGO DALLAS DENVER DETROIT HUNTSVILLE  
LOS ANGELES NEW YORK PORTLAND SEATTLE  
Complete line of Electrical Air and Liquid Heating Equipment for  
Residential, Commercial & Industrial Applications

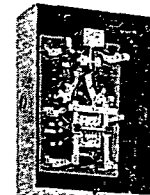
BASEBOARD PERIMETER PANELS available in standard lengths for simple, inexpensive installation without special tools or metal cutting. Heating lengths: 32 in. and 48 in., 157 watts (536 Btu) per lineal foot. Control Section (thermostat and switch) 6 in. long. Approved by UL.



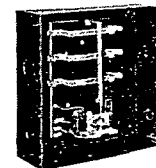
AUTOMATIC ELECTRIC BRACKET TYPE HEATER for commercial, institutional or industrial applications, these units are available in a large range of sizes and types including explosion-proof models for use in Class I, Group C and D locations. Approved by UL.



AUTOMATIC ELECTRIC WALL FURNACE sizes range from one to eight kilowatts for use in domestic and commercial installations. Available in radiant-convection (model illustrated), convector or blower type (5000 watt maximum). Approved by UL.



DUCT HEATERS utilizing either Wesix "dust free" or conventional transverse fin elements, these units may be ordered from a wide variety of self contained, standard units, or built to order. Units available complete with sensitive integral overtemperature control.



LOAD REGULATORS control electric heating capacity automatically by switching voltage supply from 240 volts to 120 volts by means of outdoor thermostat control. Controls heating loads up to 24 kw. Approved by UL.

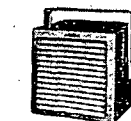
INDUSTRIAL UNIT HEATERS—BLOWER TYPE for horizontal or vertical mounting either as suspended unit heaters or duct system use in standard sizes to 60 kw. Larger sizes or models for special applications on order. Approved by UL.

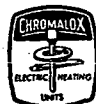
QUIET AUTOMATIC SWITCH, a motor operated contactor for resistance loads to 24 kw, 1 $\phi$  or 40 kw 3 $\phi$ , 240 volts and 33 kw 1 $\phi$  or 55 kw 3 $\phi$ , 480 volts. Actuated by SPDT switch or thermostat. Available with sequence action for control from single switch of two or more contactors. Approved by UL.

COMMERCIAL UNIT HEATERS—AXIAL FLOW sizes from 3 to 40 kw for ceiling or pedestal mount. Feature Wesix longitudinal fin, "dust free" inclosed heating elements. Approved by UL.



HEAVY DUTY WALL THERMOSTAT AND SWITCH for control of electric heating apparatus directly up to 30 amp, this unit includes a lockout switch double-pole in the "off" position. Thermostat action is bi-metallic, sensitive to  $\pm 2^{\circ}\text{F}$ . Fits standard wall box mounted horizontally. Approved by UL.



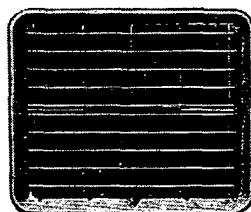


## Edwin L. Wiegand Company

7672 Thomas Boulevard Pittsburgh 8, Pa.

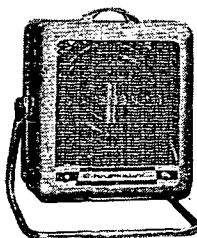
Representatives in all Principal Cities

**PRODUCTS:** Over 15,000 types, sizes and ratings of Chromalox electric heaters for Industry and Home. All heating elements are metal or alloy sheathed in metal for strength and corrosion resistance, fully insulated for safety.



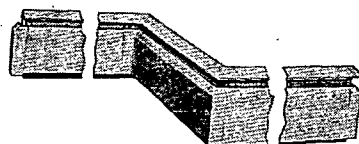
### CHROMALOX RADIANT WALL PANEL

Heavy gauge, all-metal construction including breakproof, moistureproof, shockproof, radiant heating plate. Quickly supplies gentle radiant heat controlled by optional on-off switch or built-in thermostat. For flush or recessed mounting in homes, motels, playrooms, doctors' offices, cottages, first aid rooms. Easy installation. Available in 1000 watts for 120 or 240 volts a-c, and 1500 watts for 240 volts a-c.



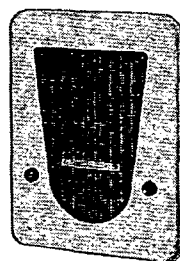
### CHROMALOX HI-FLOW PORTABLE

Fully-enclosed metal sheathed elements quickly heat the high volume of air forced through the unit by the smooth running fan and motor. Heavy-gauge case in metallic blue finish. Controlled by manual on-off switch with protective device and reset button. UL listed cord 5½ ft long with polarized plug. For bedrooms, dens, kitchens, drugstores, etc. In wattages from 2000 to 4000 for 115-120 to 230-240 volts a-c.



### CHROMALOX BASEBOARD RADIATORS

Clean, balanced radiant and convected heat supplied by rugged baseboard measuring only 8¾ in. high and 2¾ in. deep. Lengths in standards of 1 ft with 100 watts, 2 ft with 300 watts, 5 ft with 800 watts, 8 ft with 1250 watts. Extremely easy to install. Heating element is all-metal fully enclosed, flat strip type which is breakproof, moisture-proof and shockproof. Designed for maintenance-free heating in homes, offices and public buildings.



### CHROMALOX FORCED-AIR WALL HEATERS

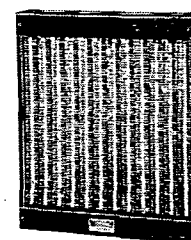
Smooth molded contours of heavy-gauge steel form the front grill of this forced-air recessed wall heater. Recessed section contains a quiet, fully-enclosed motor and smooth-running dustproof fan. Metal sheathed fin-tube element and fan are controlled by manual on-off switch. Variable temperature control knob for setting automatic built-in thermostat. Available in wattages from 1500 to 4000 for 240 a-c supply for gamerooms, living rooms, motels, reception rooms, cottages, etc.



## Edwin L. Wiegand Company

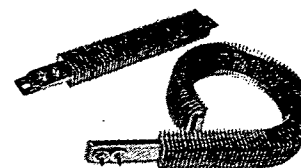
7672 Thomas Boulevard Pittsburgh 8, Pa.

Representatives in all Principal Cities



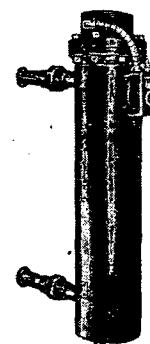
### CHROMALOX AIR DUCT HEATERS

For use in square or rectangular forced air ducts. Construction of heater allows free-flow of existing forced air circulation. Finned radiator design presents maximum surface contact for fast heating and minimum air friction. For room heating and process work requiring heated air blasts. Ratings from 6 kw to 100 kw.



### CHROMALOX FINSTRIP HEATERS

Finstrip heaters are used in air ducts having forced circulation, in ovens, dryers and for process work requiring heated air blasts. Temperatures to 750 F can be maintained accurately with thermostatic controls.

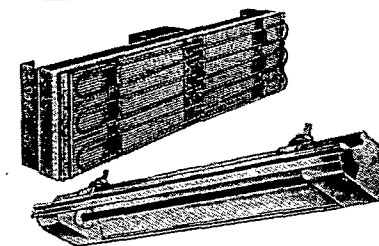


### CHROMALOX CIRCULATION HEATERS

Circulation Heaters heat fluids in convection or forced heating systems; for washrooms, laundries, dishwashers, central heating systems, superheating and drying steam, preheating fuel oils and heat transfer fluids, heating nitrogen and other gases. Temperatures to 750 F.

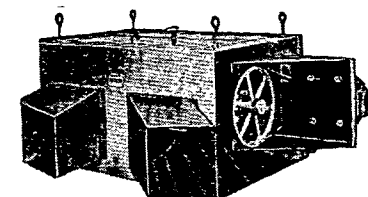
### CHROMALOX PORTABLE UNIT HEATERS

High volume comfort heater for industrial offices, shipping depots, stockrooms and isolated small buildings. Sturdy construction of motor fan gives long, dependable service and a reliable supply of heated air. Available with manual or automatic controls in 1.5 to 4.0 kw capacities.



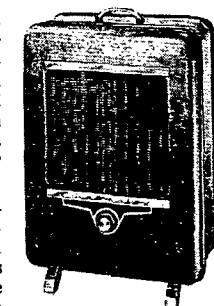
### CHROMALOX FAR-INFRARED UNITS

Far-Infrared Radiant Heat for mass heating, drying, baking, dehydrating and similar uses. Compact pre-engineered panels, heaters and lamps can be made into banks, tunnels, and ovens. All-metal construction gives protection against breakage, splash of liquids plus high safety against shock hazards.



### CHROMALOX HIGH VOLUME HEATERS

For heating of larger areas or as central heating system for distribution of heat through ducts to desired locations. Ratings from 15 to 40 kw.

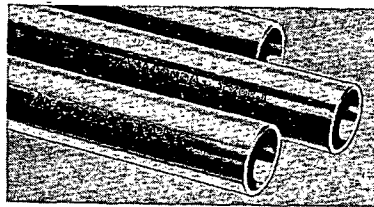


## The American Brass Company Waterbury 20, Conn.



District Offices in Principal Cities  
IN CANADA: ANACONDA AMERICAN BRASS LIMITED, NEW TORONTO, ONTARIO

**PRODUCTS**—Anaconda Phosphorized Copper Tubes and Fittings; Anaconda "85" Red Brass Pipe; Everdur Metal for storage heaters, storage tanks, ducts and air-conditioning equipment



### ANACONDA COPPER TUBES AND FITTINGS

For Heating, Plumbing and Air Conditioning

Anaconda Types K and L Phosphorized Copper Tubes, assembled with solder joint Fittings, offer an unusual combination of advantages for hot water and low pressure steam heating systems, including radiant panels. These advantages may be summarized briefly as follows:

**Low Friction Loss**—Because the inside surfaces of copper tubes are inherently smoother than those of pipe and tubes made of ferrous materials and also because they do not become roughened by the formation of rust, these tubes offer a lower resistance to flow. In addition, the long-radius turns of elbows and the smooth inside surface of wrought copper fittings further reduce friction losses.

These factors naturally increase the efficiency of the system, particularly when it includes a forced-pressure circulator.

**Ease of Installation**—In many places the flexibility of copper tubes simplifies connections that ordinarily would be awkward and expensive to make with rigid pipe and threaded fittings. Solder joint fittings are compact. They can be installed in restricted space where the use of a wrench would be impossible.

They meet the requirements for these types of tubes in Federal Specification WW-T-799a and ASTM Specification B88. Type K, the heavier, is recommended for heating lines and general piping.

Anaconda Copper Tubes, in standard sizes are furnished soft in 60- and 100-ft coils; also hard and soft in 20-ft straight lengths.

### CUSTOM-MADE CAPILLARY TUBES

Anaconda Custom-Made Capillary Tubes, for restriction purposes, are made to specific mutually-agreed-upon airflow limits. These limits alone are the base for production.

Initial shipments contain Master Reference Sample Tubes with labels giving maximum and minimum flow capacities agreed upon. Duplicate Master Samples are kept in the mill files. Every subsequent shipment of tubes will be made to the limits of the Master Samples.

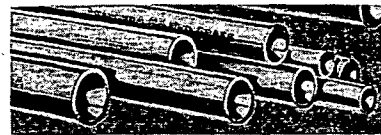
### REFRIGERATION TUBING

Anaconda Dehydrated Copper Refrigeration Tubes are manufactured in accordance with the ASTM Specification for this product in all standard sizes up to and including 3/4 in. O.D., in 50-foot coils. The tubes are sealed immediately after annealing and dehydrating.

### VIBRATION ELIMINATORS

American Vibration Eliminators—Compressor vibration and noise are muffled in a line equipped with an American Vibration Eliminator. The corrugated bronze tubing is *seamless*. Copper ferrules and tube ends are *brake welded*. Each unit is pressure-tested under water, is spotlessly clean and dry, with ends firmly sealed.

## The American Brass Company



### ANACONDA "85" RED BRASS PIPE

Anaconda "85" Red Brass Pipe, in standard pipe sizes, is considered the highest quality corrosion-resistant pipe commercially obtainable at a moderate price and is recommended for steam return lines.

Anaconda "85" Red Brass Pipe contains 85 per cent copper and conforms to Government specifications for Grade "A" water pipe. The mark "Anaconda 85" is stamped in the metal at one-foot intervals throughout each length.

### EVERDUR\*

Everdur Metal is the original copper-silicon alloy group. It is manufactured by The American Brass Company in five standard compositions and in practically all commercial forms.

These high-strength engineering alloys are resistant to a wide range of corroding agents. Because of a versatile combination of useful properties, Everdur has become standard as a material for equipment in many fields of engineering and industry.

In addition to their non-rusting properties and high strength, Everdur alloys possess many qualities not usually found in metals of this character. They are unusually resistant to general atmospheric conditions and other normally corrosive factors. Everdur alloys have excellent machining and working characteristics and can be fabricated into a variety of forms and shapes. Everdur

alloys are available for oxyacetylene, carbon-arc and inert-gas arc welding.

**Everdur Tanks**—Everdur copper-silicon alloy is an ideal material for durable, non-rusting water tanks of every description—from domestic range boilers to large storage heaters for hotels, laundries, hospitals, textile plants, schools or breweries.

Everdur is made in all commercial shapes, including annealed tank plates which have physical properties as given in ASTM Specification B96.

Minimum specification requirements for hot-rolled-and-annealed tank plates are: Tensile Strength, 50,000 psi.; Yield Strength (at 0.5 per cent elongation under load) 18,000 psi.; Elongation, 40 per cent in 2 inches.

Welds made with annealed Everdur tank plates meet the requirements for construction in the A.S.M.E. Boiler and Pressure Vessel Code.

For additional data and names of fabricators address our nearest District Sales Office.

### EVERDUR FOR AIR-CONDITIONING EQUIPMENT

Because of its strength and welding properties, Everdur may be substituted for steel and fabricated by substantially the same methods, with much the same equipment as steel.

Everdur metal has been used with marked success for fans, blowers, ducts, humidifiers, cast and wrought parts of other equipment items subject to corrosive influences.

### EVERDUR LITERATURE

Descriptive literature containing much pertinent tabular data will be sent on request.

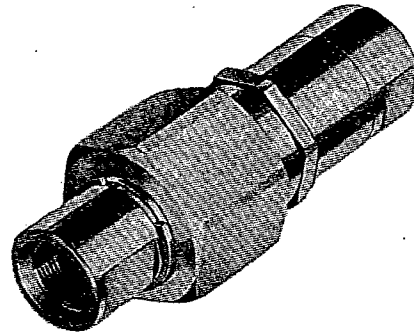
\*"Everdur" is a trademark of The American Brass Company registered at the U. S. Patent Office.

RESTRICTOR TUBE • FORMED TUBE PARTS • HARD COPPER TUBE CUT TO LENGTH • COPPER TUBE IN COILS AND STRAIGHT LENGTHS • FITTINGS FOR TYPES K AND L TUBES • VIBRATION ELIMINATORS • FLEXIBLE REFRIGERATION TUBING CONDUIT • DIE PRESSED FORGINGS • COPPER, BRASS, BRONZE IN SHEETS, WIRE, RODS, TUBES AND SPECIAL SHAPES

Aeroquip Corporation, Jackson, Michigan

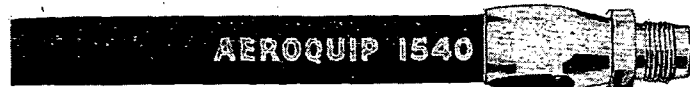


# AEROQUIP SELF-SEALING COUPLING FOR "FREON 12" AND "FREON 22"



This new coupling for "Freon 12" and "Freon 22" applications is finding wide use for all refrigeration and air-conditioning applications. Convenient connection and disconnection without loss of refrigerant or inclusion of air and moisture. Simplifies production and charging

and testing of equipment and permits shipping of factory charged units for easy field installation. Rapid assembly in equipment by means of sweat-type adapters and mounting flanges. Sizes through 1½ in. O.D. tube size.



# AEROQUIP 1540 HOSE FOR "FREON 12" APPLICATIONS

| Dash Size | O.D. Tube Size | Min. Burst Pressure | Operating Pressure psi | Min. Bend Radius |
|-----------|----------------|---------------------|------------------------|------------------|
| 4         | ¼              | 2000                | 350                    | 3                |
| 6         | ⅝              | 2000                | 350                    | 4                |
| 8         | ¾              | 2000                | 350                    | 4½               |
| 10        | ⅝              | 2000                | 350                    | 5¼               |
| 12        | ¾              | 1400                | 350                    | 6¼               |
| 16        | 1              | 1400                | 350                    | 7½               |
| 20        | 1¼             | 1400                | 350                    | 9                |
| 24        | 1½             | 1400                | 350                    | 11               |
| 32        | 2              | 1200                | 350                    | 13¼              |
| 40        | 2½             | 700                 | 175                    | 24               |
| 48        | 3              | 700                 | 175                    | 33               |

Aeroquip 1540 hose and reusable fittings are designed for refrigerating and air conditioning systems using "Freon 12." Aeroquip flexible hose lines can be installed easily, even in confined areas, withstand compressor vibration and reduce noise. Ease of assembly makes Aeroquip hose and fittings ideal for engineering mockups and production models. Available in sizes from ¼ in. to 3 in. Operating pressures up to 350 psi; temperature range -40 F to +170 F.

# REVERE

COPPER AND BRASS INCORPORATED

Executive Office: 230 Park Avenue, New York 17, N. Y.

MILLS—BALTIMORE, MD.; BROOKLYN, N. Y.; CHICAGO, CLINTON, and JOLIET, ILL.; DETROIT, MICH.; LOS ANGELES and RIVERSIDE, CALIF.; NEW BEDFORD, MASS.; NEWPORT, ARK.; ROME, N. Y. DISTRICT SALES OFFICES—ATLANTA, GA.; BOSTON, MASS.; BUFFALO, N. Y.; CINCINNATI, OHIO; CLEVELAND, OHIO; DALLAS, TEX.; DAYTON, OHIO; GRAND RAPIDS, MICH.; HARTFORD, CONN.; HOUSTON, TEX.; INDIANAPOLIS, IND.; MIAMI, FLA.; MILWAUKEE, WIS.; MINNEAPOLIS, MINN.; NEW YORK, N. Y.; PHILADELPHIA, PA.; PITTSBURGH, PA.; PROVIDENCE, R. I.; ROCHESTER, N. Y.; ST. LOUIS, MO.; SAN FRANCISCO, CALIF.; SEATTLE, WASH.

# TUBE AND PIPE FOR GENERAL CONSTRUCTION

Revere produces a wide range of Pipe and Tube for various industrial uses including condensers, aftercoolers and similar heat exchangers.

The services of Revere Technical Advisors are available without obligation to assist Engineers, Designers and Contractors in the selection of suitable Revere products for various applications.

# REVERE COPPER WATER TUBE

For:

Hot and cold water service lines  
Underground systems for water, oil or gas  
Drainage line and soil pipe  
Fuel oil and compressed air lines  
Heating systems—hot water and steam  
Radiant Panel Heating (technical booklet, "Design Procedure and Installation Practices for Radiant Panel Heating" available upon request).

# LENGTHS, TEMPER AND OPERATING PRESSURES

| Type | Temper | Pressure Pounds | Standard Lengths |
|------|--------|-----------------|------------------|
|      |        |                 | Straight         |
| K    | Hard   | up to 400       | Coils            |
| K    | Soft   | " " 250         | 12 and 20 ft     |
| L    | Hard   | " " 250         | 60 ft            |
| L    | Soft   | " " 150         | 60 ft            |
| M    | Hard   | " " 250         | "                |

# STANDARD DIMENSIONS AND WEIGHTS

| Size in In. | Type K  |                |                 | Type L  |                |                 | Type M  |                |                 |
|-------------|---------|----------------|-----------------|---------|----------------|-----------------|---------|----------------|-----------------|
|             | O.D. in | Wall Thick. in | Wt. Lb. per Ft. | O.D. in | Wall Thick. in | Wt. Lb. per Ft. | O.D. in | Wall Thick. in | Wt. Lb. per Ft. |
| ¼           | .375    | .035           | .145            | .375    | .030           | .128            | .375    | .035           | .145            |
| ⅝           | .500    | .049           | .269            | .500    | .035           | .198            | .500    | .025           | .145            |
| ¾           | .625    | .049           | .344            | .625    | .040           | .285            | .625    | .028           | .204            |
| ⅞           | .750    | .049           | .418            | .750    | .042           | .362            | .750    | .032           | .328            |
| 1           | .875    | .065           | .641            | .875    | .045           | .455            | .875    | .032           | .328            |
| 1¼          | 1.125   | .065           | .830            | 1.125   | .050           | .655            | 1.125   | .035           | .465            |
| 1½          | 1.375   | .065           | 1.04            | 1.375   | .055           | .884            | 1.375   | .042           | .682            |
| 1¾          | 1.625   | .072           | 1.36            | 1.625   | .060           | 1.14            | 1.625   | .049           | .940            |
| 2           | 2.125   | .083           | 2.06            | 2.125   | .070           | 1.75            | 2.125   | .058           | 1.46            |
| 2½          | 2.625   | .095           | 2.93            | 2.625   | .080           | 2.48            | 2.625   | .065           | 2.03            |
| 3           | 3.125   | .109           | 4.00            | 3.125   | .090           | 3.33            | 3.125   | .072           | 2.68            |
| 3½          | 3.625   | .120           | 5.12            | 3.625   | .100           | 4.29            | 3.625   | .083           | 3.58            |
| 4           | 4.125   | .134           | 6.51            | 4.125   | .110           | 5.38            | 4.125   | .095           | 4.66            |
| 5           | 5.125   | .160           | 9.67            | 5.125   | .125           | 7.61            | 5.125   | .109           | 6.66            |
| 6           | 6.125   | .192           | 13.9            | 6.125   | .140           | 10.2            | 6.125   | .122           | 8.92            |

Revere Copper Water Tube does not rust. It is smooth inside and out, easy to install and bends and flares readily. There is no thread cutting; it takes solder or compression type fittings.

# Specifications:

Federal: WW-T-799 ASTM: B88

# REVERE DRYSEAL COPPER TUBE

For:

Air conditioning and refrigeration systems  
General service work  
Revere Dryseal Copper Tube is dehydrated and sealed at the factory before packaging. It is soft and flexible and when flared for compression fittings, it does not split on the ends. Its ability to take smooth hand bends virtually eliminates the need for fittings.

50 ft. coils in sizes from ¼ in. to ¾ in. O.D., with wall thicknesses from .030 in. to .035 in., are packed in individual cartons.

# REVERE RED BRASS & COPPER PIPE

For use when threaded pipe is required. Both are manufactured in standard pipe sizes—hence can be used with standard threaded or silver brazed fittings. Because of their extraordinary resistance to corrosion, they function with unimpaired efficiency even after many years of normal service.

# Specifications:

Revere Red Brass Pipe meets the following specifications:

Federal Standard: WW-P-351, Grade "A"

Navy Department: 44P12, Grade "A" ASTM: B43 (Red Brass)

Revere Copper Pipe meets the following specifications:

Federal Standard: WW-P-377

Navy Department: 44P2

ASTM: B42

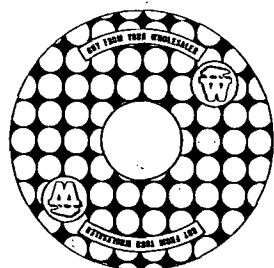


## Wolverine Tube

1463 Central Avenue • Detroit 9, Michigan  
Manufacturers of Quality-Controlled Tubing and  
Extruded Aluminum Shapes

Plants in Detroit, Michigan and Decatur, Alabama  
Sales Offices in all Principal Cities.

Wolverine Trufin is available in Canada through the Unifin Tube Co.,  
London, Ontario.



### WOLVERINE COPPER WATER TUBE

... a roll of tube that rolls

Wolverine's round cartons for rolls of copper water tube represent a new packaging concept. The carton now becomes even more functional than its primary job of protecting the contents. For example, it can be rolled like a hoop to storage or job site. There's an arm hole in the middle for convenient carrying. And also important to users, it can be used as a reel with the carton protecting the tube right up to its last inch. The package is extra sturdy, designed with a

heavy corrugated core for extra protection. It's easy to open, easy to identify, and color coded.

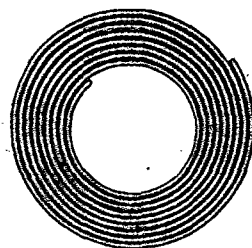
### WOLVERINE COPPER WATER TUBE

Wolverine copper water tube is available in all three types:

Type K—in straight lengths and coils—is recommended for general plumbing involving severe service conditions and for heating, gas, steam and oil lines and for underground service. It is available in nominal sizes from 1/4 in. through 6 in.  
Type L—in straight lengths and coils—is recommended for general plumbing involving less severe service conditions and for interior applications for heating, gas, steam and oil lines. Available in nominal sizes from 1/4 in. through 6 in.

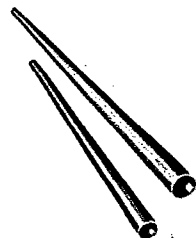
Type M—in straight lengths only—suitable for use with soldered fittings only; for interior applications, for heating and for waste, vent, soil and other non-pressure applications. Available in nominal sizes from 3/8 in. through 6 in.

Wolverine also manufactures S.P.S. and extra heavy pipe in copper and red brass. Pipe is available in standard lengths of 12 and 20 feet. Sizes range from 1/2 in. through 3 1/2 in.



### WOLVERINE COPPER REFRIGERATION TUBE

Wolverine copper refrigeration tube is well-known in the industry. It, too, is packaged in round cartons. It has mirror-bright inside diameter finish, is dehydrated, is consistent in quality and soft in temper. **CONVENIENT NEW SEAL:** Wolverine has a new refrigeration tube seal that keeps tubing clean and dry. Because the O.D. of the seal is no larger than that of the tube proper, it makes it easier to insert through partitions.



## Wolverine Tube

1463 Central Avenue • Detroit 9, Michigan  
Manufacturers of Quality-Controlled Tubing and  
Extruded Aluminum Shapes

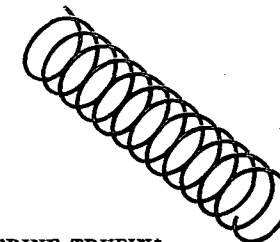
Plants in Detroit, Michigan and Decatur, Alabama  
Sales Offices in Principle Cities

Wolverine Trufin is available in Canada through the Unifin Tube Co.,  
London, Ontario.



### WOLVERINE CAPILATOR\*

Wolverine Capilator\* is designed for precision control in the metering of gases, liquids or air. Capilator is plug drawn—has a smooth, mirror-bright bore held to exceptionally close limits. It can be made of copper or aluminum and is available in sizes from .026 in. to .090 in. inside diameters. Capilator is washed, deburred, flow-tested and its ends are paper wrapped.

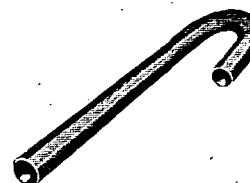
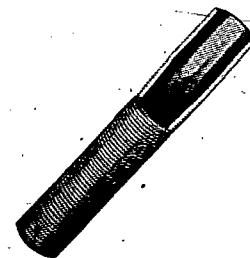


### WOLVERINE TRUFIN\*

Wolverine Trufin is an extended surface tube with fins extruded from the tube wall. It increases heat transfer surface—transfers more Btu's per foot of tube. Fins resist vibration, temperature changes and fluctuating pressures. Trufin is available in a wide range of sizes, alloys and fin spacings in copper, copper base alloys, aluminum, electric-welded steel and bi-metal.

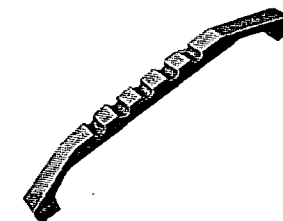
### FABRICATED TUBULAR PARTS

Wolverine's fabrication facilities include the Wolverine Spun End Process†. One-piece tubular shaped parts with closed or partially closed ends can be produced in one fast operation. Other fabrication techniques include finning, coiling, bending, expanding, flaring, brazing and soldering and piercing, to name but a few.



### ALUMINUM TUBE AND SHAPES

Wolverine produces strong, lightweight aluminum tube—plain or finned—drawn or extruded—in the following alloys: 1100 (2S); 3003 (3S); and 6063 (63S). Wolverine aluminum extruded shapes, in the same alloys, are rigidly quality controlled, can help you save machining and assembly time and reduce material requirements.



### FIELD ENGINEERING SERVICE

For the convenience of our customers, Wolverine maintains a Field Engineering Service. Highly-trained tubing technicians are ready at all times to help you solve such problems as design, corrosion and fabrication.

\* Reg. U. S. Pat. Off. † A. patented process Re. 22465.



## Air Devices Inc.

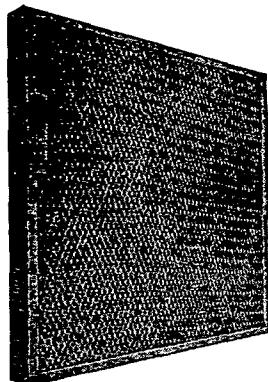
Air Diffusers Exhausters Air Filters Filter Holding Frames Industrial Furnaces

185 Madison Ave.  
New York 16, N. Y.



Agents in All  
Principal Cities

### AGITAIR AIR FILTERS



Type FM  
HIGH  
VELOCITY  
•  
ALL  
METAL  
•  
PERMANENT  
•  
CLEANABLE

#### HOW IT WORKS

High turbulence of many finely divided air streams is the keynote of Type FM air filters. The media divides the air into countless fine streams and throws those streams into violent cyclonic turbulence against countless viscous-coated "wiping surfaces" which virtually scrub the air clean by catching and holding the dirt.

#### HIGH VELOCITY

The Agitair FM Filter is designed to perform at highest efficiency at an approach velocity of 432 fpm—or 1200 cfm through a 20 x 20 in. filter panel.

#### 1/3 LESS SPACE REQUIRED

The ability of the FM to filter, with greater efficiency, 50 per cent more air at the high velocity of 432 fpm reduces the number of filter panels required. Now TWO FM's will do the work of THREE ordinary filters . . . 1/3 less space required . . . fewer units to be installed . . . fewer units to be serviced . . . overall installation and maintenance costs reduced to a minimum.

#### HIGH EFFICIENCY

At the recommended velocities, the Agitair FM has a high dust arresting efficiency, which increases as the dust load is applied.

### LOWER RESISTANCE

The sustained low resistance of the Agitair FM means sustained peak volume of air for longer periods of time . . . no loss in air volume . . . no danger of unloading . . . clean filtered air at all times.

### HIGHER DUST HOLDING CAPACITY

Employing a new formula for air filtration the new Agitair FM holds more dirt, from two to six times as much as ordinary 2 in. permanent, cleanable filters. No early clogging of air passages . . . less frequent servicing . . . lower maintenance cost.

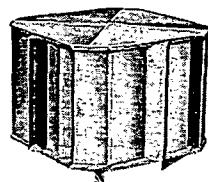
### TWO TYPES OF HOLDING FRAMES

**Individual type:** Designed and constructed for easy handling in single unit installations, and to facilitate "on the job" assembly, into a multiple unit bank. **Pre-Fabricated Type.** Made of heavy gauge steel and delivered completely knocked down. They can be quickly and easily bolted together to form a sturdy panel bank.

### GREASE FILTERS

**Strong Expanded Metal Media** recommended for use in kitchens where grease-laden air is a fire hazard and a maintenance problem. Prevent grease from entering exhaust ducts, eliminate frequent duct cleaning, protect fans, greatly reduce fire hazard, and help maintain good ventilation.

### AGITAIR WIND-ACTUATED EXHAUSTERS



Type CNO

Provide proper ventilation regardless of wind direction, and with positive elimination of down-draft. Functions at peak efficiency at average low wind velocities. Will not restrict the exhaust of air or gases when there is no movement of out-door air across the head.

## Air Filter Corporation

108G North Water St. Canadian Representative Milwaukee 2, Wis.  
DOUGLAS ENGINEERING CO., LTD. MONTREAL



(formerly Aircor)

AIR FILTERS

Permanent-Cleanable

GREASE FILTERS

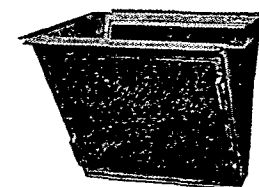
### AIRSAN AIR FILTERS

Industrial Domestic Commercial

Airsan's expanded metal face plate acts as a lint arrestor to provide easier cleaning and servicing. It distributes air evenly over entire filtering area providing high filtering efficiency and dust-holding capacity with low resistance. Media is viscous type, permanent, cleanable, and is constructed of multiple layers of galvanized wire mesh to give maximum air resistance. All Airsan Filters have full bronze welded corners, galvanized steel frames and drain slots for quicker, easier cleaning.

Airsan Air Filters are available in standard 1 in. and 2 in. thickness—*Bulletin L301*. Also HEAVY DUTY filters for industrial and special applications in 2 in. to 4 in. thickness—*Bulletin L401*.

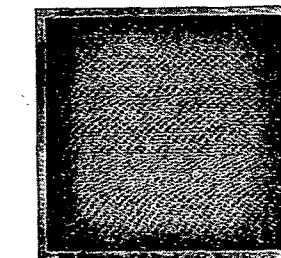
### AIRSAN GREASE FILTER



Permanent cleanable type Airsan Grease Filters specially designed for range canopies, galleys, kitchens.

Removes grease at source, reduces fire hazard in exhaust ducts and prolongs life of fans, motors and other mechanical equipment. Assemblies for mounting on ceiling or wall, single or multiple units—includes holding frames, supporting angles and end seals. *Bulletin L503*.

Initial Resistance: .07 in. w.g. at 216 fpm  
Efficiency Rating: 98.5% Stand.  
Thickness: 2 in.



AIRSAN VIRO-CRIMP FILTER

Pat. No. 2,653,876

The specially designed high velocity Airsan Viro-Crimp filter core is viscous type and constructed of horizontal layers of galvanized wire mesh so arranged as to assure a large filter-area with no appreciable pressure drop.

Its outstanding Viro-Crimp is designed to operate at face velocities of 300-500 fpm at minimum resistance. Viro-Crimp edges are hemmed, an important safety feature that provides a smooth surface, extra rigidity and filtering area.

Airsan Viro-Crimp filters are easily cleanable. Drain slots are provided, hasten drying and aid in cleaning. Airsan Viro-Crimp Air Filters are of all metal construction throughout, the formed galvanized steel frames having full bronze welded corners and joints. *Bulletin W801*.

### ENGINEERING DATA

| Initial Resistance                                         | Rated Efficiency |
|------------------------------------------------------------|------------------|
| Type F <sub>1</sub> (1 in. thick) .060 in. w.g. at 288 fpm | 98.5%            |
| Type F <sub>2</sub> (2 in. thick) .065 in. w.g. at 288 fpm | 98.5%            |
| Type D <sub>1</sub> (2 in. thick) .09 in. w.g. at 288 fpm  | 98.5%            |
| Type D <sub>2</sub> (4 in. thick) .10 in. w.g. at 288 fpm  | 98.5%            |
| Type W (2 in. thick) .07 in. w.g. at 300 fpm               | 95.1%            |
| Type W (2 in. thick) .012 in. w.g. at 500 fpm              | 97.9%            |

### AIRSAN FILTER RETAINER

Meticulous design includes such features as positive snap locks, oil resistant rubber seals to assure no by-pass of air. Particularly flexible to any type of installation of flat or "V" banks. Easily built up to any height or width by progressive addition of Airsan Filter Retainers. Available in 2 or 4 in. sizes. *Bulletin L608*.

Write AIR FILTER Corp. for Complete Bulletins

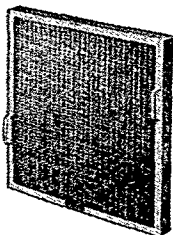
## AIR-MAZE CORPORATION

25000 Miles Rd. Cleveland 28, Ohio

THE FILTER ENGINEERS

Representatives in all principal cities

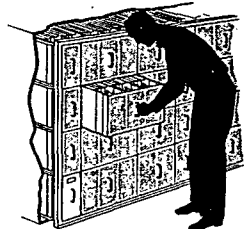
Since 1925, Air-Maze engineered air filtration has been successfully applied to every phase of the heating and ventilating industry. A complete line of filters are available for fresh air and re-circulated air intakes, kitchen range canopies, railroad, marine and aircraft applications. Send for catalog sheets on specific products. General catalog also available on request.



AIR FILTER PANELS

Available in metal washable, viscous impingement types, and dry disposable types. Dry filters also available with washable strainer-type filter element.

ELECTROMAZE ELECTRONIC AIR FILTER



Super-cleans air. Has semi or completely automatic vertical spray washing system. Removes particles as small as 0.1

micron diameter, has rated efficiency over 90 per cent, as tested by the *National Bureau of Standards* Discoloration Method. Collects smoke, fumes, pollens, and soot.

AUTOMAZE AUTOMATIC AIR FILTER



Where continuous operation without servicing is required, the Automaze "pulse action" automatic self-cleaning filter should be used. It combines a double filter panel curtain with a positive effective panel cleaning action to provide the best in viscous impingement air filtration with a minimum of maintenance. New self contained drive mechanism and unitized control system simplifies installation. Standard Automaze filter media is satisfactory for most installations, but other media types are available for special applications.

ACCESSORIES

Cleaning tanks, holding frames, complete assemblies for range canopies, viscous adhesive coatings, spray guns, etc. are available for complete installation and service requirements.

## American Air Filter Company, Inc.

673 Central Avenue, Louisville 8, Ky.

AMERICAN AIR FILTER OF CANADA, LTD., MONTREAL, P. Q.

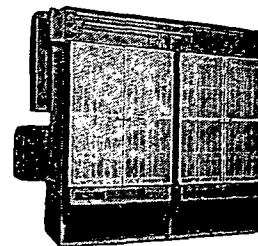


**THE COMPANY:** The American Air Filter Company, Inc., is recognized internationally as an authority on air filtration and dust control. In 30 years, its leadership and scientific "know how" have been responsible for installations of AAF equipment in every industrialized part of the world. Because its continuous research, high engineering standards and exclusive specialization have been consistently maintained, AAF equipment is used by leading companies in nearly every industry and is specified by leading architects and engineers for use in commercial and industrial air conditioning.

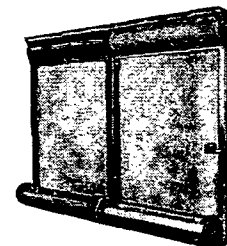
The American Air Filter Company, Inc., manufactures a complete line of air filtering and dust control equipment. A few representative types are shown here. AAF's years of experience and the scope of its knowledge dealing with the elimination of air-borne particles in every form insures maximum efficiency in application, design, manufacture and installation... with a minimum of field engineering. Write AAF on all problems of air filtration and dust control, or its Herman Nelson Division (see pages 1296-1297) on heating or ventilating problems.

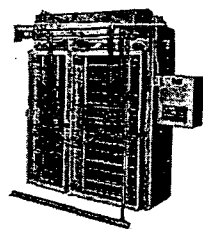
### AAF AIR CLEANING PRODUCTS

**Electro-Matic Self-Cleaning Electronic Precipitator**—The Electro-Matic Precipitator is an automatic electronic precipitator combining advanced principles of electronic air cleaning with an exclusive self-cleaning principle. It eliminates the necessity of shutting down the filter for manual cleaning, minimizes the need for personal attention and permits continuous high-efficiency operation. It also allows the Electro-Matic filter to be built in standardized self-contained sections, easy to install and with all exposed parts of the filter casing electrically grounded for the protection of operating personnel. Send for *Bulletin No. 250*.

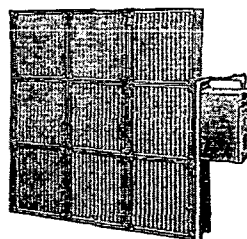


**ROLL-O-MATIC Renewable Media Filter**—An automatic air filter featuring a low cost, renewable media filtering curtain of bonded glass fibers supplied in convenient roll form. The media, mounted at top of filter, moves down the face of the **ROLL-O-MATIC** and is re-rolled on a driven spool at bottom. Introduction of clean material to maintain desired operating resistance is controlled by an automatic time switch. **ROLL-O-MATIC's** maintenance-free operation provides continuous, high efficiency cleaning at less than half the operating cost of a disposable type filter of equal capacity. Send for *Bulletin 248*.

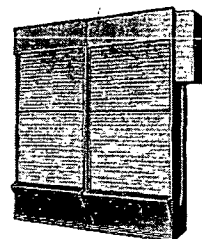




Electro-Cell Electronic Filter



Electro-PL Electro-matic Filter

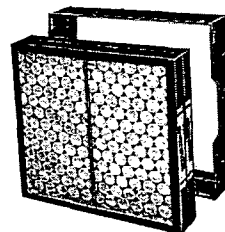


Multi-Duty Automatic Filter

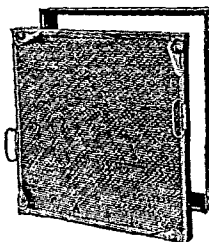
**Electro-Cell Electronic Filter**—A plate type electronic precipitator offering simplified design, improved performance and maintenance advantages. Built in vertical sections 2-ft and 3-ft wide. Hinged ionizers extend the full height of the sections for easy access. Collector assemblies may be removed for individual cleaning—washed in place manually—or, with the addition of Type "H" Washer, cleaned automatically by traveling water sprays. Write for *Bulletin No. 252*.

**Electro-PL**: An exclusive dry-type electronic air filter with charged Airmat collector element which combines air filtration and electronic precipitation in a single unit. Gives intermediate efficiency at lower cost, when the need for super-clean air is not indicated. However, it has twice the efficiency of uncharged dry-type filters. Available in Straight Bank or "V" arrangement to meet virtually any space or capacity requirement. Send for *Engineering Bulletin No. 257*.

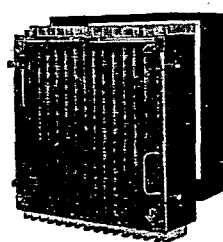
**Multi-Duty Automatic Filter** provides outstanding features of performance and design and will accommodate either armored screen panels or die stamped louvre panels available in three types. Offers advantage of uniformly constant air supply, fixed operating resistance and automatic operation. Ideal for ventilation and air conditioning service. Available in any size or capacity. Send for *Bulletin No. 241-A*.



AMER-glas Disposable Filter



American Type HV-2



Airmat Type PL-24

**AMER-glas Replaceable Unit Filters.** A new viscous impingement type for eliminating atmospheric dust from forced air heating systems. The highly efficient filtering media consists of continuous, curled and interlaced, extremely fine glass filaments, bonded with thermoplastic to form a thick resilient pad. The pad is sprayed with a special Viscosine and odorless and the Viscosine remains in a fluid-jell state for the life of the filter. Available in 15 sizes. Write for *Bulletin No. 211-A*.

**Airmat Type PL-24**—Airmat filters use standard Airmat medium, renewable after collecting dust load. Used both for comfort and industrial air conditioning. Available with unit frames to be set up to meet any capacity requirement or space condition. Send for *Bulletin No. 230*.

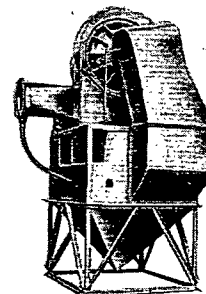
**Type HV-2 Filter**: A high capacity, low-resistance unit designed for velocities up to 500 fpm. Exclusive pyramid pocket media design eliminates through-air passages and gives uniformly high efficiency over wide range of air velocities. HV-2 has large dust capacity, long life, and decided advantages where space is limited. Available in three designs. Write for *Engineering Bulletin No. 203*.

## AAF ROTO-CLONE DYNAMIC DUST PRECIPITATORS

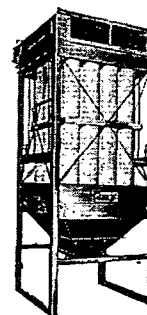
**THE ROTO-CLONE** is an exclusive, patented development of AAF combining the functions of exhausting, separating and storing dust in one simple, compact, self-contained unit. Most types of dust collectors or separators are so large that they are usually installed outdoors, which requires long pipe runs, increased power consumption, and higher installation costs. The **ROTO-CLONE**, however, eliminates expensive ductwork

and reduces both installation and operating costs to a minimum. Available in a wide variety of types and sizes for either individual unit or central system installations and with wet or dry type collectors, the **ROTO-CLONE** has a proven record of economy and efficiency covering thousands of production line and individual applications. Write for profusely illustrated 35-page application and *Engineering Bulletin No. 274-A*.

**Type D ROTO-CLONE**—A dynamic precipitator designed for dry collection of granular industrial process dust. Combines functions of exhauster, dust separator and storage facilities in one compact unit. High collection efficiency remains constant over entire pressure volume range. Adapted for individual unit or central system use. Capacities—from 100 to 15,000 cfm. Write for *Bulletin No. 274*.



Type W ROTO-CLONE



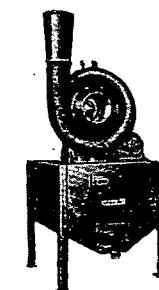
AMERjet

**Type W ROTO-CLONE** offers high dust separation efficiency where extreme fines and heavy dust loads are involved. Combines dynamic precipitation with integral water sprays. Delivers a constant air volume and collects dust as a sludge. Compact design makes for easy, low-cost installation. Capacities from 1,000 to 50,000 cfm. Write for *Bulletin No. 274*.

**Type N ROTO-CLONE** is a hydro-static collector, with induced water scrubber. Requires minimum space—easy to install. No moving parts, spray nozzles or pumps. Completely self-contained with dust discharged as a sludge. Capacities—from 1,000 to 50,000 cfm. Write for *Bulletin No. 277*.

**AMERjet**—A reverse jet type fabric arrester offering high collection efficiency, constant pressure drop (constant air volume), compact design and continuous operation. Other features are (1) tension control to compensate for variation in fabric dimensions, (2) rugged mechanism for dislodging collected material with high pressure air jets and (3) venturi-shaped inlet for dust-laden air which extends life of cloth. Available in range of capacities. *Bulletin No. 279*.

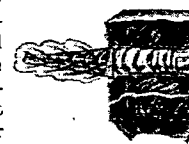
**AMERclone**—A dry centrifugal dust collector designed to handle large exhaust volumes containing dust in high concentrations. Unit requires small space due to compact design and high cleaning capacity of the AMERclone tubes. Abrasion resistant construction featured throughout. Collection efficiency remains practically constant over wide range of exhaust volumes. Available in wide range of capacities. Write for *Bulletin No. 291*.



Type D ROTO-CLONE



Type N ROTO-CLONE



AMERclone

**Barnebey-Cheney Company**  
Cassady at Eighth  
Columbus 19, Ohio  
In Canada: BARNEBEY-CHENEY LTD.,  
St. Johns, Quebec

Odor Removal  
Solvent Recovery  
Reactivation Service

#### PUR AIR RECOVERY

By purifying and recirculating air which is already heated or cooled, as much as 40 per cent can be saved on operation costs of heating or air conditioning equipment. A Pur Air RECOVERY system can reduce the volume of outside air necessary for ventilation by 90 per cent. "First cost" of new systems can also be reduced 20 to 45 per cent by incorporating activated carbon for Air Recovery.

#### ODOR REMOVAL

Pur Air adsorbers eliminate odors from fresh air intakes, from exhausts, or from enclosed spaces. Pur Air Activated Carbon adsorbs or physically removes odors, staleness or stuffy air, revitalizing it for re-use at low cost.

#### AIR PURIFICATION

Air Purification is sometimes necessary without possibility of recovery, when industrial wastes, processing or combustion odors, vaporous impurities, atmospheric contaminants or other nuisance situations must be handled. Pur Air Activated Carbon does a thorough job of air purifying.

#### SOLVENT RECOVERY

Our Solvent Recovery Division designs, engineers, fabricates and erects complete systems for industries requiring recovery of volatile solvents which are normally lost in "thin air." Such systems readily amortize installation costs in savings of solvent.

#### ACTIVATED CARBON and REACTIVATION SERVICE

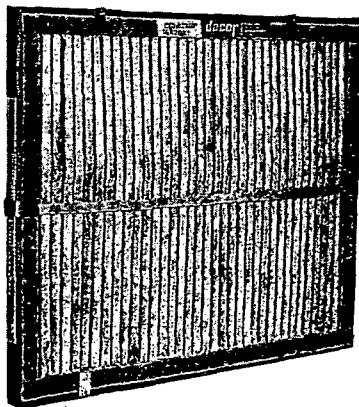
We manufacture high-grade Activated Carbon for all heating and ventilating, as well as industrial uses. We also reactivate any carbon of suitable type or hardness to peak adsorptive capacity.

#### PUR AIR ACTIVATED, COCONUT-SHELL CARBON ADSORBERS

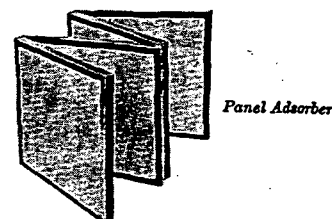
Barnebey-Cheney Company manufactures both the Activated Carbon and the equipment to use it. This combined, integrated function permits the Pur Air Division to offer the greater protection of better quality carbon and adsorbers designed to utilize this basic ingredient to the fullest extent. Pur Air adsorbers are compact, easy to handle, and designed specifically for the special jobs they're meant to do.

#### DACOR

DACOR stands for Disposable Activated Carbon Odor Remover. It utilizes high-grade activated carbon in a lightweight framework of porous fiber tubes. DACOR clips easily to either permanent or throw-away dust filters in forced air furnaces or air conditioning units. It is also available with built-in dust filter. DACOR is designed to adsorb all odors after several recirculations, will last from three months to one year—depending on conditions—and can easily be replaced. DACOR "soaks up" odors, allows pure, fresh air to recirculate. Stocked in standard dust filter sizes; other sizes are manufactured to order.



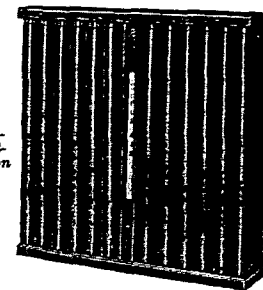
1322



Panel Adsorber

#### PUR AIR PANEL ADSORBER

The Pur Air activated, coconut-shell charcoal Panel Adsorber permits installation of the most carbon in the smallest possible space. For precision results, install one Panel Adsorber per 100 cfm. Air resistance only 0.30 (w.g.). Available in assembly frame components or self-contained units.



Filter Fold, Model M available with built-in dust filter on request

#### PUR AIR FILTER FOLD "FF"

Another Pur Air "package filter" that does a big job for its size. In a small space—24 in. x 24 in. x 8 3/4 in.—it recovers (deodorizes) 1000 cfm of "used" air. Can be used in multiples in duct work. Removes stuffiness, body odors, smoke irritants, etc., in homes, public buildings, restaurants or any type of enclosed spaces. Model M handles 1000 cfm, contains 45 lb carbon, Model D, 500 cfm, with 22 1/2 lb. carbon. Stat. 125 in. mg.

#### M-15 CANISTER

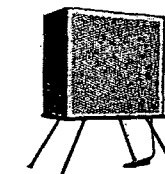
For replacement on existing systems, or new installations where canister-type equipment is indicated.



Canister

#### BREEZE UNIT

Modern design portable unit for home or office. Uses Dacors to adsorb common household odors, reduce amount of outside air needed for ventilation. Three sizes available.



Breeze Unit

#### AIR FRESH'NER

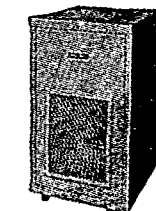
Purifies air, removes odors from small laboratories, offices, hospital rooms, darkrooms, toilets, etc. Capacity is 65 cfm. Serves up to 1500 cubic feet.



Air Fresh'ner Unit

#### PORTABLE UNIT

Suitable for larger areas—offices, recreation rooms, hospital rooms, libraries, vaults, etc. 500 and 1000 cfm models available.



Portable Unit

#### FIXED MOUNT UNIT

A complete line of self-contained units available for warehouses, cold storage areas, industrial space, etc. Made in 12 sizes, from 220 cfm to 2640 cfm. Is particularly adapted to apple storage use, to prolong life of stored fruit.



Fixed Mount Unit

#### STANDARD EQUIPMENT

Efficient air recovery and odor removal requires selection of proper Pur Air adsorbers for each application and problem involved. Standard units available to purify air and remove odors in practically any occupied space.

#### CUSTOM DESIGN

Custom design and fabricating service available for special requirements of abnormal odor problems, industrial solvent recovery, etc. Inquiries invited on any phase of air recovery, odor removal and air purification. Key personnel have security clearance for handling classified military documents.

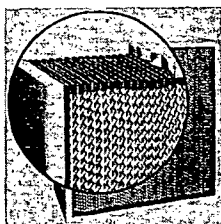
1323

## Cambridge Filter Corporation

736 East Erie Boulevard—Syracuse 3, N. Y.



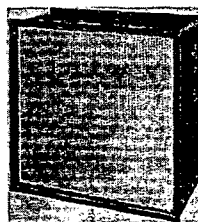
Manufacturers of High-Efficiency Air Filters  
Offices in all Principal Cities



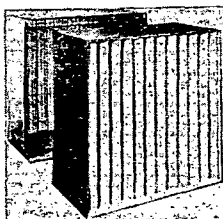
### CAMBRIDGE ABSOLUTE FILTERS

A Series

B Series



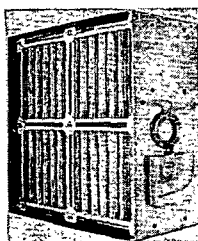
This type of filter has been used for many years by the Atomic Energy Commission for the removal of radioactive particles and by many leading companies in the industrial field which have critical air cleaning problems. Removes essentially all smoke, dust, bacteria and mold spores. Every filter is individually tested with 0.3 micron smoke particles and has a guaranteed efficiency of 99.95 per cent. Initial  $\Delta p$  1.0 in. w.g. at rated air flow. Long life—6,000 hours and longer when prefiltered—provides economical owning and operating costs. Over 200 sq ft of filtering area in a 1,000 cfm unit (24 in. x 24 in. x 11½ in.). Filters are easily installed—No supporting frames. Provide positive, trouble-free cleaning. No costly shut downs. No product contamination. Filters in standard size units from 25 cfm to 1,250 cfm available for immediate shipment. Special size units upon request. A-Series—For Standard Applications. Asbestos bearing cellulose filter media, rubber base sealer. D-Series—For High Humidity and Fire Resistant Applications. All glass filter media, rubber base sealer. Similar to A-Series in appearance. B-Series—For Fireproof Applications. All glass media, refractory sealer. Will withstand temperatures up to 1,000°F.



### CAMBRIDGE AEROSOLVE FILTERS

Cambridge Aerosolve

A Model of a  
Bank of Filters



A new, widely accepted, high efficiency, low pressure drop system of air filters designed for multi-filter banks in industrial and comfort ventilation and air conditioning supply systems. Also used in filtration of exhaust gases. Filters consist of a permanent cadmium plated steel frame and interchangeable cartridges. Filter media used in the cartridges composed of special glass mats, available in efficiencies from 35 per cent to over 90 per cent, based on the Discoloration Test Method developed by the National Bureau of Standards. All tests employ normal atmospheric dust. This is the same test as used in rating Electrostatic Precipitators. Initial pressure drops range from 0.16 in. to 0.35 in. w.g. The greater area and thickness of these specially designed mats provide long life, which together with a low initial cost guarantee economical owning and operating costs. Installation is easily made. Multi-filter banks quickly erected. Cartridges slide easily into frames and are held tightly in place by quick-acting fasteners. Operation is reliable and trouble-free. Protective screens and prefilters available if desired. 1,000 cfm unit 24 in. x 24 in. x 12 in.

## CAREY Electronic Engineering Company

METAL WOOL DIVISION

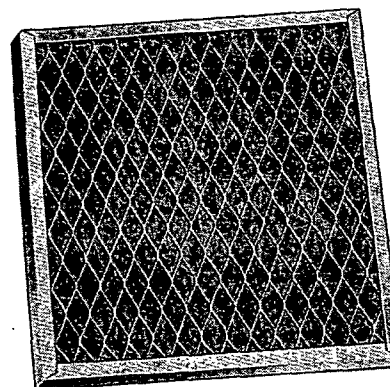
**A-Lum-O-Aire**  
FILTERS



**A-Lum-O** ALUMINUM  
AND  
COPPER WOOL

1875 CLIFTON AVENUE

SPRINGFIELD, OHIO



### CONSTRUCTION

The A-LUM-O-AIRE Filter is a permanent-type, all-metal air filter designed for top economy and efficiency in all warm-air heating, air-conditioning and ventilating applications. In 90 per cent of all installations, the A-LUM-O Aluminum Wool media catches and holds dirt—without the aid of oils and adhesives. Rustproof and fireproof, the media can be quickly cleaned with water. Frames, with corners welded for extra support, are aluminized steel which combines the strength of steel with the protection of an aluminum surface.

Mat retainers are heavy-gauge expanded steel, plated after cutting to size. Media is securely locked in position to prevent slipping or moving.

### EFFICIENCY

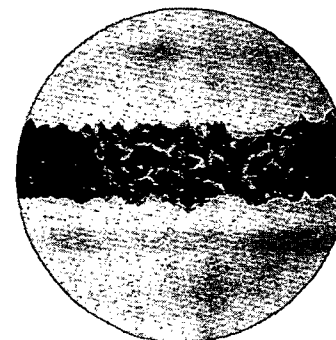
The Metal Wool Division of Carey Electronic Engineering Co. has devoted many years to the research and development of the uses and methods of producing A-LUM-O Aluminum and Copper Wool. Hundreds of tests, under simulated operating conditions, have proved its unusually high efficiency as a filter media. Millions of tiny barbs provide an extremely rough surface which catches and holds even the most minute particles. Consisting of continuous strands with no short fibers, the wool is processed from special alloys produced to rigid specifications developed by Carey for this particular purpose.

### AVAILABILITY

Furnished in all standard ½, 1 and 2 in. sizes, A-LUM-O-AIRE Filters are also available in special sizes to order. Copper wool media with copper-plated mat retainers available for acid and corrosive conditions. Units can be loaded with proper media for specific operating requirements. Thousands in use in all phases of industry have proven the advantages of greater efficiency and economy in all types of installations.

### ENGINEERING

Carey maintains one of the most modern engineering laboratories in the industry to aid you in solving your air filtration problems. The facilities for research, design and testing—plus the experience and assistance of competent personnel—are entirely at your disposal. You are invited to submit specifications for complete recommendations.



Above is a photomicrograph of aluminum wool showing the countless rows of barbs and ridges which screen out dirt, dust and lint. In a standard 30 x 30 x 1 filter there is an area of more than 69 sq ft of wool media—with literally millions of barbs in each inch of filter surface.



## CONNOR ENGINEERING CORP.

Danbury, Conn.



Representatives in  
All Principal Cities

Air Recovery

Air Purification

In Canada: Douglas Engineering Co., Ltd., Montreal, P. Q.

### WHERE TO APPLY AIR RECOVERY

Air Recovery is simply the conversion of foul or stale air to fresh air. It has been used to advantage wherever air is conditioned to enhance comfort, raise production efficiency, extend food preservation or protect product quality. Depending on the source of contamination, Dorex Air Recovery Equipment has been installed to remove

odors and other gaseous impurities from intake air, from recirculated air or from exhaust air.

When applied to recirculated air, Dorex Adsorbers reduce the amount of unconditioned outdoor air needed for ventilation and effect savings in installation and operation costs. For example: Given an air conditioning requirement of an area of 20,000 cfm, of which it is assumed 14,000 cfm would be recirculated and 6,000 would be outdoor ventilation before installation of Air Recovery Equipment, it may be possible to cut the amount of unconditioned outdoor air intake to 2,000 cfm by converting 4,000 cfm of used, already conditioned recirculated air to fresh air. Figured for average temperate zones, this 33 1/4 per cent load reduction would lower the installation and operating cost substantially because each 1,000 cfm of heated or cooled air that is converted saves: (1) 100,000 Btu of installed heating capacity, (2) 2.6 tons of installed refrigeration, (3) 1,800 kw hours of current per cooling season, (4) 1,500 gallons of fuel oil or 9 tons of coal per heating season, and (5) incidental water consumption and maintenance. In existing systems, the application of Dorex Air Recovery Equipment will enable the system to serve a larger space or satisfy a greater conditioning load without increasing cooling or heating equipment and without consuming more fuel or power.

#### Activated Carbon Traps Gases and Odors

Activated carbon removes gases and odors by adsorption—a natural phenomenon which takes place when airborne gases or vapors come in contact with it. An instantaneous condensation occurs and the condensed impurities are held tenaciously until the carbon is forced to give them up in reactivation. For air conditioning purposes, however,

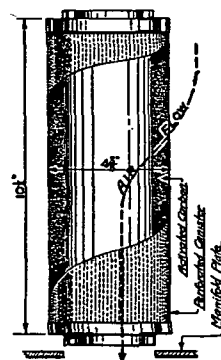


Fig. 1. Dorex Canister

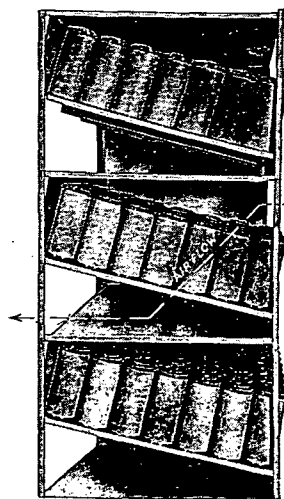


Fig. 2. Typical Canister Arrangement—side view

## Connor Engineering Corp.

the carbon must be especially processed, activated, and impregnated to meet the following specifications: (1) High activity (adsorptive capacity) for a wide range of gases and vapors; (2) High retentivity over an entire range of normal operating conditions; (3) No retentivity for water vapor; (4) Extreme hardness to avoid dusting in handling and in service; (5) High apparent density (in the granular form) of not less than 0.45; (6) Adaptability to repeated reactivation without appreciable loss in activity or retentivity. In actual use, Dorex activated carbon has removed and retained 95 per cent of all gaseous impurities from the air passed through it and maintained that efficiency from six months to two years, depending on the air contamination.

#### Equipment to Suit Individual Requirements

Dorex Air Recovery Equipment is available in a range of types and sizes to suit individual requirements. Each type is designed to hold the correct amount of activated carbon in a manner to provide a maximum area for decontamination, a minimum of air resistance and uniform air flow through the carbon. The average resistance to air flow ranges only from 0.15 to 0.2 in. wg.

#### TYPE H—Adaptable to Most Central Systems for Recovering the Freshness of Intake Air and Recirculated Air and for Eliminating Exhaust Nuisances

Type H Equipment—for complete decontamination of all air passed through it—consists of removable, perforated, carbon-filled canisters which are mounted in multiple on one or more supporting manifold plates. Fig. 1 shows a canister and its function; Fig. 2 shows a typical arrangement of canisters as installed. The flexibility of this arrangement makes Type H Equipment readily adaptable to a wide variety of space limitations. Write for *Bulletin 105-B*.

#### TYPE C—Equipment for Recovering the Freshness of Recirculated Air.

Dorex Type C Air Recovery Cells were developed to meet a need for a large capacity, easily handled and installed air purification unit. Each cell measures only 24 in. x 24 in. x 8 3/4 in. deep and completely purifies 1,000 cfm. They require no more engineering than that required for ordinary dust filters and can be mounted right along with them in either flat or "V" arrangement. (Fig. 3) Write for *Bulletin 117-C*.

TYPE G—for "Package" Conditioners, Unit Heaters, Refrigerated Spaces, Airplane, Bus, Railway Car, and Marine Installations and Other Systems Where Space is at a Premium. Write for *Bulletin 106-C*.

These compact panels consist of sturdy metal frames, each housing a battery of exposed perforated metal tubes which contain the activated carbon. Standard units of one, two or three tube rows in depth are available in a range of stock sizes for arrangement in air ducts. (Fig 4)

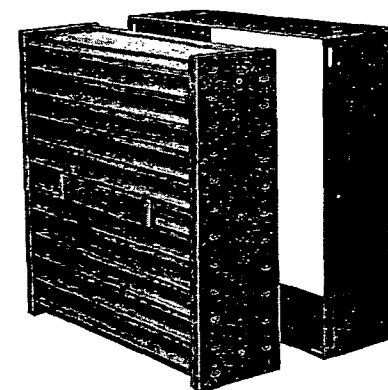


Fig. 3. Dorex Type C Air Recovery Cell

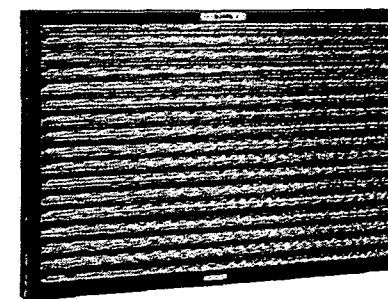


Fig. 4. Dorex G Panel

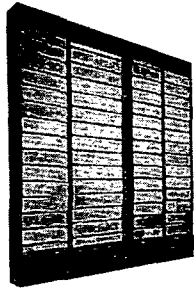
**CONTINENTAL**



**AIR FILTERS, Inc.**

P. O. BOX 1647

LOUISVILLE 1, KY.

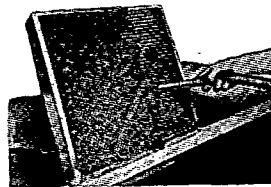
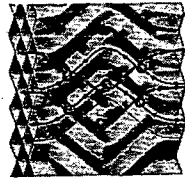


**CONTINENTAL AUTOMATIC, SELF-CLEANING** Air Filters, viscous impingement type; 91.3 per cent efficient, 0.28 W.G. resistance at 500 fpm (ASHVE method test). Features: Patented E-Z-Wash media, "Ferris Wheel" action of continuous rotating filter curtain, and positive automatic flush-cleaning of curtain in each rotation cycle.

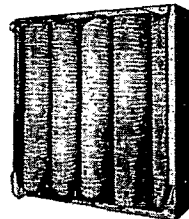
Ferris Wheel action passes filter sections from front to rear curtain without reversing them to the direction of air-flow... thus eliminating problem of trapped dirt being blown into clean air stream.

Cam action tilts and lowers each filter section while in oil reservoir so as to forcefully flush filter oil through the media counter to air-flow.

**E-Z-WASH PATENTED MEDIA** is a honeycomb of opposed V-corrugated metal strips which provides exceptional efficiency with extremely low resistance and effective self-cleaning... because air passages are relatively large and smooth-walled. Write for *Bulletin No. 801-D*.



**CONTINENTAL E-Z-WASH UNIT FILTERS**, available in all standard dimensions, 2 in. or 4 in. thick, use same advantageous patented media as discussed above. Can be washed easily by brisk cold water hosing, and quickly re-oiled with E-Z-Oil spray bomb. Write for *Bulletin No. 401-A*.



**DYCON CA-24**, dry-type air filters have an excellent dust-holding capacity because the efficient media is a blanket of specially prepared synthetic fibers. Low maintenance cost: quickly and easily restored to like-new efficiency by cold-water rinsing. No oil involved. Write for *Bulletin No. 501-A*.



**DYCON, Type DY**, one-inch dry-type filter for domestic and commercial use, is available in a wide range of standard sizes, and custom sizes as well—for air-conditioners, warm air furnaces, and air-handling units. Write for *Bulletin No. 550*.

**GREASE FILTER, Type GW**, uses same type media as E-Z-Wash filters, thus affords extremely low resistance. Since fatty acids of kitchen exhausts would be highly corrosive upon steel, Continental grease filters are made entirely of corrosion-resistant 3S aluminum. A sturdy permanent filter, type GW is easily washed in a commercial dishwasher. Write for *Bulletin No. 700*.

**Electro-air Cleaner Company**

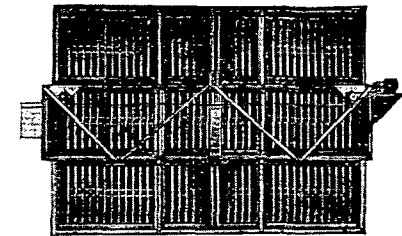
1285 Reedsdale St., Pittsburgh 33, Pa.

Representatives in Principal Cities



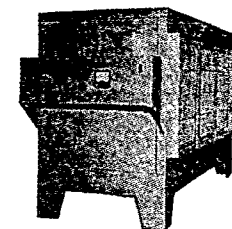
Electro-air Electronic Air Cleaners have been developed for ease of installation, maintenance-free operation, and high efficiency (90 per cent by the *National Bureau of Standards* Dust-Spot Test). New features such as selenium rectifiers and a self-adjusting, ballasted, single circuit are incorporated in the design of all Electro-air equipment. All parts, including selenium rectifiers are unconditionally guaranteed for two years.

"Built-up Line" equipment is manufactured in every capacity to handle all sizes of buildings. All units have aluminum frame-work and top and side panels. Washing systems can be of either the "fixed horizontal manifold" type, or with a "traveling vertical manifold and adhesive applicator" operated by semi-automatic or completely automatic controls. "Built-up Line" units are also furnished with "enclosures" complete with drain pans and 2½ ft. of ducts before and after the Electro-air.



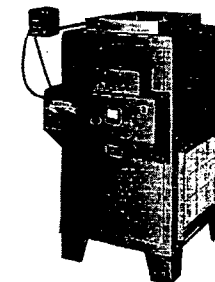
"Built-up Line" Electro-air

"Custom Line" units are furnished as complete "packages" and are designed for use in those cases where space is limited and access doors in ducts are not practical. These units are furnished in capacities from 1,350 to 12,000 cfm and are complete with required number of collecting cells, drain pans, washing systems, and power packs. "Custom Line" Electro-airs are furnished in either horizontal or vertical ("up or down" air flow), and may be floor mounted or suspended.



"Custom Line" Electro-air

"Compact Line" Electro-airs are moderately priced and are designed for easy installation in homes and smaller commercial and industrial buildings which have forced air ventilation. They are available in nine models, both horizontal and vertical (down) flow, in capacities from 800 to 4,800 cfm. Horizontal flow models may be either floor mounted or suspended. "Compact Line" units include most of the features of larger "made-to-order" Electro-air models.



"Compact Line" Electro-air





## Dollinger Corporation

6 Centre Park Rochester 3, N. Y.



Filters for Building Ventilation,  
Air Conditioning, Engine Intake, Pipelines and  
Many Other Special Applications.

Representatives in Principal Cities

### STAYNEW MODEL A-3 AUTOMATIC FILTER

An endless curtain type oil-bath filter for handling large volumes of heavily dust-laden air at low cost. The efficiency of Staynew Model A-3 is outstanding among mechanical self-cleaning filters.

**Operation and Features:** Double filter curtains (1) carried on heavy roller chains driven by sprockets keyed to the shafts of the curtain rollers (2). These rollers float on ball bearings for quiet, frictionless operation. Curtains consist of removable panels (3) made of a single layer of bronze screen cloth to which are attached layers of woven copper mesh.

The first of the curtains is the denser, having about twice the impingement surface of the second or rear curtain. This first curtain acts as the filter and travels through the oil reservoir. The second curtain does not enter the reservoir, but acts only as a safeguard against oil entrainment. This design permits a direction of certain travel such that cleaned panels (4) are always on the filtered air side. Therefore no dust can be carried across the back or return side of the front curtain to be blown off and carried on by the flow of air.

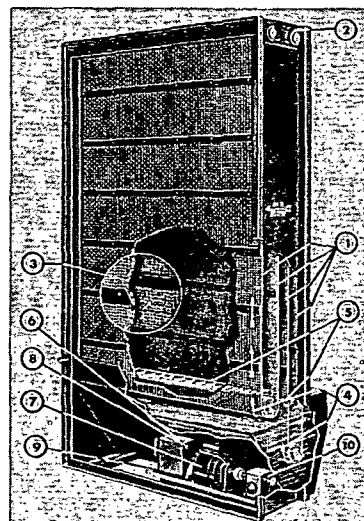
Patented, exclusive Staynew Compressed Air Curtain Cleaners (5) are available for special conditions.

#### Specifications

Model A-3 Filters are sectional and may be bolted together to obtain any required capacity. Sections come in two widths, 4 ft 3 in. and 2 ft 9 in. Curtain drive and control mechanism (6) arranged either as an integral part of filter unit or for remote mounting, includes a 1/4 hp motor (7) driving through a reduction gear and a momentary contact time switch (8) for testing and checking curtain travel and compressed air control. All are mounted on a common base plate (9) on clean air side of filter. Shear pin (10) is provided for protection of moving parts from accidental damage.

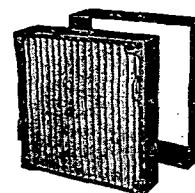
Drive motor operates for a few seconds at 15 minute intervals, and compressed air curtain cleaners can be arranged to operate simultaneously.

1330



Model A-3 Automatic Filter (numbered features are referred to in accompanying description)

### STAYNEW PANEL TYPE FILTERS

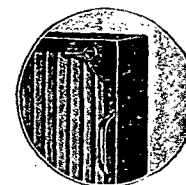


Model WKE  
Panel and Frame

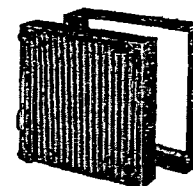
**Model WKE:** Dry-type finned panel filter for use in ventilation and air conditioning systems. Extremely large filtering area in relation to overall size. Adaptable to wide variety of filtering media—in fact, almost any medium obtainable in sheet form that can be crimped. Steel mesh on both sides of medium prevents sagging and makes the WKE *fire-resistant* (models available to meet Class I *Fire Underwriters* approval), and cleanable without possible damage from vacuum cleaning tool or cleaning nozzle. It may also be washed or dry cleaned when and if necessary. There are no cross bars, spacer bars, or other obstructions to interfere with the cleaning operation. Unaffected by temperature changes.

Filter cells are held in rigid box-type supporting frames of heavy gauge metal by spring-loaded cam-type locking latches. Two lifting handles are provided on each cell. Filtering medium supplied already crimped and cut to size. It may be inexpensively replaced in 2 to 5 minutes right at the filter bank—no special tools required.

Frames are drilled so that they can be riveted together to form a flat bank, or by the addition of angle uprights into a "V" or staggered arrangement.



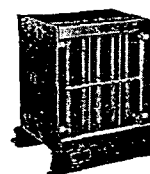
Handles and Latches



Viscous Model DPV  
Panel and Frame

**Viscous Panel (Model DPV):** A permanent type panel for air conditioning systems used in heavy duty industrial service. Filtering media consist of a series of layers of crimped galvanized screen cloth and woven mesh. These media when coated with PD-10 Pingene Filter Oil form an unusually efficient filter. Model DPV filters are cleaned easily with live steam or by washing in a suitable solvent. Spring-loaded locking latches and lifting handles are provided as in Model WKE.

Both Model WKE and DPV cells are furnished in 2 in. and 4 in. depths in various standard sizes.

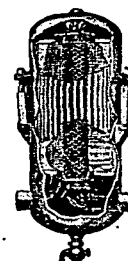


1200 cfm  
Electro-Staynew Precipitator

**Electro-Staynew Electronic Filter:** Ionizer and Collector Cell built into one compact unit. Highly efficient—removes 90 per cent of all air-borne dirt, including smoke, dust, pollen, oil mist. Available in single units of 1200 and 1800 cfm; any capacity in multiple units.

### STAYNEW LIQUID FILTER

**Model ELS:** Widely used for the filtration of cooling water to prevent clogging of spray nozzles. Exclusive, low-cost SLIP-ON INSERT easy to remove, clean, replace. Radial Fin Construction provides all possible filtering area in smallest possible space. Standard models available to handle up to 1000 gpm.



Model ELS  
(Sectional View)

Representatives in Principal Cities

Complete Information from Factory on request

FILTERS FOR INTERNAL COMBUSTION ENGINES  
COMPRESSORS, PIPE LINES; ALSO  
DUST COLLECTORS

1331

## Farr Company

Manufacturing Engineers

P.O. Box 45187, Airport Station

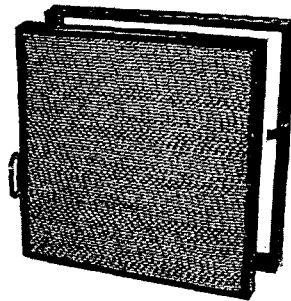
Los Angeles 45, Calif.

Chicago New Orleans

New York

Manufactured under license by Farr Co. Mfg. Ltd., Montreal, Canada

### FAR-AIR® FILTER AND HOLDING FRAME



A high velocity, low resistance, viscous impingement unit for industrial and commercial applications. Available in a wide range of types and sizes for dirt, lint, grease, entrained water, ink, paint, etc. Herringbone-crimp media design assures higher performance, larger dirt holding capacity, lower pressure loss, easier cleanability and reduced maintenance costs. Standard interlocking holding frames are 16 gauge steel. Various protective coatings available.

#### FAR-AIR CAPACITIES

Recommended net face velocity is 519 fpm although velocities up to 700 fpm may be used. The following chart is a

guide in estimating FAR-AIR Filter requirements. 4 in. filter thickness has twice the pressure loss of the 2 in.

| NET<br>FACE<br>VEL.<br>F.P.M.         | CAP.<br>C.F.M.<br>Per<br>Sq. In. | PRES-<br>SURE<br>LOSS<br>CLEAN<br>In. H <sub>2</sub> O | NOMINAL FILTER SIZE                               |               |               |               |               |                    |               |               |               |               |
|---------------------------------------|----------------------------------|--------------------------------------------------------|---------------------------------------------------|---------------|---------------|---------------|---------------|--------------------|---------------|---------------|---------------|---------------|
|                                       |                                  |                                                        | Standard Stocked Filters                          |               |               |               |               | Other Common Sizes |               |               |               |               |
|                                       |                                  |                                                        | 16" x 20" 16" x 25" 20" x 25" 20" x 30" 25" x 30" |               |               |               |               |                    |               |               |               |               |
|                                       |                                  |                                                        | 16" x 20" #44                                     | 16" x 20" #16 | 16" x 25" #20 | 20" x 25" #25 | 20" x 30" #30 | 25" x 30" #35      | 10" x 20" #10 | 16" x 16" #16 | 20" x 20" #20 | 25" x 30" #30 |
| FILTER CAPACITY CUBIC FEET PER MINUTE |                                  |                                                        |                                                   |               |               |               |               |                    |               |               |               |               |
| 346                                   | 2.40                             | 0.06"                                                  | 625                                               | 795           | 800           | 1020          | 360           | 485                | 1235          | 1575          |               |               |
| 390                                   | 2.70                             | 0.07"                                                  | 700                                               | 895           | 900           | 1145          | 405           | 550                | 1390          | 1775          |               |               |
| 433                                   | 3.00                             | 0.09"                                                  | 780                                               | 995           | 1000          | 1275          | 450           | 610                | 1545          | 1970          |               |               |
| 476                                   | 3.30                             | 0.10"                                                  | 860                                               | 1095          | 1100          | 1400          | 495           | 670                | 1700          | 2170          |               |               |
| 519                                   | 3.60                             | 0.12"                                                  | 935                                               | 1195          | 1200          | 1530          | 540           | 730                | 1855          | 2365          |               |               |
| 563                                   | 3.90                             | 0.14"                                                  | 1015                                              | 1290          | 1300          | 1655          | 585           | 790                | 2010          | 2550          |               |               |
| 606                                   | 4.20                             | 0.16"                                                  | 1090                                              | 1390          | 1400          | 1780          | 630           | 855                | 2165          | 2760          |               |               |
| 650                                   | 4.50                             | 0.19"                                                  | 1170                                              | 1490          | 1500          | 1910          | 680           | 915                | 2320          | 2980          |               |               |
| 693                                   | 4.80                             | 0.21"                                                  | 1250                                              | 1590          | 1600          | 2035          | 725           | 975                | 2475          | 3155          |               |               |

#### MEDIA DESIGNATION AND APPLICATION

Type 44: 14 mesh zinc-electroplated steel screen. For ventilation, paint, lint, ink, oil.

Type 44F: Coated with vinyl or other special paint. For fume-resistant applications.

Type 44G: Standard filter, uncoiled. For grease arrestance.

Type 44MZ: Screen painted with zinc

chromate before and after assembly. Frame hot dip galvanized. Marine ventilation application.

Type C4C4H: All copper media and filter frame. Corrosive atmosphere and water elimination applications.

Type A4A4: All aluminum media and filter frame. Stainless steel and monel filters for special applications can be supplied on special order.

\*Trade Mark Reg.

### HOW TO SPECIFY STANDARD TYPE 44 FILTERS & FRAMES

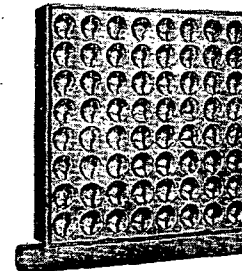
Filter shall be permanent, impingement, washable, all metal, panel type. Media shall be zinc electroplated, 14 mesh steel screen, arranged in alternate layers of flat and herringbone-crimped screens, so that at no point is air flow restricted to flow through the screen, 4 layers of each per inch, 1/8-in. rod reinforced, and enclosed in a frame of 16 gauge steel with flush mitered corners. Resistance to air flow of a clean filter

shall not exceed 0.12 in. w. g. at 3.6 cfm per square inch of net face area.

Holding frames shall be factory built on 16 gauge steel "T" section, with felt air seal, interlocking edges, and filter locking device.

Filters shall be Far-Air Type 44 and frames shall be Far-Air Standard Interlocking as manufactured by Farr Company, Los Angeles 45, California.

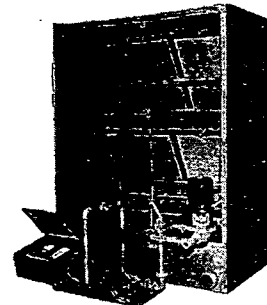
#### ROTONAMIC



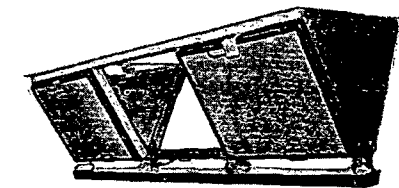
#### ROTONAMIC

The Rotonamic is a compact, multiple tube, cyclonic type air cleaner with continuous dirt removal by air bleed. Efficiency averages 98 percent on 5 to 10 micron dust of 2.5 specific gravity. Efficiency is even higher on larger particles or on denser material. Rating of 20 x 20 x 4 1/8 in. panel is 1000 to 2000 cfm depending on available pressure. Apparent straight through air flow requires no difficult change in duct direction. Bleed off piping is simple. Deflecting vanes form a high velocity vortex in each tube. Internal reversal of the direction of flow doubles the cyclonic action, producing the high efficiency.

#### SELF WASHING FILTERS



These completely automatic units wash and re-oil themselves on any frequency cycle desired. Each is made up from 4 in. thick corrosion-resistant filters in combination to meet any cfm requirement. Washing water and contaminated oil is immediately flushed away, eliminating messy sludge and oil sumps. There is no oil entrainment. Each unit has a safety deluge valve that automatically prevents fire from passing the unit. Installation is simple and inexpensive.



#### ENDLESS GREASE ELIMINATORS

FAR-AIR Endless Grease Eliminators halt the deposit of highly combustible grease and lint in the air ducts, reduce maintenance, protect blower and fan, provide better ventilation and sanitation. Available in one-sided and two-sided models in sizes to meet any cfm requirement.

Full catalog and technical information on any FAR-AIR product is available on request.

## The Goodyear Tire &amp; Rubber Company, Inc.

Akron 16, Ohio

## PLIOTRON\*

## AIR CLEANER

## WHAT IT IS

PLIOTRON is a self-charging, electrostatic, washable, permanent-type air cleaner. Revolutionary feature is its new filter medium of shredded polyethylene. Sound engineering and construction insure long life and minimum maintenance.

## HOW IT WORKS

Shredded polyethylene carries inherent positive and negative charges in close proximity to each other. These charges are greatly increased with the passage of air. Since particles of dirt are similarly charged, the meshed plastic does an effective job of attracting and capturing them.

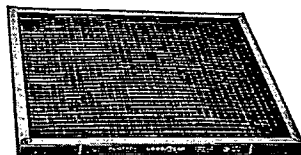
## SPECIAL SHREDDING INCREASES EFFICIENCY

A special method of shredding produces

a feathered edge with thousands of cilia-like serrations. These increase the area exposed and create a heavy turbulence that brings the dirt particles into intimate association with the statically charged polyethylene.

## AVAILABILITY INFORMATION

PLIOTRON is supplied through distributors located in every major marketing center across the country. It is presently available in four standard sizes, all 1 in. in thickness. It is so designed as to stay in the general resistance range of ordinary, 2 in. thick, impingement filter, yet do a superior job of air cleaning. Spacer clips which are also available, or another PLIOTRON, are recommended in instances where a filter greater than 1 in. in thickness is required.

SELF-CHARGING  
ELECTROSTATICWASHABLE  
PERMANENT TYPE

| Net Face Velocity<br>fpm | Static Pressure Drop<br>Inches H <sub>2</sub> O | Filter Size            |                 |                 |                 |
|--------------------------|-------------------------------------------------|------------------------|-----------------|-----------------|-----------------|
|                          |                                                 | Nominal                | 16 x 20 x 1     | 16 x 25 x 1     | 20 x 20 x 1     |
|                          |                                                 | Actual 15 1/4 x 19 1/8 | 15 1/4 x 19 1/8 | 15 1/4 x 24 1/8 | 19 1/8 x 19 1/8 |
|                          |                                                 | sq x .938              | sq x .938       | sq x .938       | sq x .938       |
|                          |                                                 | Sq Ft (Net Area) 2.22  | 2.78            | 2.78            | 3.47            |
| Filter Capacity cfm      |                                                 |                        |                 |                 |                 |
| 200                      | 0.08                                            | 445                    | 555             | 555             | 695             |
| 300                      | 0.15                                            | 665                    | 835             | 835             | 1040            |
| 375                      | 0.22                                            | 830                    | 1040            | 1040            | 1300            |
| 450                      | 0.30                                            | 1000                   | 1250            | 1250            | 1560            |
| 500                      | 0.36                                            | 1110                   | 1390            | 1390            | 1735            |
| 600                      | 0.48                                            | 1330                   | 1670            | 1670            | 2080            |

\* PLIOTRON—T.M. The Goodyear Tire & Rubber Company, Akron, Ohio.  
NOTE: Additional standard sizes available from stock are: 10 x 10 x 1, 10 x 20 x 1 and 15 x 20 x 1. Special sizes in 1 in. thickness available from factory. Contact your Distributor or write Goodyear, Pliotron Sales, Dept. 722, for prices and delivery.

## Charles E. Manning Co.

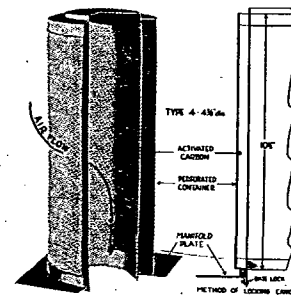
90 Clairton Blvd.

Pittsburgh 36, Penna.

AIR PURIFICATION AIR RECOVERY SYSTEMS



## REFILLABLE ACTIVATED CARBON AIR RECOVERY CANISTER

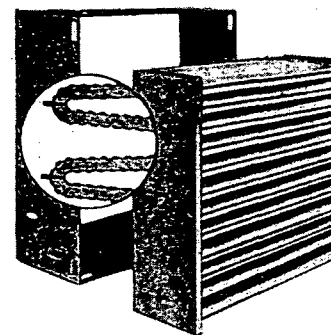


PERFORMANCE CHART C-4

| CFM | Pressure Loss*<br>(Inches W.G.) |
|-----|---------------------------------|
| 5   | 0.02                            |
| 10  | 0.045                           |
| 15  | 0.075                           |
| 20  | 0.11                            |
| 25  | 0.15                            |
| 30  | 0.2                             |
| 35  | 0.25                            |
| 40  | 0.32                            |

\* Resistance is overall

## NU-AIR TYPE "A" AIR RECOVERY UNIT



TYPE "C"—CANISTER, a perforate metal cylinder filled with granular carbon (for 15 to 35 cfm each with recommended maximum of 25 cfm). Made up of one perforate metal cylinder within another, with the side walls of the two forming an open area which is filled with granular activated carbon. The top is completely sealed with a cap that encloses both the inner and outer shell. Air flows through the cylindrical side-wall and carbon bed, into the hollow center of the inner cylinder—then down through the opening punched manifold plate upon which it rests.

The Canisters may be set on the manifold plate in any arrangement that best suits the requirements and available space. Canisters and/or manifold plate can be furnished in stainless steel, brass or aluminum for special installations.

The Type "A" panel Air Recovery unit handles from 700 to a maximum of 1000 cfm. For use in removing odor and gaseous impurities where those concentrations are light to medium. The shape of the carbon bed offers a great exposed area to the air flow for maximum efficiency. The carbon bed is formed by two parallel sheets of perforated metal, fashioned in a series of S-curves, comprising the surface through which the air flows.

PERFORMANCE TABLE

| CFM  | Static Pressure Loss*<br>V-Arrangement | Flat  |
|------|----------------------------------------|-------|
| 500  | 0.105                                  | 0.08  |
| 600  | 0.15                                   | 0.105 |
| 700  | 0.177                                  | 0.13  |
| 800  | 0.23                                   | 0.17  |
| 900  | 0.275                                  | 0.19  |
| 1000 | 0.33                                   | 0.23  |
| 1100 | 0.377                                  | 0.26  |
| 1200 |                                        | 0.3   |
| 1300 |                                        | 0.345 |

\* Resistance is overall.

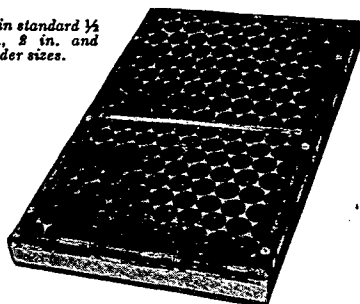
Both types of equipment can be used in single or multiple units for required capacities. Complete technical data available in new bulletin 15-CX, 15-DX, by writing the manufacturer.

# Owens-Corning Corporation

Toledo 1, Ohio

**DUST STOP**

Available in standard 1/4 in., 1 in., 2 in. and made-to-order sizes.



## AIR FILTERS



### THE ALL-PURPOSE, REPLACEMENT-TYPE AIR FILTER

Air flows freely through a Fiberglas Dust-Stop® Air Filter, yet virtually all dirt is trapped inside. Correctly sized fibers mean peak efficiency . . . minimum resistance. "Depth-loading" extends filter life.

#### THE FILTER

Dust-Stop Air Filters are impingement-type filters constructed of glass fibers which are non-absorptive, fire-proof and will not shrink or swell. Fibers are coated with a non-evaporating odorless adhesive which effectively traps dust, lint and pollen. Dust-Stops are replacement-type filters and should not be laundered.

Uses—Dust-Stop Filters may be used at approach velocities up to 450 fpm without impairment of their high efficiency characteristics but with higher resistances. Maximum permissible resistance of filters is 1 1/2 in. water gage.

#### DUST-STOP FILTER FRAMES

Dust-Stop Filter Frames are designed for the convenience of the engineer in constructing filter banks. Metal frame is of universal style, suited to use in flat or "V" banks. Designed-in, self-locking device permits fast, economical assembly. Made to take 2 in. or 4 in.

#### DUST-STOP RESISTANCE INDICATOR

The Dust-Stop Resistance Indicator acts as a guide to economical bank maintenance. With adjustable filter-change marker set at resistance level specified by engineer as point where filters should

#### Resistances

| Resistance—  | inches, water gage | 300 fpm | 450 fpm |
|--------------|--------------------|---------|---------|
| 1 in. filter | .080               | .170    |         |
| 2 in. filter | .135               | .300    |         |

In cases where velocities approach 450 fpm, care should be taken to see that fan capacity is adequate to overcome increased resistances.

Cfm Capacities—Rated capacities of standard 20 in. x 20 in. Dust-Stop Filters are 800 cfm at 300 fpm velocity and 1250 cfm at maximum permissible velocity of 450 fpm.

depth of standard 20 in. x 20 in. or 20 in. x 25 in. filters. Black painted or galvanized finish. Front, back and side angle uprights for V-bank assembly are also offered in 20 in. increments up to 160 in. length.

be changed, this indicator provides a guide to "when-to-change filters." Insures operation at rated capacity and efficiency.

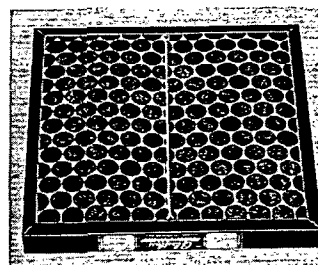
\* FIBERGLAS and DUST-STOP are trade-marks (Reg. U.S. Pat. Off.) of Owens-Corning Fiberglas Corporation for a variety of products made of or with fibers of glass.

# Pittsburgh Plate Glass Company

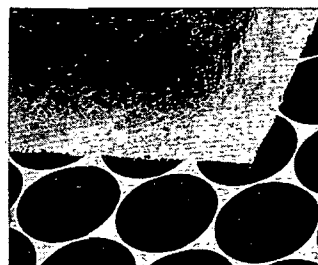
FIBER GLASS DIVISION  
One Gateway Center  
Pittsburgh 22, Pennsylvania



Where clean air is a necessity for either residential, commercial or industrial applications specify GLASFLOSS filters. Products of the Pittsburgh Plate Glass Company, these filters are composed of extremely long and exceptionally fine glass fibers. Because of this fineness, they furnish a greater dust-collecting area and provide unusually complete filtering action. GLASFLOSS filters are available in three forms, to suit all filtering requirements:

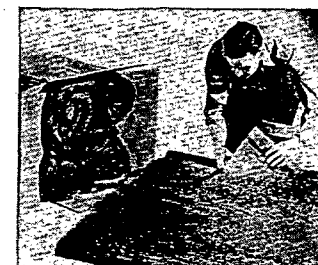


**GLASFLOSS I-S FILTER**—To the long, fine glass fibers used in the STANDARD Air Filter a special strainer mat has been added. This means that the I-S filter is actually two filters in one. For industry, where clean air is essential, or in the meticulous home equipped with forced air heating, Glasfloss I-S provides new quality air filtering.



#### GLASFLOSS STANDARD AIR FILTER

—Provides millions of fine, glass fibers scientifically bonded and treated with a special fire-resistant, dust-catching adhesive, to trap and hold more dirt. This extends the life of the filter and makes it ideal for normal home heating and air conditioning equipment.



**GLASFLOSS ROLL-PAK**—For bulk users of air filters who are faced with the problem of continuous replacement. The Glasfloss Roll-Pak provides substantial savings . . . as high as 30 per cent. It offers quick replacement of filter media, and is available in rolls of 40 in. wide and 10 in. long and in 1/2 in., 1 in. and 2 in. thicknesses, packed five rolls per carton, to suit every size commercial air filter.

#### ACTUAL DIMENSIONS

| Width | Height | Thickness |           |
|-------|--------|-----------|-----------|
|       |        | 1" Filter | 2" Filter |

#### TOLERANCES

| Plus 0.00" Minus 1/8" |         | Plus or Minus 1/8" |             |
|-----------------------|---------|--------------------|-------------|
| 19 1/4"               | 24 1/4" | 1 1/4"             | 1 1/4"      |
| 19 1/4"               | 19 1/4" | 1 1/4"             | 1 1/4"      |
| 15 1/4"               | 24 1/4" | 1 1/4"             | 1 1/4"      |
| 15 1/4"               | 19 1/4" | 1 1/4"             | 1 1/4"      |
| 14 1/4"               | 19 1/4" | 1 1/4"             | 1 1/4"      |
| 9 1/4"                | 19 1/4" | 1 1/4"             | 1 1/4"      |
| 9 1/4"                | 9 1/4"  | 1 1/4"             | 1 1/4"      |
| 11 1/4"               | 30 1/4" | 1 1/4"             | 1" only     |
| 19 1/4"               | 22 1/4" | 1 1/4"             | 1" only     |
| 15 1/4"               | 22 1/4" | 1 1/4"             | 1" only     |
| 6 1/4"                | 23 1/4" | 1 1/4"             | 1 1/4" only |
| 9 1/4"                | 11 1/4" | 1 1/4"             | 1 1/4" only |

|                                      | Nominal Sizes                                                         | Volume of Air Cleaned |
|--------------------------------------|-----------------------------------------------------------------------|-----------------------|
| GLASFLOSS<br>STANDARD<br>AIR FILTERS | 20" x 25"                                                             | 1000 CFM              |
|                                      | 20" x 20"                                                             | 800 CFM               |
|                                      | 16" x 25"                                                             | 800 CFM               |
|                                      | 16" x 20"                                                             | 640 CFM               |
|                                      | 15" x 20"                                                             | 600 CFM               |
|                                      | 10" x 20"                                                             | 400 CFM               |
|                                      | 10" x 10"                                                             | 200 CFM               |
|                                      | 12" x 30 <sup>3</sup> / <sub>4</sub> " x 1"                           | 735 CFM               |
|                                      | 20" x 22 <sup>1</sup> / <sub>4</sub> " x 1"                           | 890 CFM               |
|                                      | 16" x 22 <sup>1</sup> / <sub>4</sub> " x 1"                           | 715 CFM               |
| Special sizes<br>available           | 7" x 23 <sup>3</sup> / <sub>4</sub> " x <sup>1</sup> / <sub>4</sub> " | 330 CFM               |
|                                      | 10" x 12" x <sup>1</sup> / <sub>4</sub> "                             | 240 CFM               |
|                                      |                                                                       |                       |
| GLASFLOSS<br>I-S<br>AIR FILTERS      | 20" x 25"                                                             | 1000 CFM              |
|                                      | 20" x 20"                                                             | 800 CFM               |
|                                      | 16" x 25"                                                             | 800 CFM               |
|                                      | 16" x 20"                                                             | 640 CFM               |
|                                      | 15" x 20"                                                             | 600 CFM               |



## Research Products Corporation

Madison 10, Wisconsin

AIR FILTERS FOR  
HEATING AND VENTILATING

Grease Filters for Kitchen Exhaust Systems—Paint Arrestor Pads

### RP AIR FILTERS

Controlled turbulence design is provided in every RP filter. Scientifically staggered baffles cause thousands of sharp reversals of air flow in the filter. Media gradation, insures RP depth loading, an important longevity feature. Air borne particles are centrifuged

### REPLACEMENT



"Snap-In" Grid Air  
Filter Installation  
Showing Self-  
Seal Edge.

### Fiber Self-Seal Air Filter

The highly efficient, soft, resilient, non-fracturing RP replacement media is held in a sturdy, refillable wire grid. Media pad is oversize and no channel is required or used on edge which provides the self-sealing feature. Used in domestic and commercial units and in central system filter banks. Available in  $\frac{1}{2}$  in., 1 in. and 2 in. thicknesses in standard and special sizes.

### Snap-In Grid Air Filter

Designed for central system use of the inexpensive Fiber Self Seal Pad. Paint Arrestors

Specially designed, inexpensive and efficient pad removes overspray from paint spray booth exhaust air. Snap-in grid retains pad in frame.

against the baffles and are held by adhesive in the air filter and by the viscous qualities of the particles, themselves, in the grease filter and paint arrestor applications.

Constructed of slit and expanded material, RP filters are uniform in construction and performance.

### WASHABLE

#### E Z Kleen Air Filter

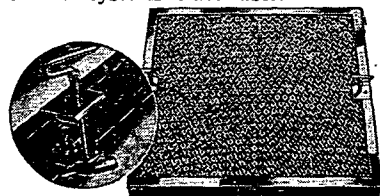
The RP Alumaloy, E Z Kleen Air Filter is an economical selection for many applications. Like all RP washable air filters, this filter is extremely easy to clean.

#### Industrial Air Filter

RP Alumaloy Industrial air filters are multi-velocity filters, which have extremely low initial resistance and slow build-up resistance. Holding frames for filter banks, combination lift and lock handles, lift handles and water soluble filter coat adhesive are available.

#### Grease Filter

Efficiency in excess of 99 per cent on grease vapors, gleaming appearance, ease of cleaning and light weight have made RP Alumaloy Grease Filters a volume performance leader in its field. A free comprehensive data booklet on kitchen exhaust systems is available.

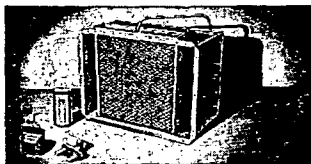


RP Alumaloy Air Filter and Inset Showing Handle Lock

### ADHESIVE

Two types of adhesives are available. RP Filter Coat for removal of dust and other impurities—RP D-O Kote which has the additional quality of odor removal. Both are for application to RP Alumaloy washable filters.

### APRILAIRE Automatic-Electric HUMIDIFIER



Positive control by humidistat and high capacity are features of Aprilaire Humidifiers. Three models available: Plenum Model (illustrated) for installation in forced air furnaces; Universal Model, for installation in building with steam or hot water heat; Portable Model requiring no installation for any type home or office.

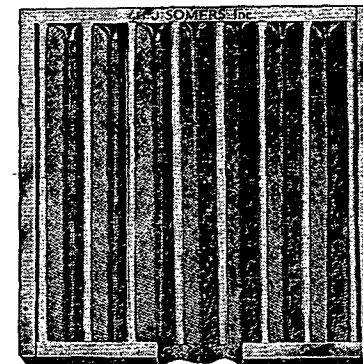
## Somers Corporation

6063 Wabash Ave., Detroit 8, Mich.

Established 1925

REPRESENTATIVES IN PRINCIPAL CITIES

### SOMERS Heavy Duty Industrial Filter



Patented

Somers Hair Glass Filters provide everything required in an efficient air-cleaning system.

### FEATURES

- High rating for dust, soot and bacteria separation.
- Require no adhesive, coating or impregnation.
- Indestructible in normal service.
- Minimum low-pressure drop.
- Odorless and non-absorptive.
- Fireproof.
- No periodic replacement.
- Washable.
- Permanent—Do not rot nor disintegrate.
- All welded zinc-plated 20 gauge steel frame.
- 100 hour salt spray test.
- Metal protection strip on apex.
- Glass cloth between hot-dipped hardware cloth.
- Glass ribbon seal so air cannot short circuit.
- Refills.

Somers Hair Glass Filters consist of a 20 gauge zinc plated frame holding galvanized wire cloth packed with hair-spun glass strands. The glass strands are flexible, do not break up and cannot be drawn into air stream.

Hair Glass being chemically inert, has no facility of absorption; it cannot rust and lasts indefinitely in service. Water either hot or cold may be used to clean it, without impairing its efficiency.

Available in all standard and special sizes. Quotations and further engineering data will be sent on request. Master holding frames available.

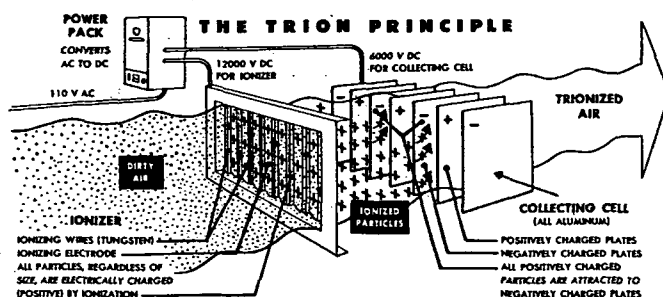


## TRION, INC.

1000 Island Avenue, McKees Rocks, Pa.  
In Metropolitan Pittsburgh

Designers and manufacturers of equipment for cleaning and purifying air and other gases.

### TRION ELECTRONIC AIR CLEANERS



Highest efficiency air purification equipment. Electronically removes more than 90 per cent (*National Bureau of Standards Dust-Spot Test* using normal atmospheric air) of dust, dirt, smoke, pollen, germs and virus from air. All airborne particles are electronically charged (positive) as they enter the Trion. They are then attracted to and collected upon plates having an opposite electrical charge (negative). An integral washing system flushes the dirt to a sewer.

**Field Assembled:** Built to specifications for required cfm and assembled on job.

**Custom-Built:** Built to specifications up to 9330 cfm and shipped as a complete unit.

**Standard Packaged:** Residential and small commercial units. Seven sizes up to 4,800 cfm. Shipped from stock.

**Special:** Designed for specific requirements such as by-product recovery, gas purification, nuisance elimination.

### TRION OIL MIST PRECIPITATOR

Electronically recovers coolant oil mist from high speed cutting and machining operations. Unit includes blower.

### TRION MECHANICAL AIR FILTER

Inexpensive, viscous impingement air filtering equipment featuring high velocity, progressive loading, low pressure drop, high dirt holding capacity and non-clogging. Manufactured from wire screen or aluminum strip media with exclusive "air scoop" design.

**Fixed Panel:** Permanent and cleanable panels for filtering larger particles of dirt, pollen and grease. Automatic self cleaning accessories available.

**Traveling Curtain:** Advanced design automatic filters with continuous self cleaning features for large volumes of air where filtering of coarse particles is sufficient.



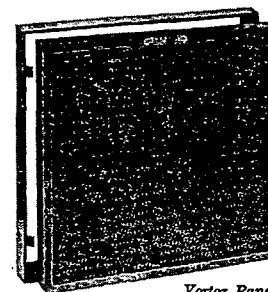
## Vortex Company

Claremont, California

Panel Air Filters for all Industrial Applications



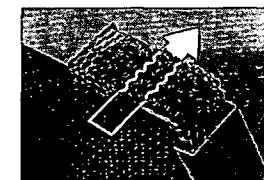
Vortex Panel Air Filters are of the cleanable, impingement, viscous-coated type with exceptionally low air flow resistance. They are made for use in air conditioning, ventilation, range canopies, engine intakes, and general air filtration.



Vortex Panel  
Filter with Frame

**EFFICIENCY.** Vortex Panel Air Filters are efficient at both high and low air flows. Consequently to reduce costs of the original installation or to save space, fewer Vortex Filters may be used at higher air velocities. To assure a longer service life, more Vortex Filters may be used at lower velocities. In either case Vortex Panel Air Filters provide better cleaning at lower cost.

**OPERATION.** Numerous changes in direction of dust laden air cause the dust particles to impinge on the adhesive viscous-coated surfaces of the filter



Vortex Type VR Panel Air Filter illustrated above is the type used on engine intakes and in car bodies of diesel locomotives. It is constructed to withstand the severe usage of locomotive service. It has the exceptional characteristics as in all types of Vortex Panel Air Filters.

**FILTER ELEMENT.** Fabricated of elastic units of fine steel wire positively interlocked to provide a permanent filter, the element offers many advantages: (1) In a 2 in. x 20 in. panel there are from 9300 to over 15,000 feet of fine steel wire, depending upon the type. (2) Even distribution of filaments exposes innumerable viscous-coated surfaces to the air stream, thus obtaining the most effective cleaning for space occupied. (3) Proper spacing of filaments prevents clogging and assures maximum dust removal efficiency. (4) Structural strength and permanent resilience combine to withstand "packing" effect of vibration and pulsation.

element. Coarser particles collect near the entrance, while finer particles penetrate to a greater depth. As the entrance becomes saturated the cleaning action takes place deeper in the filter and the restriction is increased slightly. Increased restriction in certain sections of the filter diverts the air to cleaner sections, thus distributing the dust load for a higher over all efficiency and a greater total dust-holding capacity. **EASY TO CLEAN.** All dust and lint are easily and completely flushed from the filter by water or steam sprays.

| Nominal<br>Size of Panel<br>Inches* | Actual<br>Outside<br>Dimensions<br>Inches | Capacity<br>Range In<br>CFM** | Outside<br>Dimensions<br>Of Holding<br>Frames Inches |
|-------------------------------------|-------------------------------------------|-------------------------------|------------------------------------------------------|
| 16 x 20 x 2                         | 15 5/8 x 19 1/4 x 1 7/8                   | 640 to 950                    | 16 1/4 x 20 1/4 x 2                                  |
| 16 x 25 x 2                         | 15 5/8 x 24 5/8 x 1 7/8                   | 800 to 1200                   | 16 1/4 x 25 1/4 x 2                                  |
| 20 x 20 x 2                         | 19 1/4 x 19 1/4 x 1 7/8                   | 800 to 1200                   | 20 1/4 x 20 1/4 x 2                                  |
| 20 x 25 x 2                         | 19 1/4 x 24 5/8 x 1 7/8                   | 1000 to 1550                  | 20 1/4 x 25 1/4 x 2                                  |

\* These filters are also made in 4-in. thickness.

\*\* Some filter manufacturers specify very high velocities which are applied to certain internal dimensions of the filter. The range of capacities stated above are computed on the basis of average to high velocities applied to the total filter area using the actual outside dimensions of Vortex Panel Air Filters.





## Westinghouse Electric Corporation Sturtevant Division

Heating, Ventilating, Dust Control and Fume Removal  
Equipment, Electronic Air Cleaners, Mechanical  
Draft Equipment

Hyde Park

Offices in Principal Cities

Boston 36, Mass.

### ELECTRONIC AIR CLEANING

**PRECIPITRON** high efficiency electronic cleaners save money by removing harmful dust and dirt from ventilating air.

In commercial buildings **PRECIPITRON** catches dirt and grime before it settles on walls, merchandise, light fixtures and equipment. In industrial plants **PRECIPITRON** protects valuable equipment, and improves working conditions.

#### Oil Mist Control Units

Designed to collect oil coolant mists generated by high-speed cutting, grinding operations. Have built-in fan for individual machine ventilation. Available in 600 and 1200 cfm capacities.

#### Horizontal and Vertical Air Flow

Manual wash type for installation in ducts. Sizes range from 1200 to 100,000 cfm for operation at 90 per cent efficiency by Blackness Test. Units easily maintained by manual washing. Uses 115 volts single phase power—only 40 watts per 1000 cfm.

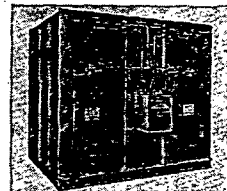
Push-Button washing type; washes and applies adhesive with a built-in motorized moving nozzle washing mechanism operated by remote control. Allows operator to service the unit quickly and economically from outside the duct. Sizes from 5000 to 72,000 cfm.

Automatic Washing type for large, heavy duty applications. Washes and applies adhesive automatically without interrupting the air flow. Mobile washer boxes isolate small section of unit for complete servicing. Capacities from 24,000 cfm up.

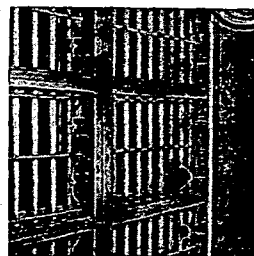
Vertical Unit for up or down, air flow—manual washing. Suited to small and medium size installations where space is at a premium. Capacities 1200 to 9600 cfm.



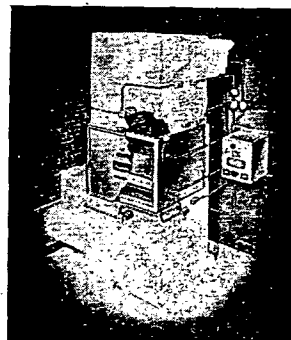
Oil Mist Control Unit



Encased Precipitron Horizontal Airflow



Commercial Precipitron With "Push-Button" Wash

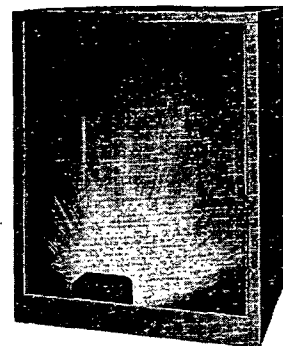


Commercial Vertical Airflow Unit



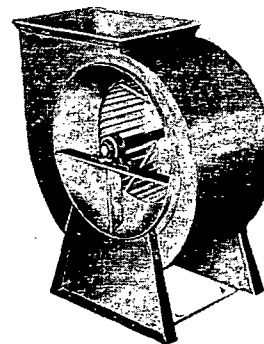
## Air Fan Engineering Company

7401 Telegraph Rd.,  
Los Angeles 22, Calif., U. S. A.  
(Telephone RAYmond 3-3354)



### AIRFAN AIR WASHER EVAPORATOR COOLER

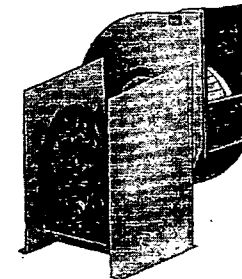
The Airfan Air Washer Evaporator Cooler has high cooling efficiency and is next in line to mechanical refrigeration, yet low in cost. Units available from 2,000 cfm to 100,000 cfm.



### AIRFAN H-D BLOWER

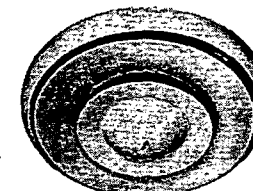
Airfan builds a complete line of forward and backward heavy duty blowers, rotatable discharge housing and extended streamlined air inlets for quiet operation and low horsepower. Capacities range from 600 cfm to 100,000 cfm.

Technical Data Catalogs on all Airfan Products are available upon request to building contractors, engineers and dealers.



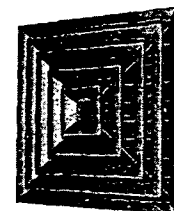
### UTILITY SETS

For general ventilation complete with weather-proof covers. Self contained package units for easy installation. 300 cfm to 20,000 cfm. Wheel diameters 10 inch to 36 inch.



### ROUND DIFFUSER

Precise control of air delivery and radius of diffusion with Airfan round ceiling diffusers. Nine sizes, 8 inch to 36 inch. Outlets from 200 cfm to 15,500 cfm.



### SQUARE DIFFUSER

Also 2-way, 3-way and 4-way square and rectangular ceiling outlets. From 400 cfm to 20,000 cfm capacity.





## Binks Manufacturing Company

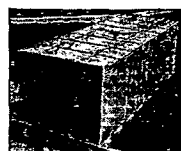
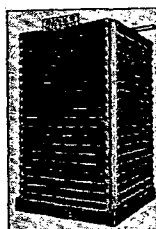
3130-36 Carroll Ave., Chicago 12, Ill.

Representatives in all principal cities

Water cooling systems and nozzles . . . a size and type for every purpose

### Binks atmospheric spray cooling towers

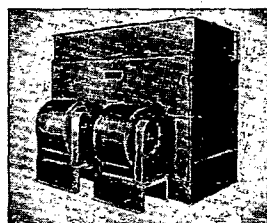
Small sizes, in a variety of standard units with capacities ranging from 10 to 125 gpm—larger units handle from 600 to 1200 gpm. Special designs furnished in sizes of exceptionally large capacity. Standard tower capacity and temperature performance are based on nozzle pressure of 7 lbs per sq in. Ask for *Bulletin 312*



Atmospheric cooling towers, Type "S"

### Binks blower type induced draft cooling towers

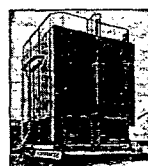
The squirrel cage blower provides extremely quiet operation. Available in single or multiple types, capacity range from 9 to 800 gpm of cooling water. Ask for *Bulletin 477*.



Blower type towers, Type "BB"

### Binks steel cased induced draft cooling towers

Towers of this type are of the spray filled or deck filled type—made in 20 standard sizes of sq ft rated area. Larger models are engineered to specification. Air propulsion assemblies for either type can be arranged for V-belt or reduction gear drive, as required. Ask for *Bulletin 333*



Induced draft towers, Types "K-S", "K-W"

### Binks induced draft masonry cooling towers

Engineered for large scale air conditioning systems in towers that harmonize with the architectural features of the building. Spray or deck filled. Ask for *Bulletin 333*



Induced draft towers with masonry walls

### Binks non-clogging Rotojet spray nozzles

Non-clogging Rotojet nozzles are the heart of every Binks water cooling system. They account largely for the efficiency and satisfactory operation of Binks water cooling installations. In addition to cooling tower applications, Binks Rotojet nozzles have found a wide number of uses in brine-spray and quick-freeze refrigerating systems, air washing equipment, metal cleaning and treating machines, chemical plants, etc. Rotojets produce a uniformly fine fluid breakup in a hollow cone pattern. Standard small and medium Rotojet nozzles are machined from brass bar stock, but can be made on special order from monel, stainless steel, or other machinable metals. Large, heavy-duty Rotojet nozzles for use in large cooling towers and spray pond installations, are cast from high quality brass with precision machined threads and orifices. These nozzles may be cast in other metals for special purposes.

### Binks small and medium capacity Rotojet nozzles

To fit  $\frac{1}{8}$  to  $\frac{3}{4}$  in. pipe connections. Regularly supplied in brass, with male or female threads, as specified. Discharge orifices are available over a considerable range for each size. Rotojet nozzles of this type are designed on the side inlet whirl chamber principle, which produces a fine fluid breakup and a uniform spray pattern.



### Binks heavy-duty Rotojet nozzles

To fit 1 to  $2\frac{1}{2}$  in. pipe connections. Female threads only. Discharge orifices available in various sizes, from  $\frac{3}{16}$  in. to  $1\frac{1}{4}$  in. The totally unobstructed involute type of whirl chamber produces a uniformly fine water breakup at low pressures (5 to 7 lbs).



### Binks Spra-Rite nozzles

Produce a solid mass cone spray pattern. Small sizes for  $\frac{1}{4}$  to  $\frac{3}{4}$  in. connections are widely used for air washing, cooling, brine refrigeration, rapid evaporation processes, filtering systems, chemicals, etc.



### Binks large capacity Spra-Rite nozzles

To fit 1 to 3 in. connections meet a variety of heavy-duty uses in blast furnace gas washers, vibrating and revolving screen coal and gravel washers and water cooling.



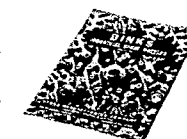
### Binks pneumatic atomizing nozzles

Series 50 nozzles are designed for use wherever conditions of controlled humidity must be maintained, as in the storage of perishable products, paper storage and printing plants, textile mills, greenhouses, etc. Nozzles of all brass construction deliver round or flat spray and are designed for use with automatic siphon or pressure feed installations.



### Free technical bulletin and engineering service

Binks 40 page *Bulletin No. 5600* contains a wealth of useful information for anyone specifying spray nozzles for air conditioning, refrigeration, humidifying, heating and ventilating, or similar heat transfer processes. Nozzles shown above and all other nozzles in Binks line are illustrated and described. Data given include nozzle dimensions, capacities and spray angles. Cutaway drawings explain nozzle operation in many cases. "Blue print" drawings show installation details for heating and cooling uses where this information is required. Write for a free copy without obligation.



Binks engineering service in planning and installing cooling systems is available without obligation or cost to architects, heating and ventilating engineers and builders.



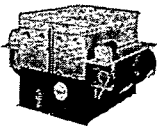
## Baltimore Aircoil Company, Inc.

2615 Mathews Street  
Baltimore 18, Maryland

Manufacturers of Evaporative Condensers and Cooling Towers

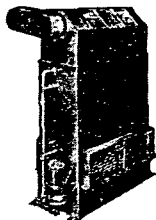
B. A. C. Evaporative Condensers and Cooling Towers are rigidly built for long, trouble-free service. Casings are of galvanized steel construction throughout. Galvanized steel Cooling Tower surface is designed for long and efficient operation.

The above basic construction is further protected against corrosion by the use of B. A. C. Zinc-Chromatized Aluminum Paint and Special B. A. C. Mastic. These finishes have proven through years of research and field testing to be outstanding in corrosion resisting and long wearing properties.



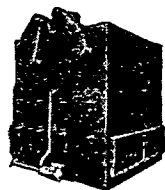
Model "MC"

Model "MC" Evaporative Condenser: (Pat. Pending) Centrifugal fan type . . . indoor or outdoor installation . . . Freon or Ammonia . . . Capacities: up to 350 TR.



Model "U"

Model "U" Evaporative Condenser: Centrifugal fan type . . . indoor or outdoor installation . . . Freon or Ammonia. Capacities: up to 100 TR.



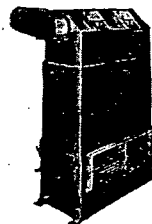
Model "UL"

Model "UL" Evaporative Condenser: Centrifugal fan type . . . indoor or outdoor installation . . . Freon or Ammonia. Capacities: 105 to 300 TR.



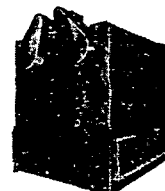
Model "MT"

Model "MT" Cooling Tower: (Pat. Pending) Centrifugal fan type . . . indoor or outdoor installation . . . Capacities: up to 400 TR.



Model "UT"

Model "UT-1" Cooling Tower: Centrifugal fan type . . . indoor or outdoor installation. Capacities: up to 100 TR.



Model "LT-1"

Model "LT-1" Cooling Tower: Centrifugal fan type . . . indoor or outdoor installation. Capacities: 115 to 240 TR.

## FLUOR PRODUCTS COMPANY

A Division of The Fluor Corporation, Ltd.  
12000 East Washington Boulevard, Whittier, California

Manufacturers of Counterflow Mechanical Draft Cooling Towers—Aerator Natural Draft Cooling Towers

SALES OFFICES AND REPRESENTATIVES IN: BIRMINGHAM, BOSTON, BUFFALO, CHICAGO, DENVER, DETROIT, HOUSTON, LOS ANGELES, MINNEAPOLIS, NEW YORK, PHILADELPHIA, PITTSBURGH, SAN FRANCISCO, TULSA.

ASSOCIATES: FLUOR CORPORATION OF CANADA, LTD., TORONTO, CALGARY, HEAD-WRIGHTSON PROCESSES, LTD., LONDON, ENGLAND

Thirty-four years of intensive development work in research, design, fabrication and erection of cooling towers enable Fluor to offer both natural draft and mechanical draft cooling towers with guaranteed performance, quality construction, and long-life service.

### COUNTERFLOW MECHANICAL DRAFT COOLING TOWERS

**DESIGN:** Counter-flow principle of design which enables the greatest possible utilization of available driving force for cooling. Available in a variety of distribution systems, tower heights, and arrangements. Exterior appearance designed to complement modern plants and buildings.

**PERFORMANCE:** Efficient counter-flow principle provides economy cooling for all services. Costs studies made on individual design conditions dictate the type of tower to be offered from the many available designs.

**MAINTENANCE:** Decking withstands repeated washing and cleaning and the abuse of removing and replacing. Enclosed distribution system eliminates algae growth. Stainless steel fan blades support a man's weight at their tips. Heavy-duty, precision gear units are designed specifically for the conditions peculiar to cooling tower operation.

**MANUFACTURE:** Completely prefabricated. Tower structure based on 4 in. x 4 in. members with fan and gear supported on structural beams. Two-inch redwood in fan deck and stack. Internal gusset plate and bolt-type structural joints take both tension and compression loads. Over 250 tower sizes and combinations are furnished from only 258 prefabricated parts to enable fast delivery and erection.

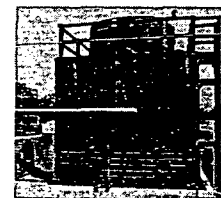
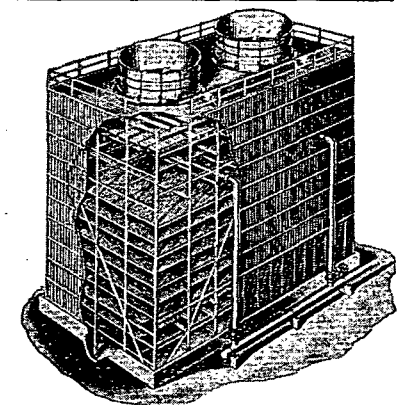
### FLUOR COOLING TOWERS FOR AIR-CONDITIONING—

#### REFRIGERATION SERVICE

The new FLUOR SERIES L.H. is a small, compact cooling tower designed expressly for the air-conditioning and refrigeration industries. The height of the top deck above basin is less than eleven feet on all models. This low height is accomplished by the use of extended surface packing, and the advantages of counter-flow cooling are maintained. Construction is normally of Select Heart and Clear All Heart redwood with

sheathing of double-walled redwood or inner redwood with asbestos cement board outer.

Ten different models are available ranging from 150 to 1500 tons of refrigeration. This "package unit" meets the same high standards of performance, quality of construction, prefabrication and long-life service that are embodied in the larger Fluor Counterflow Towers. Write for Details.



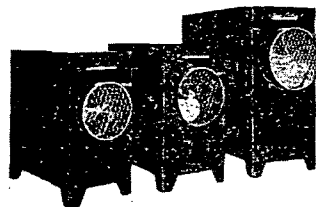
Be Sure  
with Fluor

## E. D. Goodfellow Co., Inc.

Memphis, Tennessee

### Good-Fellow COOLING TOWERS

**GOOD-FELLOW RS Series:** This series is suitable for residential application. Their compact size and extremely quiet operation make them suitable for this type of application. They are shipped completely assembled with lifetime lubricated, totally enclosed motor. *Bulletin PF56-1.*

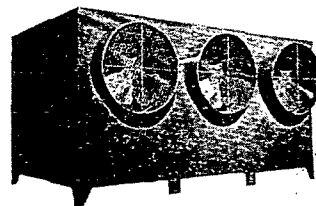


RS Series

**GOOD-FELLOW PF Series:** These models are manufactured in tonnage from 8 to 100 TR. All sizes of this series are designed to withstand a wind pressure of 30 lb per sq ft. Large diameter, slow speed fans produce efficiency and quiet operation. *Bulletin PF56-1.*

Select Redwood fill is used in both the RS and P series. Salt and acid resistant mastic coating spray applied to the interior assures complete corrosion resistance. Normally shipped completely assembled, they can be separated for ease of installation and rigging.

The PF series conform to Military Specification MIL-T-16278B for Type 2, Style 2, induced draft cooling towers.

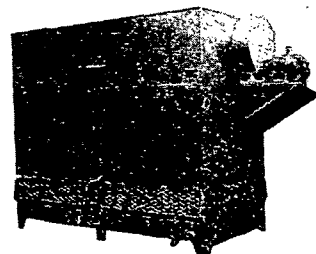


PF Series

**GOOD-FELLOW CF Series:** These models are produced in capacities from 2 to 100 TR. They are available with our standard corrosion resistant finishes or hot-dipped galvanized (after fabrication). Standard units have double air inlet and vertical discharge. Front or rear horizontal discharge and/or front or rear air inlet are available on order. This series is available with pump and motor mounted for uni-drive operation or with fan motor only, or with separate arrangement for close-coupled pump mounting. These models are leakproof. Models 15 tons and larger are constructed in three sections to facilitate erection and installation. They are normally shipped completely assembled.

The CF series conform to Military Specification MIL-T-16278B for Type 2, Style 1, or Style 2, induced draft cooling towers.

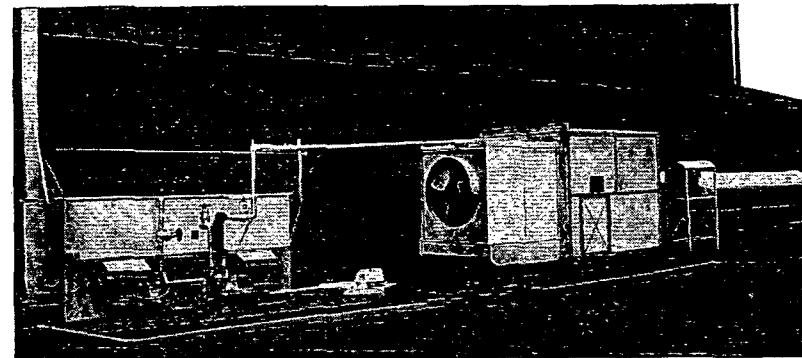
We believe the CF series is one of the most versatile types of cooling tower available. *Bulletin CF56-1.*



CF Series

## Havens Structural Steel Company

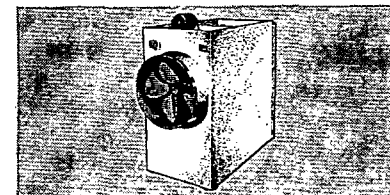
1713 Crystal Avenue • Kansas City, Missouri



**HAVENS TESTING TOWER . . .** This 80-ft testing laboratory is shown accurately measuring air quantity, water quantity and temperatures of a 50-ton Havens Cooling Tower for exacting tower performance. All Havens Towers are given this same rigid test, and a certified guarantee covers all phases of performances.

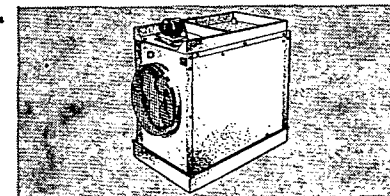
### HAVENS 2 TO 10 TON WRAPAROUND

. . . A small, economical tower that is ideal for light industrial and home use. Complete, lightweight and constructed for rugged service, it is furnished with combination motor cover and belt guard as are all Havens Towers. Lined inside and out with new HAVENS-COAT, it is guaranteed to withstand the corrosive effects of weather, salt air, water and chemicals.

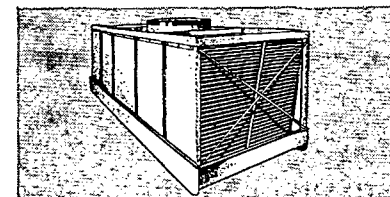


### HAVENS 5 TO 60 TON KNOCK-DOWN

. . . Shipped assembled, this tower may be disassembled in a matter of minutes for installation in inaccessible places. Designed for medium size installations, it is constructed of heavy gauge steel sheets and select all heart California redwood and is, of course, lined inside and out with HAVENS-COAT.



**HAVENS 60 TO 200 TON . . .** A heavy duty tower in a completely new design that does a tremendous job for large installations. A unique bearing design cuts maintenance time and costs. The rugged construction of this tower plus HAVENS-COAT means years of lasting service.



**ALL HAVENS COOLING TOWERS** are available with erection yokes at no extra charge for rapid one-piece installation.

**WRITE FOR FREE BOOKLET GIVING COMPLETE DETAILS ON ALL HAVENS COOLING TOWERS**



## Halstead & Mitchell

Bessemer Bldg., Pittsburgh 22, Pa.

Plant: Zelenople, Pa.

One of the world's largest manufacturers of Counter-Flow, Water-Cooled Condensors

### HALSTEAD & MITCHELL COOLING TOWERS

The Halstead & Mitchell cooling tower saves and re-uses over 95 per cent of the cooling water used in an air-conditioning and refrigeration system. It does this by saving the thousands of gallons of water which would normally be wasted to the sewer each month by the conventional condensing system.

This economy of operation is one consideration. Waste of water is a second. With water tables falling throughout the country, many municipalities now prohibit wasting air conditioning cooling water, and Halstead & Mitchell cooling towers meet all local specifications in areas where their use is mandatory.

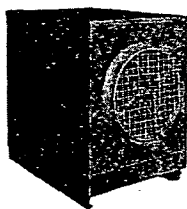
### H & M COMMERCIAL-INDUSTRIAL COOLING TOWERS

Halstead & Mitchell's WT and CT cooling towers are designed in a range of sizes from 5 to 60 tons specifically for industrial and commercial applications. Halstead & Mitchell makes cabinets of both 10-gauge and 14-gauge steel as a part of its regularly scheduled production, and all of these units are protected by the 20-Year Guarantee on the wetted deck surface against rotting or fungus attack. The *Protected Steel* concept also adds many vital years of life.



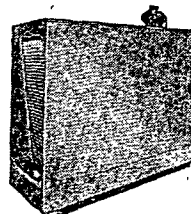
### H & M RESIDENTIAL COOLING TOWER

The Halstead & Mitchell Type RE residential cooling tower is for home use. This H & M tower incorporates major features found in larger cooling towers. H & M residential cooling towers are protected by the 20-Year Guarantee on the wetted deck surface against rotting or fungus attack. Deep pitch, 4-bladed fans insure quiet, efficient operation. The steel is specially protected, and fans are made of stainless steel. Capacities are 2 through 7½ tons.



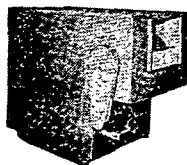
### H & M TAKE-APART COOLING TOWER

This cooling tower can be taken apart for installation in difficult places, and can be moved easily to roof tops without the expense of riggers, or down narrow stair wells for basement installations. The K-Series of Halstead & Mitchell take-apart cooling towers is specifically designed for this feature. All of the important long life advantages have been built into the Take-Aparts. Capacities are 5 through 60 tons.



### H & M CENTRIFUGAL COOLING TOWER

Halstead & Mitchell's centrifugal fan cooling tower for home, hospital and other quiet applications can be relied on to meet the most stringent municipal decibel codes. These Type KB towers feature the 20-Year Guarantee on the wetted deck surface against rotting or fungus attack, as well as the *Protected Steel* concept which adds many years of life. They may be installed both indoors and out and are also of the Take-Apart design. Centrifugal fans are for duct-work installation. Capacities are 5 through 25 tons.



### H & M COOLING TOWER CONSTRUCTION DETAILS

#### 20-YEAR GUARANTEE!

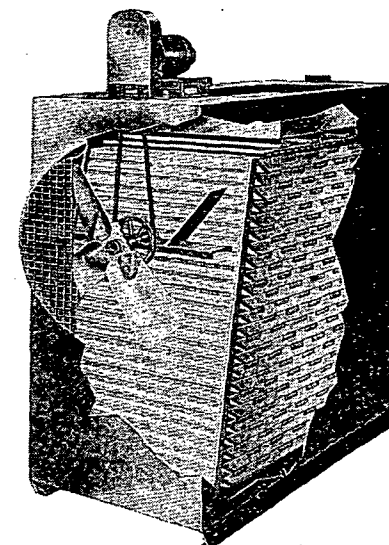
#### ON THE WETTED

#### DECK SURFACE

against rotting or against damage due to fungus attack

#### WETTED DECK SURFACE

Halstead & Mitchell's use of Koppers Pressure-Creosoted wood makes possible a 20-Year Guarantee on the wetted deck surface against rotting or damage due to fungus attack.



Cutaway View, H & M Commercial Cooling Tower

#### MOTOR

Special weather and splash-proof, suitable for operating exposed under all weather conditions. Weather shield for motor pulley and belt on all except residential cooling towers permits operation even under icing conditions.

#### HOUSING

Halstead & Mitchell offers electrically welded sheet-steel cabinets of both 10-gauge and 14-gauge steel. The *Protected Steel* concept controls rusting with hydraulically applied coatings of Vinsynite, Vinyl Zinc and chlorinated rubber.

#### WATER DISTRIBUTION

Efficient gravity-type distributing pan eliminates extra pumping head required on spray type towers, and cuts down windage losses due to atomizing of water. The sump level is continuously and automatically controlled by float. (Note: Pumping head due to tower is represented by height of tower.)

#### DRIVE

Drive shaft is stainless steel. Fan bearings are . . . ball bearing . . . permanently grease sealed and lubricated . . . and protected against water drift. Belt tension is adjustable. RE tower motors are totally enclosed and thoroughly protected against moisture, fans being direct driven.

#### FANS

Deep-pitch, stainless steel, 4-blade fans. Type KB units use centrifugal fans for ultra-quiet operation.

#### COMPLETE ASSEMBLY

For installation in cramped quarters, towers with sectional housings are available. All towers easily accessible for cleaning through inlet in back.

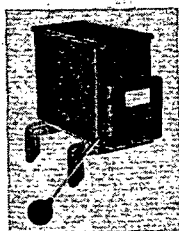
## Heller Laboratories, Inc.

124 Fort Lee Road, Leonia, N. J.

SPECIALISTS IN WATER TREATMENT

Equipment, Chemicals and Service for Control of Scale, Corrosion, Algae and Slime  
Agents in Principal Cities

Heller Laboratories furnishes water treating equipment, analysis service and chemicals for treatment of any cooling water application, large or small. Heller Laboratories' chemicals are tailored to suit individual requirements determined after operating surveys and water analyses are made. Heller Laboratories furnishes treatment control equipment as listed below.



HYDROTROL for accurate concentration control and chemical feeding.

HYDROTROL maintains a desired fixed range of mineral concentration and feeds chemicals in proportion to requirements. HYDROTROL assures good treatment results and saves chemicals and water which are normally wasted when the usual fixed bleed-off method is used to reduce excessive mineral concentration.

Excessive mineral concentration is caused by adding natural minerals, contained in the fresh makeup water, but losing only pure water vapor from the system on evaporation. When mineral concentrations build up too high scale may form. When concentrations are too low corrosion may take place and treatment chemicals are wasted with the bleed-off.

Fixed bleed-off obtained by the usual float valve and overflow arrangement cannot maintain a fixed range of mineral concentration because the evaporation load in a cooling system is not fixed.

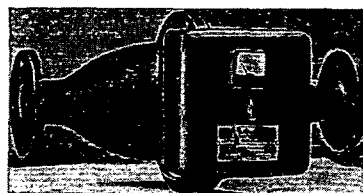
HYDROTROL does maintain a fixed range of mineral concentration and controls bleed-off and chemical feed in proportion to evaporation by means of differential level regulation. HYDROTROL works as follows: When a predetermined, fixed, adjustable amount of water is evaporated a fixed adjustable amount of water is bled off, then a fixed adjustable amount of chemical is added while the fresh water is added back to the full operating level.

HYDROTROL is entirely automatic and can maintain accurately a concentration as high as 50 cycles when windage loss is negligible.

HYDROTROL units are available from stock in three sizes: For systems up to 25 ton, 50 ton and 100 ton. Larger sizes are available on order.

HYDROTRON is a patented process and equipment used to apply an electro-physical treatment to control mineral scale formation. It is used for cooling systems working under difficult operating conditions where chemicals or softening are not practical or too costly for control of scale formation.

Water is treated electro-physically in the HYDROTRON unit by subjecting the water to a closely controlled and proper range of voltage while the water is brought into intimate contact with a special electrode. This treatment brings about a change in nucleation and crystal habit so that after treatment, when saturation is reached, hardness minerals are precipitated as a fine soft sludge instead of a cement-like coating on heat exchange surfaces. The sludge formed is removed by normal blowdown or flushing.



Hydrotron for Scale Control

The HYDROTRON Process is applicable for treatment of water for use in cooling systems, boilers, condensers, hot water generators and many other types of heat exchange equipment where scale forms due to concentration of hardness minerals.

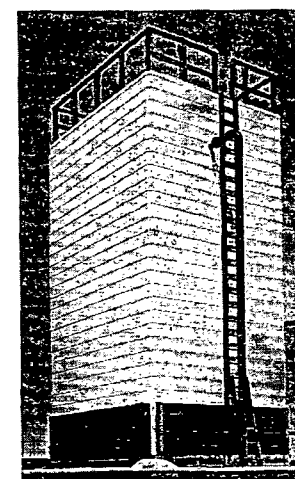
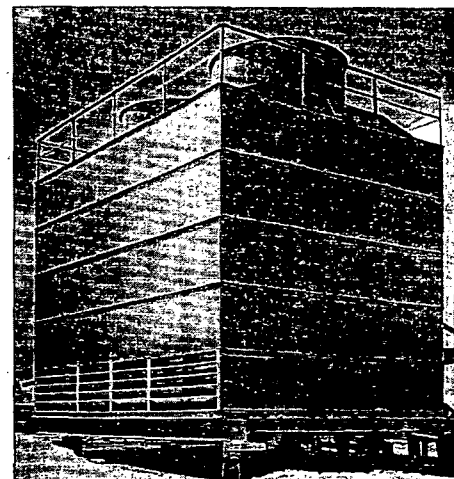
HYDROTRON equipment requires very little attention or maintenance, gives life time service and saves the cost of chemicals used for scale control. HYDROTRONS are available from stock in sizes to treat up to 10,000 gph, larger sizes are available on order.

## Lilie-Hoffmann Cooling Towers, Inc.

Exclusive Builders of Cooling Towers Since 1898

1450 So. Vandeventer Ave., St. Louis 10, Mo.

Two Modern Plants—St. Louis, Mo., and Plainview, Texas

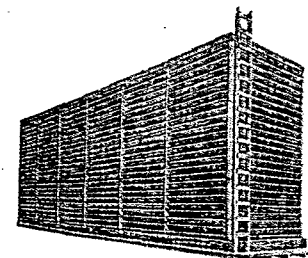


### INDUCED DRAFT TOWERS

New type filling reduces static pressure. Filling consists of slats, assembled in grids. Slat arrangement insures maximum wetted surface, minimum pressure drop of air flowing through tower packing, and uniform distribution of water and air over the entire effective area within the tower. Gravity distribution system requires only one riser pipe. Teco timber connectors develop 100 per cent working stress of members. Normally constructed of selected California redwood. All fans furnished by Lilie-Hoffmann are P.F.M.A. tested and certified.

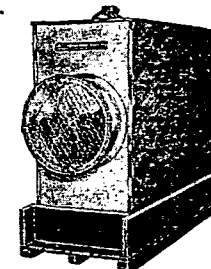
### ATMOSPHERIC SPRAY TYPE

Generally offered in capacities up to 3000 gpm. Distribution by galvanized pipe header with smaller lateral arms, equipped with non-clogging spray nozzles. Water atomized as finely as possible. Sides and ends of towers equipped with narrow louvers, which fit into mast slots—no nails required. Recommended where cost is prime factor; and close approach to wet bulb is unnecessary.



### HORIZONTAL DRAFT (Package Type)

Designed specifically for 4 to 100 ton refrigeration installations. Structure and basin of California Redwood. Sides of corrugated and flat cement asbestos sheets with stainless steel trim; no painting required. Distribution of splash gravity type, non-sag, non-warp removable filling.

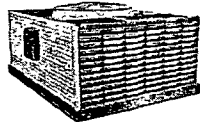


## The Marley Company

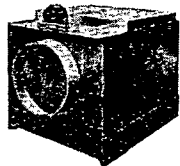
222 W. Gregory, Kansas City 14, Missouri

Representatives in All Principal Cities (Consult Classified Phone Directory)

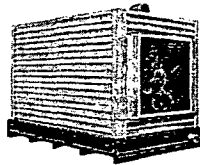
Water Cooling Towers of All Types and Capacities.



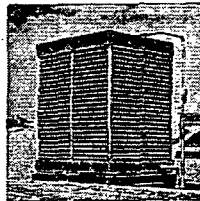
**MARLEY DOUBLE-FLOW AQUATOWER** . . . Series 8 and 12 of this "low silhouette", low pumping head cooling tower fill every intermediate capacity cooling requirement for air conditioning and refrigeration. They combine the efficiency of Marley Double-Flow design with the simplicity of Marley Aquatowers. Mechanical equipment has been field proved in thousands of Marley industrial installations. Available with either wood or steel structure for easy job erection, for either single or multi-cell installations. Write for *Bulletin DFA-56*.



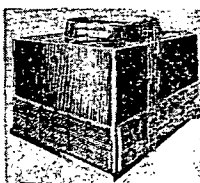
**MARLEY AQUATOWER** . . . Available in a complete range of 11 sizes, rated for servicing from 3 to 60-tons of air conditioning or refrigeration. Thousands of steel packaged units have proved themselves in years of maintenance-free operation. They are stocked by dealers throughout the country—are shipped completely assembled and require no field construction. Large units may be readily disassembled for easy handling. Write for *Bulletin AQ-56*.



**MARLEY FORCED-DRAFT WOOD AQUATOWER** . . . This new series of cooling towers, specifically designed to combat corrosive atmosphere and water, is produced in 10 models for services of 3 to 50 tons. It utilizes the forced-draft, cross-flow and vertical discharge principles. Because air discharge is vertical, these towers are applicable to many restricted locations. Tower structure is all redwood with heavy asbestos cement board or wood casing; fan and mechanical equipment are located out of hot, humid air stream. Small models are factory assembled; larger models are shipped disassembled. Write for *Bulletin WAQ-56*.



**MARLEY SPRATOWERS** . . . These heart quality redwood cooling towers are available in two series, one designed primarily for air conditioning and refrigeration applications up to 50 tons and a series of larger towers which are built in standardized units for larger capacities and are also available with atmospheric sections for cooling of jacket water, oils and gases. Write for *Bulletin ST-56*.



**MARLEY COUNTER-FLOW SERIES, STEEL AND WOOD** . . . This series of Marley counterflow cooling towers is designed especially for heavy duty air conditioning and refrigeration service wherever appearance is important. The all-steel model (with the exception of corrugated asbestos cement board casing) is designed to meet fire codes in all metropolitan areas. Both the steel and wood models blend well with modern architecture. May be installed with any combination of louvered walls open providing unusual flexibility and maximum utilization of usable space. Write for *Bulletins CS-56 and CW-56*.

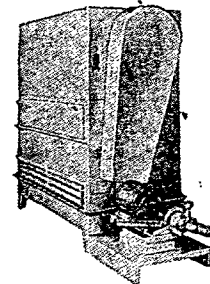
**MARLEY CROSS-FLOW** . . . For large capacity industrial cooling, Marley offers 3 towers that utilize the patented Marley Cross-Flow principle—The Double-Flow, Twin-Flow and Single-Flow. Write for *Bulletin CF-56*.

## Marlo Coil Co.

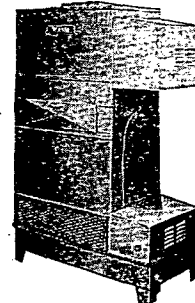
6135 Manchester Ave., St. Louis 10, Mo.

Manufacturers **MARLO-HEAT TRANSFER** Equipment  
Since 1925

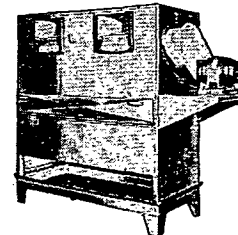
Industrial Coolers—Unit Coolers—Evaporative Condensers—Low Temperature Units—Air Conditioning Units—Heating and Cooling Coils—Cooling Towers—Diesel Engine and Oil Evaporative Coolers.



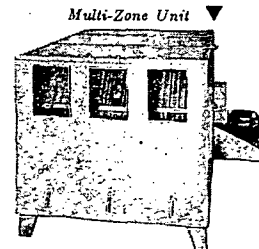
Cooling Towers



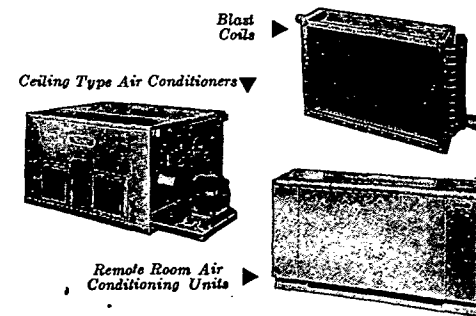
"Thrift-Tower"



Industrial Coolers



Multi-Zone Unit



Blast Coils

Ceiling Type Air Conditioners

Remote Room Air Conditioning Units

**COOLING TOWERS**—industrial and commercial—20-100 tons—induced draft, wetted deck surface, water spray—out-door-indoor. "THRIFT-TOWER"—smaller adaptation for residential, light commercial use—2-16 tons. Write for *Bulletins 406, 6154*.

**CEILING TYPE AIR CONDITIONING UNITS**—cooling, heating, dehumidifying, humidifying. 14 sizes—1 to 175 tons—480 to 37,200 cfm. Ceiling suspended, floor types. Write for *Bulletin 3055*.

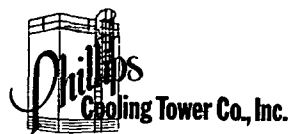
**INDUSTRIAL COOLERS**—15 unit sizes—1,000 to 26,400 cfm—blow-through and pull-through type. Write for *Bulletin 412, Section 40, pp. 1-6*.

**REMOTE ROOM AIR CONDITIONING UNITS**—permit individual climate selection. No ductwork, only simple piping needed. Floor and ceiling type units. Write for *Bulletin 3355*.

**BLAST COILS**—air conditioning, industrial refrigeration, heating. Any material—all refrigerants—every application. Pressure-expanded staggered tubes, continuous plate-type fins. Write for *Bulletins 396-A, 495*.

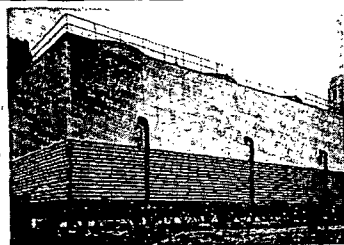
**MULTI-ZONE UNIT**—complete winter and summer functions—individual zone control—1,300 to 37,000 cfm. Write for *Bulletin 3155*.



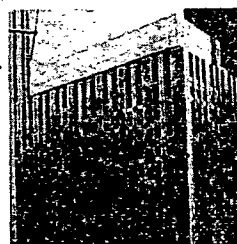


220 Dupont St., Brooklyn 22, N. Y.

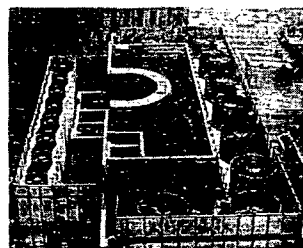
Phillips Standard Induced Draft Counterflow cooling towers are designed in Steel and Corrugated Transite, Redwood and Corrugated Transite, or all Redwood in sizes from 150 tons upward. Transite Siding is attached to tower frame by use of Stainless Steel fastenings to prevent staining or deterioration. All steel in Standard Towers is *hot dipped galvanized after fabrication*. All California Redwood is of Select Heart grade. The slip-fit fill construction and box type drift eliminators are extremely efficient and produce maximum cooling with minimum water loss. Fans are of Stainless Steel or Cast Aluminum with low tip speed to reduce sound level to a minimum. Right angle worm gear drives having tapered roller bearings and forced feed lubrication are used to assure long trouble-free life. Weatherproof motors of standard makes are supplied on all models. Bulletins PC-211 or 212.



Phillips Standard Induced Draft Counterflow



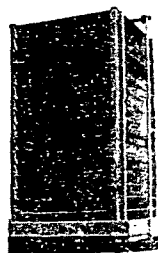
Phillips Special Steel &amp; Transite



Phillips Special Steel and Transite

Phillips Spracoolers or Natural Draft Cooling Towers are designed in Steel and Transite, or California Redwood. This type of tower is available in sizes up to 150 tons. It is particularly adaptable where space is not limited and air circulation is not restricted. Bulletin PC-209.

Phillips Spray Ponds and Spray Pond Fences are available in all sizes and arrangements. Bulletin PC-213.



Phillips Spracooler or Natural Draft Cooler

## Monarch Manufacturing Works, Inc.

2509 E. Ontario St., Philadelphia 34, Pa.

SPRAY NOZZLES FOR WATER AND OIL

### NON-CLOG AIR WASHER NOZZLES

produce an exceptionally efficient, evenly distributed hollow cone spray. Single large tangential inlet to swirling chamber minimizes any possibility of clogging. Also available in  $\frac{3}{8}$  in. to 1 in. pipe sizes inclusive, and of Brass, Stainless and Monel.

Capacities: Gallons per Hour

| Pipe/Orifice     | Lead             | Lbs Operating Pressure |      |      |      |      |      |
|------------------|------------------|------------------------|------|------|------|------|------|
|                  |                  | 10                     | 20   | 30   | 40   | 60   | 100  |
| 60               | 60               |                        |      | 2.9  | 3.3  | 4.0  | 5.1  |
| 61               | 61               |                        | 4.0  | 5.0  | 5.5  | 7.0  | 8.7  |
| 61               | 53               | 4.4                    | 6.2  | 7.5  | 8.3  | 10.3 | 13.0 |
| 53               | 53               | 5.8                    | 8.2  | 9.8  | 10.9 | 14.1 | 17.3 |
| 49               | 49               | 9.1                    | 11.1 | 13.2 | 15.0 | 19.5 | 24.6 |
| $\frac{3}{32}$ " | $\frac{3}{32}$ " | 11.8                   | 16.6 | 20.4 | 23.4 | 29.0 | 36.5 |
| $\frac{1}{4}$ "  | $\frac{1}{16}$ " | 19.5                   | 27.6 | 33.3 | 39.1 | 49.0 | 60.0 |
|                  | $\frac{3}{32}$ " | 24.3                   | 34.6 | 42.8 | 50.0 | 64.0 | 78.5 |
|                  | $\frac{1}{8}$ "  | 31.5                   | 45.1 | 57.0 | 64.1 | 81.9 | 105  |
|                  | $\frac{9}{32}$ " | 52.2                   | 75.0 | 92.5 | 109  | 138  | 189  |
|                  | $\frac{5}{16}$ " | 78.0                   | 112  | 138  | 163  | 205  | 257  |
|                  | $\frac{3}{8}$ "  | 82.0                   | 121  | 152  | 180  | 225  | 300  |
|                  | $\frac{7}{16}$ " |                        |      |      |      |      |      |
|                  | $\frac{1}{2}$ "  |                        |      |      |      |      |      |



Fig. 651

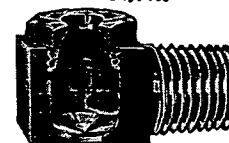


Fig. 659

### AIR CONDITIONING AND OIL BURNER NOZZLES

Water Capacity in Gallons per Hour



Fig. F-30

| Nozzle No. | Lb Operating Pressure |      |      |      |      |
|------------|-----------------------|------|------|------|------|
|            | 25                    | 40   | 60   | 80   | 100  |
| 1.35       |                       | .57  | .69  | .83  | .92  |
| 1.65       |                       | .75  | .89  | .99  | 1.12 |
| 2.00       |                       | .94  | 1.14 | 1.28 | 1.40 |
| 2.50       |                       | 1.13 | 1.45 | 1.64 | 1.86 |
| 3.00       | 1.03                  | 1.39 | 1.62 | 1.85 | 1.95 |
| 3.50       | 1.36                  | 1.77 | 2.11 | 2.46 | 2.80 |
| 4.00       | 1.56                  | 2.00 | 2.42 | 2.77 | 3.16 |
| 4.50       | 1.85                  | 2.32 | 2.77 | 3.21 | 3.68 |
| 5.00       | 2.20                  | 2.88 | 3.57 | 4.09 | 4.59 |
| 5.50       | 2.22                  | 2.96 | 3.75 | 4.31 | 4.78 |
| 6.00       | 2.55                  | 3.35 | 4.01 | 4.78 | 5.23 |
| 7.00       | 2.90                  | 3.91 | 4.60 | 5.17 | 6.00 |

Produce finest breakup possible with direct pressure only. Capacities above are on water. "Nozzle No." is capacity on 34 second Saybolt viscosity oil at 100 lb pressure. Larger sizes up to 60.00 gph and smaller sizes down to 0.60 gph.

Furnished of all Brass for Water—Stainless Steel tip and disc for Oil. Standard with  $\frac{3}{8}$  in. or  $\frac{1}{4}$  in. female pipe Brass adapter and Monel gauze strainer.

### SPRAY POND NOZZLES

For recooling condenser water, etc. Operate on pressures from 5 lb upward. Made of Cast Red Brass and in pipe sizes 1 in.,  $1\frac{1}{2}$  in., 2 in., and  $2\frac{1}{2}$  in. Capacities from 4.1 to 88 gpm at 7 lb pressure.

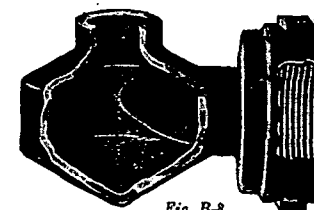


Fig. B-3

Write for Detailed Catalogs





## ACME INDUSTRIES, INC.

JACKSON, MICHIGAN, U. S. A.

Manufacturers of Quality Air Conditioning and Refrigeration Equipment since 1919

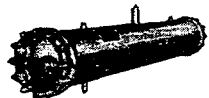
37 years experience stands behind these ACME products

Since 1919 Acme has been building units to serve the air conditioning and refrigeration field. They have experimented with thousands of models and installations. Today, Acme has a complete line of commercial refrigeration and air conditioning equipment. Specify Acme on your installations.



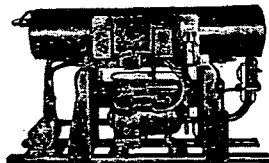
### ACME DRY-EX WATER CHILLERS

For cooling water, brines, and other fluids by direct expansion of the refrigerant. Capacities from 5 to 300 ton.



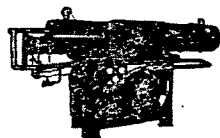
### FREON and AMMONIA CONDENSERS

The standard of the industry. Enough production combinations to assure you of the most efficient operation available. Capacities from  $\frac{1}{2}$  to 700 ton.



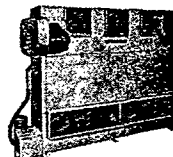
### THE FLOW-COLD LINE

A factory assembled and tested packaged liquid chiller designed for industrial process temperature control and air conditioning. Used as a heat pump for both heating and cooling. Capacities—3 through 20 ton.



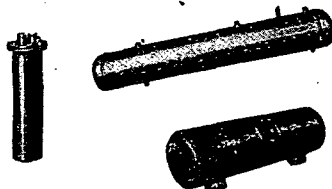
### FLOW-THERM LIQUID CHILLER

Complete, compact, packaged units of advanced design for air conditioning, heat pump and liquid cooling applications. Proven Acme components pre-piped, tested and ready for operation. With compressor or without. Capacities—20 through 300 ton.



### EVAPORATIVE CONDENSERS and COOLING TOWERS

Solid, sturdy, dependable. All fabricated steel parts are hot-dip galvanized after fabrication assuring long life. Prime surface coils or specially designed Acme Pak for Freon or Ammonia installation. Capacities from 2 to 150 ton.



### HEAT EXCHANGERS, LIQUID RECEIVERS, OIL SEPARATORS

Freon suction and liquid line heat exchangers with capacities from 3 to 200 tons; more than 70 standard sizes of liquid receivers for Freon, Ammonia, or other refrigerants; and a complete line of Freon or Ammonia Oil Separators for  $\frac{1}{4}$  to 100 ton systems.

Write for catalogs and more information on any ACME product.

## AEROFIN CORPORATION

101 Greenway Avenue  
Syracuse 1, N. Y.

## AEROFIN

Standardized Light-weight Heat Exchange Surface

There is a factory-trained Aerofin application and service engineer located near you to give you prompt service. Write, wire or phone the factory.

Aerofin is the modern Standardized Light-Weight Encased Fan System Heating and Cooling Surface originated by Fan Engineers to meet the present and future requirements of this highly specialized field. All Standard AEROFIN Units are furnished as completely encased Units, ready for pipe and duct connections. The patent casings are built of pressed steel and are exceptionally strong and rigid, protecting the Unit from all the strains of pipe connections and expansion or contraction in service. The casings are flanged on both faces, top and bottom, and template punched for bolting together adjacent Units, or for duct connection.

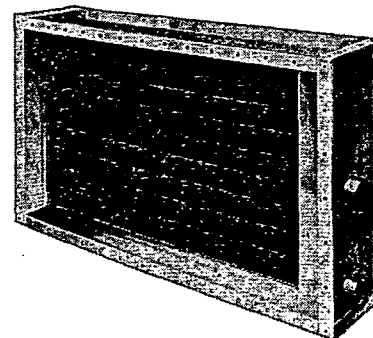


Fig. 1

Aerofin Non-freeze heater (Fig. 1) is non-freeze, non-stratifying spiral fin coil built into casing for air conditioning

units or for installing in ducts. May be installed either horizontally or vertically. Used on any two-pipe steam system for preheating or reheating. Modulating control on preheaters.

Available in 13 lengths and 3 widths, from net face area of 2.76 sq ft to 26.28 sq ft.

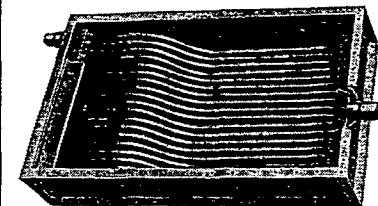


Fig. 2

Flexitube Aerofin (Fig. 2) is distinguished from all other developments by its off-set tubes, so arranged as to absorb all expansion and contraction strains.

Headers—Steel.

Tubing— $\frac{5}{8}$  in. O.D. copper, admiralty or aluminum.

Joints—Where admiralty or copper tubes are used together with bronze or steel headers tubes are brazed to headers. Where both aluminum tubes and headers are used tubing is welded to headers.

Casings—Copper, aluminum or galvanized iron.

Design—Constructed with headers on opposite ends making possible installation of units with tubes horizontal or vertical.

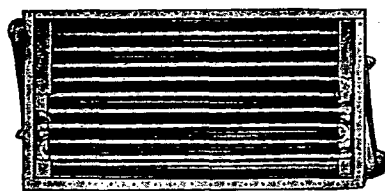


Fig. 3

Universal Aerofin (Fig. 3) is distinguished by its "S" bend construction of tubing, units designed with steel headers on opposite ends, the ends of the "S" bends being connected thereto by compression nuts, the bends taking care of the expansion and contraction of the tubing.

Recommended where close control is desired.

Headers—Pressed steel.

Tubing—1 in. O.D. copper or admiralty.

Casings—Copper, aluminum or galvanized iron.

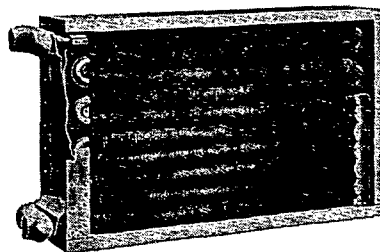


Fig. 4

Aerofin Heavy-Duty Industrial Heating Coil (Fig. 4) for use where extra-rugged coil is needed for close control. Steam pressures from 25 to 450 lb gauge; temperatures to 550 F.

Headers—Pressed steel.

Tubing—1 in. O.D. heavy copper.

Casings—12-gauge galvanized iron.

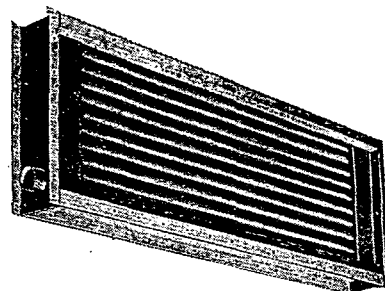


Fig. 5

Booster Aerofin (Fig. 5)—straight tube type, single pass construction for pressures from 1 to 200 lb gauge.

Headers—steel.

Tubings— $\frac{5}{8}$  in. O.D. copper.

Casings—copper, aluminum or galvanized iron. Recommended where small coils are needed or to raise the air temperatures in branch ducts.

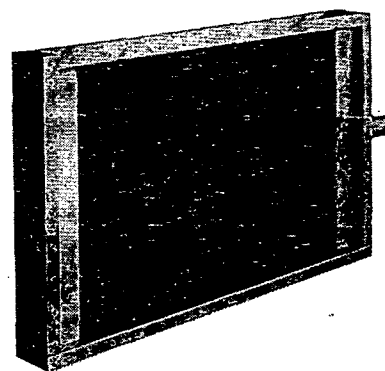


Fig. 6

Narrow Width Aerofin: (Fig. 6) recommended for water cooling or for flooded Freon systems. Made in straight tubes only with headers on opposite ends, joint between headers and tubing being brazed. Construction similar to Flexitube AEROFIN.

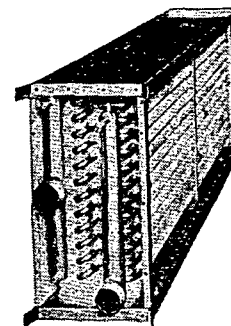


Fig. 7

Aerofin Continuous Tube Water Coils (Fig. 7) are designed for air cooling by circulating cold water through the AEROFIN and air over extended fin surface. Made for either horizontal or vertical air flow.

Tubes and fins are copper, completely tinned with permanent metallic bond between fin and tubes. Headers are made of steel and casings of heavy galvanized iron or copper.

Tested to 250 lb air with coil submerged in water.

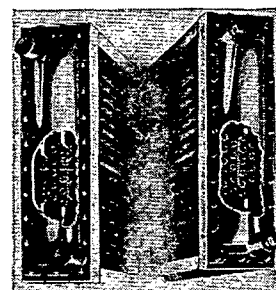


Fig. 8

Aerofin Cleanable Tube Units (Fig. 8) for cooling only made with headers removable to permit cleaning tubes. Recommended for use where sediment or scale forming chemicals are present in the cooling water.

Headers—Fabricated steel.

Tubing—Copper or admiralty.

Casings—Copper or galvanized iron.

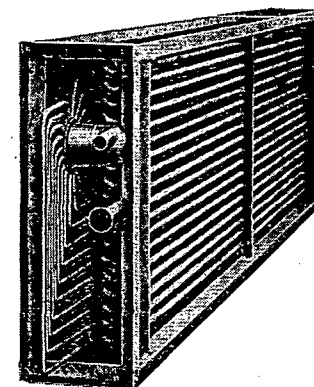


Fig. 9

Aerofin Direct Expansion Units: (Fig. 9) Centrifugal Header Type—For cooling air, using Freon expanded directly into the coil.

#### AEROFIN Sizes

Flexitube: 13 standard lengths, three widths, one and two rows deep.

Narrow: same as Flexitube.

Universal: 17 standard lengths, two widths, one and two rows deep.

Continuous Tube: 13 standard lengths, three widths, 2-3-4-5 and 6 rows deep.

Cleanable Tube: 17 standard lengths, one width, 2 and 4 rows deep.

Direct Expansion: Centrifugal Header—11 standard lengths, three widths, 2-3-4-5-6 rows deep.

Steel Supporting Legs: 18 in. and 24 in. high. Punched same bolt hole centers as standard casings. Quickly attached. No other foundation required.

Sale: AEROFIN is sold only by manufacturers of nationally advertised Fan System Apparatus. List upon request.

Write Syracuse for Heating Bulletin H-45; Direct Expansion Bulletin DE-48-1 on refrigeration type units; Continuous Tube Bulletin C.T. 39-2 for Water Cooling coils; or pamphlet on Cleanable Type Aerofin for cooling.

## The G & O Manufacturing Company

138 Winchester Avenue

New Haven 8, Connecticut



### INDIVIDUAL AND STRIP FIN TUBING

We manufacture a complete line of high efficiency heat transfer surfaces in a wide range of standard sizes with individual square, round and oblong fins.

The use of individual fins permits using fins in groups at intervals along the straight length of any tube for the manufacture of U-bends, continuous return bend, and spirally wound coils. Where space permits, the use of square or oblong fins provides proportionately greater surface than a round fin of a diameter equal to one side of the square or oblong fin.

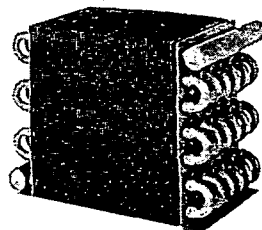
G&O Individual Fin Tubing is available for heating coils of every description, including unit heaters and blast coils, intercoolers, aftercoolers, baseboard radiation, and convactor elements.

### STRIP FIN TUBING

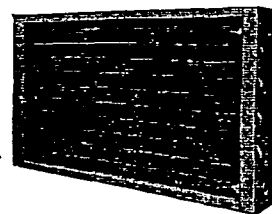
Continuous strip aluminum fin tubing is particularly suited for cooling and air conditioning coils. The lightweight all aluminum construction is of advantage in installation where weight is an important factor. Various fin spacing is available and sections can be stacked to provide any practical number of rows in direction of air flow within the limits of maximum height and width area dimensions.

G & O continuous strip fin coils are produced in two standard sizes:  $\frac{3}{8}$  in. O.D. tubing with  $\frac{1}{8}$  in. wide continuous strip fins, or  $\frac{5}{8}$  in. O.D. tubing with  $1\frac{1}{4}$  in. wide continuous strip fins.

RADIATING ELEMENTS FOR ALL HEAT TRANSFER PURPOSES ARE AVAILABLE IN A WIDE RANGE OF SIZES



Continuous Strip Fin, All Aluminum Cooling Coil



Standard No. 10

Send for Catalog and Price List

1362

## The Patterson-Kelley Company, Inc.

101 Burson Street

New York 17

101 Park Avenue

Philadelphia 3

700 Walnut Street

East Stroudsburg, Pa.

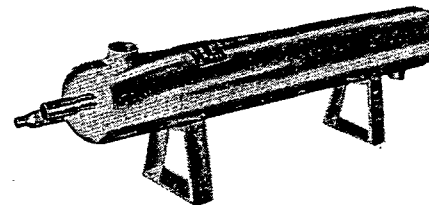
Boston 16

96A Huntington Avenue

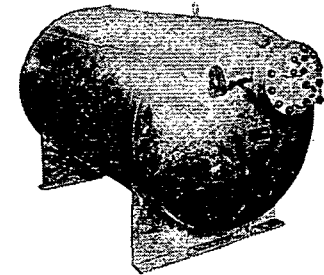
Chicago 4

Railway Exchange Building

Representatives in Principal Cities



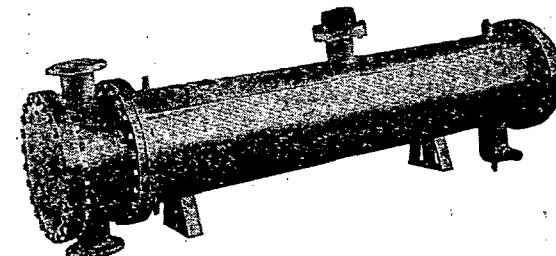
**p-k Balance Loader:** Standard capacities range from  $\frac{1}{2}$  to 50 tons. Shell sizes available from  $4\frac{1}{2}$  in. by  $12\frac{3}{4}$  in. to 14 in. by 90 in. Three types available, depending on application—trombone design, shell and coil, and shell and tube.



**p-k Storage Cooler:** Available in all commercial metals. Sizes range from 24 in. by 48 in. to 60 in. by 192 in. Designed for service where requirements are not constant or where a large volume of fluid must be held in storage for peak load periods.



**p-k Slug Eliminator:** A combination trap and heat exchanger that changes slugs of liquid refrigerant into gas before they reach the compressor. Standard capacities range from  $\frac{1}{2}$  to 60 tons.



**p-k Freon Condensers:** Capacities  $5\frac{1}{2}$  to 410 tons. Shell sizes from 8 in. by 48 in. to 24 in. by 168 in. Two or 4 pass design, built in accordance with ASME code. The integral finned copper tubing is electronically expanded to assure water-tight joints.



**p-k Dry Expansion Freon Cooler:** Catalogued from 2 tons to 232 tons. Shell sizes range from 6 in. by 40 in. to 26 in. by 220 in. Standard units are available in 1 and 2 circuit design arrangements, 3 and 4 circuit arrangements are available on request. Can be constructed of carbon steel, galvanized steel, stainless steel, cupro-nickel, silicon bronze or other alloys.

1363

# Rittling

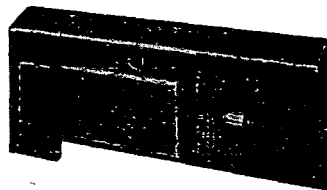
## The Rittling Corp.

103 Kentucky St.  
Buffalo 4, N. Y.

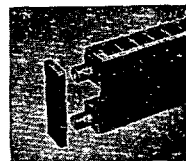
Representatives in Principal Cities  
Warehouses—Buffalo, Albany, Philadelphia, Chicago  
Factories—Hamburg and Brooklyn, N. Y.

Manufacturers of residential and non-residential Baseboard and Finned Tube Radiation, Convector-Radiators, Finned Tube Surface, Unit Ventilators and Air Conditioners, Unit Heaters, Back Draft Dampers, Air Cooled Condensers, etc.

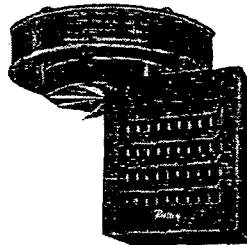
### RITTLING BASEBOARD RADIATION



### RITTLING HEAVY DUTY RADIATION



### RITTLING UNIT HEATERS

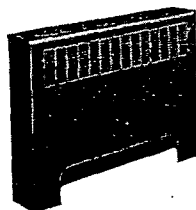


**Rittling Baseboard Radiation.** Complete line of Snap-On and PRE-FAB units for fast installation. Heating element—choice of two tube aluminum finned copper tube or single tube copper tube with steel fins. Write for catalog.

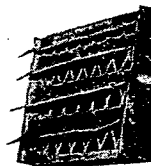
**Rittling Heavy Duty Radiation.** Complete line of heavy duty all-steel or steel finned copper tube units for commercial and industrial use. Flat and sloping top enclosures for wall and baseboard installations. Write for complete catalogs.

**Rittling Unit Heaters.** Horizontal and vertical types. Capacities from 100 to 2000 EDR. Write for catalog.

### RITTLING CABINET CONVECTORS      RITTLING BACK DRAFT DAMPERS



**Rittling Cabinet Conectors (left).** Six standard cabinet styles. Aluminum finned copper tube elements with copper headers for use with steam or forced hot water. Write for catalog giving capacities and dimensions on all sizes.



**Rittling Back Draft Dampers (right).** For high or low velocity. Positive seal. Extremely sensitive, quiet, non-metallic blades. Write for catalog.



### RITTLING UNIT AIR CONDITIONERS

Unit Ventilators for heating and cooling schoolrooms, hotels, hospitals, office buildings, apartment houses and residences. Simplified design and controls give impressive savings on first cost and maintenance. Write for catalog.

## The Rome-Turney Radiator Company

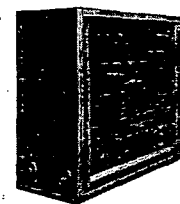
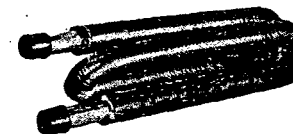
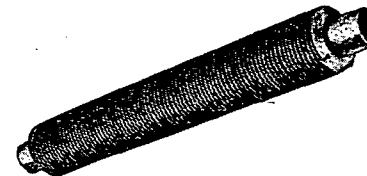
Erie Boulevard, East

Rome, N. Y.



Manufacturers of "Ro-Fin" Extended Surface (continuous helical fin) Tubing for Heat Transfer

### Nearly 100 Sizes of Helical Fin Tubing in Production



Straight lengths up to 30 feet long . . . coils . . . U-bends . . . tube-within-tube coils—sizes suitable for use with standard solder or flare-type fittings. "Ro-Fin" Tubes are adaptable for a wide variety of heat transfer equipment, meet the requirements of the most rigid specifications!

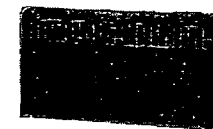
Outside tube diameters from  $\frac{1}{4}$  inch to  $1\frac{1}{2}$  inches, fin widths from  $\frac{1}{8}$  inch to  $\frac{3}{4}$  inch. Number of fins per inch ranges from 3 to 14. "Ro-Fin" tubing is made up in long, continuous lengths to meet customers' specifications. Stainless and other kinds of tubes furnished on special order.

### AIR HEATING AND AIR COOLING CASED COILS

Two foot to ten foot lengths; 3 pace widths, approximately 12 inch, 18 inch, and 27 inch—custom sizes made to your specifications when required.

### ROME CONVECTOR RADIATOR

For heating residential, commercial, or public buildings. Free standing and wall-hung cabinet styles in ten lengths and four depths for steam and forced hot water installations. Non-ferrous fins on copper tube with brass and iron headers.

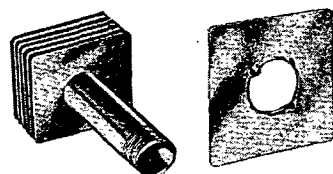


WRITE FOR INFORMATION ON YOUR INDIVIDUAL HEAT TRANSFER PROBLEMS

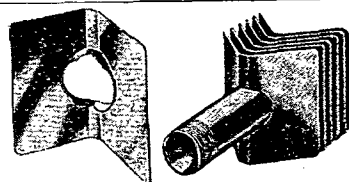
# SLANT-FIN RADIATOR CORPORATION

87-67 130th Street

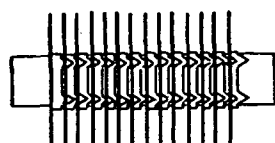
Richmond Hill 18, N. Y.



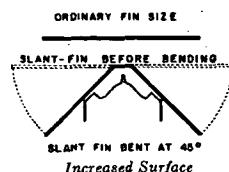
SQUARE-FIN SERIES



SLANT-FIN SERIES



Interlocking Flanges



Increased Surface

## FEATURES OF DESIGN AND CONSTRUCTION

1. **FIN TO PIPE BOND.** Pipe is forced through undersize holes in fins under hydraulic pressure. Pipe is not expanded. Fins do not cut into pipe surface. The result is a strong union of pipe and fin.

2. **THERMAL BONDING.** Standard pipe is rolled to uniform round diameter. Wide flanges of fins press solidly against entire surface of pipe.

3. **SPACING AND STRENGTH OF FINS.** Because of the uniformly wide flanges and their interlocking features, the fins fit tightly one into another.

4. **EFFICIENT AIR CIRCULATION.** Because of the increased surface, fewer of the distinctive "V" shaped slant fins than the traditional square fins can furnish the same radiation per linear foot of pipe. Therefore, fins can be wider apart and a greater volume of air flows more freely.

5. **NO SNAPPING—NO BUCKLING OF FINS.** Because of the patented notched flange, the slant-fin can expand and contract without disturbing the bond to the pipe, even under high steam pressures. The result is a radiator that is trouble-free.

## SPECIFICATIONS

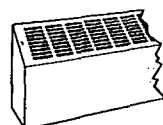
1 1/4 in. IPS and 2 in. IPS steel pipe with steel fins

1 1/4 in. nominal hard copper water tube with copper or aluminum fins.

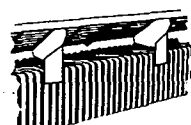
Square-Fin Spacings: 24, 32, 40 and 48 fins (4 1/4 in.) per foot.

Slant-Fin Sizes: 4 3/4 in. x 3 1/2 in. bent at 45 degrees to 3 1/2 in. x 3 1/2 in. and 5 3/8 in. x 4 1/4 in. bent at 45 degrees to 4 1/4 in. x 4 1/4 in.

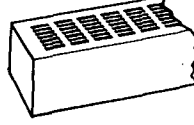
Stock lengths in every integral foot from 2 to 12 feet. On specification, lengths up to 12 feet fabricated to nearest inch.



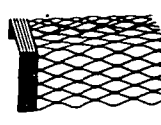
Slope-Top Enclosure



Snap-On Enclosure



Flat-Top Enclosure



Expanded Metal Cover

**RESIDENTIAL BASEBOARD HEATING** for Steam or Hot Water with a choice of 3 heating elements and 2 enclosure styles.

**CATALOG No. 505** for details on "Slant-Fin" and "Square-Fin" radiators and enclosures for commercial and industrial applications. **BULLETIN No. R-602** for residential baseboard heating.

# The Vulcan Radiator Company

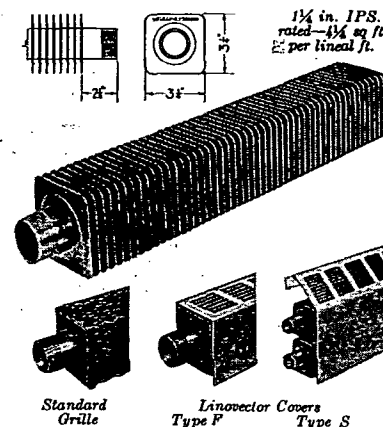
26 Francis Avenue

Hartford 6, Conn.

Representatives in Principal Cities

Vulcan Radiation (Linovector) is used in schools, industrial plants, hospitals, office buildings, churches, railroad cars and ships.

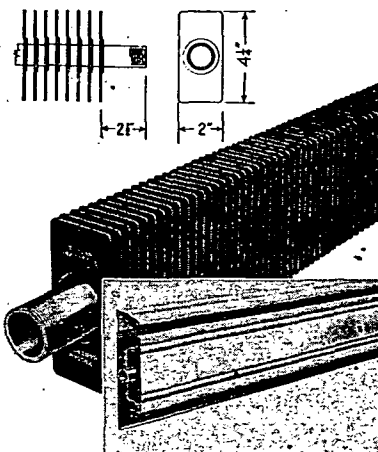
Available in steel or copper . . . easy to install . . . light in weight . . . requires few fittings and supports . . . tube ends threaded or chamfered for welding. Heat distribution is uniform. Steel radiation comes in two sizes . . . 2 in. IPS, rated—5 1/4 sq ft per lineal ft at 1 lb steam and 65 deg air . . . for 1 1/4 in. IPS see illustration—this size also available in copper. Illustrated catalog available.



Standard Grille Cover  
Type F  
Type S  
1-B-R Ratings for Vulcan Linovector available in catalog 825 B.

Vulcan Radiation is fabricated by mechanically imbedding offset fins or plates on seamless steel pressure tube or copper water tube. The patented offset fin construction gives complete rigidity to the entire assembly and extends the heating surface of the tube.

Because of its comparatively light weight and compactness, Vulcan Radiation responds quickly to thermostatic control. Full heat output is obtained almost immediately after steam is supplied. Since most of the heat is given off by convection, the result is **EVEN, UNIFORM HEAT** from floor to ceiling.



1 in. IPS TRIMLINE covers in continuous lengths up to 15 ft. Built of .034-gauge galvanized steel  
1-B-R ratings for Vulcan Radi-Vector available in Catalog No. 64.

**Vulcan Baseboard Radiation . . . fin-on-tube construction with TRIMLINE covers** combines radiant and convection heating. High safe working pressure . . . either hot water or two-pipe steam systems. Light in weight . . . easy to install . . . requires few fittings or supports. Comes in two sizes . . . 1 in. IPS . . . steel fins 2 3/4 in. wide by 3 3/4 in. high and 1 in. IPS, 2 in. x 4 1/4 in. . . for 1 in. IPS, see illustration. Also available in copper. Illustrated catalog available.

## Brunner Manufacturing Company

Dept. M-56, Utica, New York, U. S. A.



The Brunner Co., Gainesville, Ga.

In Canada:

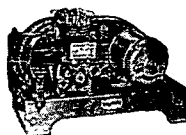
Brunner Corp. (Canada) Ltd., Toronto, Ont.

Refrigeration Air Conditioning Air Compressors Industrial Gas Compressors

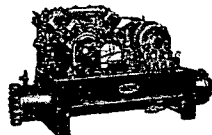
**PRODUCTS:** Refrigeration compressors and condensing units for commercial and industrial use—motor-compressor units for use with evaporative condensers, 2-stage and sub-zero units, truck units, self-contained and remote air conditioning. Also complete line of single and two-stage air compressors for pneumatic control and industrial applications. Industrial Gas Compressors for transferring Liquefied Petroleum Gas, Anhydrous Ammonia and booster for natural gas in manufacturing plants.



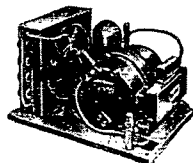
**Refrigeration Compressors**  
Complete line of 2, 4 and 8 cylinder refrigeration compressors, adaptable to any need. Designed for slow-speed operation, less wear, longer life. F-12 and F-22.



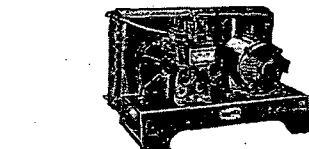
**Water-Cooled Condensing Units**  
 $\frac{1}{8}$  hp to 100 hp, for every commercial and industrial use. "Freon-12" or "Freon-22" refrigerants, with cleanable condensers.



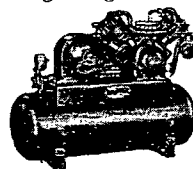
**Industrial Refrigeration**  
Sizes up to 100 hp, complete line of water-cooled condensing units and compressor units for use with evaporative condensers, for industrial refrigeration and air conditioning use. Capacity controls available.



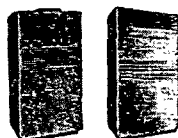
**Semi-Hermetic Condensing Units**  
Brunner-Metetics—Commercial and Low Temperature applications. Air-Cooled models, in  $\frac{1}{4}$ ,  $\frac{1}{2}$ ,  $\frac{3}{4}$ , 1, 1 $\frac{1}{2}$ , 2 and 3 hp. Water-Cooled models, in  $\frac{1}{8}$ ,  $\frac{1}{4}$ ,  $\frac{1}{2}$ , 1, 1 $\frac{1}{2}$ , 2 and 3 hp.



**Air and Air-and-Water Cooled Condensing Units**  
 $\frac{1}{4}$  hp to 3 hp, for "Freon-12" refrigerant, finned tube condenser. Also  $\frac{1}{2}$  hp to 3 hp combination air and water-cooled units, with cleanable condensers, to handle fluctuating refrigeration loads.



**Air Compressors**  
Complete line—single stage from  $\frac{1}{4}$  hp to 2 hp, two stage from  $\frac{1}{2}$  hp to 50 hp. Air compressors 5 hp and over available with water-cooled after-cooler.



**Air Conditioning Units**  
2, 3, 5, 7 $\frac{1}{2}$ , 10, 15 and 20 hp sizes, completely self-contained, in various styles for commercial and residential use. Easily installed.

## Copeland Refrigeration Corporation

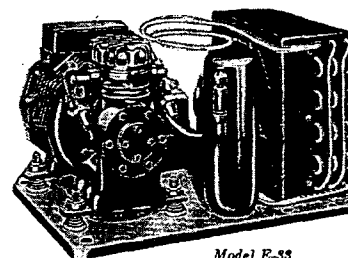
Sidney, Ohio

COPELAND compressors, motor-compressors and condensing units for all applications

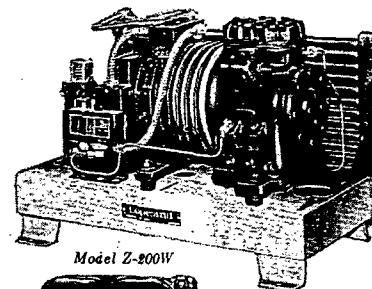
### COPELAMETIC

#### The Accessible Hermetic

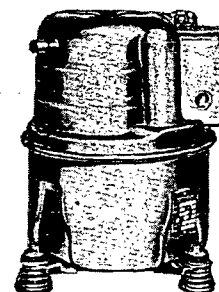
Direct-drive Copelametic units are completely accessible, making on-the-spot servicing a plus value. There are no belts or seals. No manual oiling is required. Ninety per cent of service costs removed by these features. Copelametic motor-compressors have rugged, cast-iron bodies; bronze rods, bushings and bearings; Swedish steel valve reeds. Copelametic offers unusual economies: quiet operation, long life and dependability. There are units for all applications... on thermostatic or automatic expansion valves, high- or low-side floats and capillary tubes. Remote, water-cooled from  $\frac{1}{4}$  hp through 7 $\frac{1}{2}$  hp. Air-cooled from  $\frac{1}{8}$  hp through 3 hp. Self-contained models through 2 hp.



Model E-55



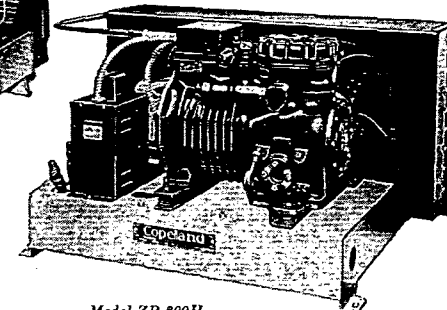
Model Z-800W



1 $\frac{1}{2}$  hp Copelaweld

### COPELAWELD MOTOR-COMPRESSORS

Engineered to Copeland's high standards, the welded motor-compressors give maximum economy in package air conditioners, water coolers, refrigerators and other equipment. Cool-running, two-cylinder Copelawelds are free from vibration and chatter. High quality, one-piece body casting for positive alignment of motor and bearings. Solid bronze rods and main bearings assure long wear. Compact size conserves space. Efficient oil pump has no moving parts, will operate in either direction. Heavy-duty, high-power-factor motor delivers high



Model ZR-300H

capacities at low power input. "Freon-12" and "Freon-22" models.

### CONDENSING UNITS WITH SUCTION-COOLED MOTOR-COMPRESSORS

Suction-cooling affords greater flexibility of installation, since no water is required. These larger sizes make possible even wider applications. 2 hp and 3 hp have a centrifugally-forced oiling system. Larger sizes incorporate a gear pump. Both systems allow motor-compressor to operate in either direction. From cast body to solid bronze rod, bearings and bushings, and Swedish steel valve reeds it is quality built. Units have oversize condensers for maximum efficiency in high ambient temperatures. Designed especially for air-conditioning and other high-suction pressure applications. Sizes 2, 3 and 5 hp.

## Curtis Manufacturing Company

Refrigeration Division



1959 Kienlen Ave.  
St. Louis 20, Missouri, U. S. A.

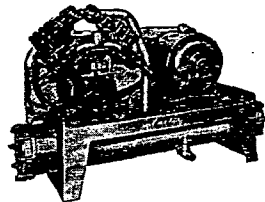
NEW YORK OFFICE  
30 VESSEY ST.

CHICAGO OFFICE  
9 S. CLINTON ST.

ESTABLISHED 1884



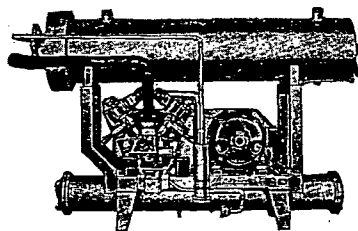
**Products:** Full line of Packaged Air Conditioners from 3 through 20 ton, Condensing Units from 1/4 through 100 hp with Cooling Towers, Air Handling Units to match, Packaged Water Chillers 7 1/2 through 100 hp, Waterless Air Cooled Packaged Condensing Units, 2 through 7 1/2 hp, Residential and Commercial.



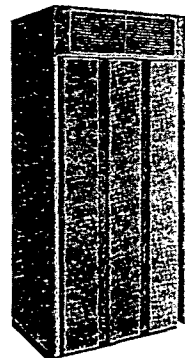
15 hp Cleanable Shell and Tube Condensing Unit. Other sizes from 7 1/2 to 100 hp.

### COMMERCIAL REFRIGERATION

Air cooled condensing units from 1/4 to 3 hp, inclusive, combination air and water cooled units from 1/2 to 3 hp, inclusive, and water cooled units from 1/2 to 40 hp, inclusive. All models charged with Freon 12 refrigerant. Mechanical advantages include Timken Bearings, Positive Pressure lubrication. Special models are available for ice cream, frozen food cabinets and for the dairy industry.

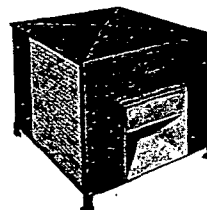


Packaged Water Chiller 7 1/2 through 100 ton. For process or solution cooling and various other types of liquid chilling applications.



Waterless Air Cooled Packaged Condensing Unit (right) for residential and commercial application 2 through 7 1/2 hp.

Packaged Air Conditioners (Left) in many combinations of pastel colors 3 through 20 ton.



## Frick Company

Waynesboro, Penna.

ATLANTA CINCINNATI  
BOSTON DALLAS  
BUFFALO KANSAS CITY  
CHARLOTTE LOS ANGELES  
CHICAGO

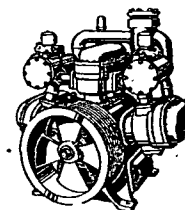
MEMPHIS PHILADELPHIA  
NEW ORLEANS PITTSBURGH  
NEW YORK ST. LOUIS  
OKLA. CITY SEATTLE  
PALATKA WASHINGTON



Distributors in

Principal Cities

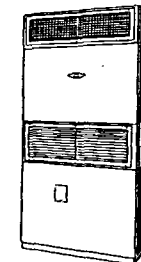
Air Conditioning, Refrigerating, Ice Making and Food Freezing Equipment



Frick "ECLIPSE" Compressors, 2, 3, 4, 6 or 9 cylinders. Bulletin 100.

### AIR CONDITIONING

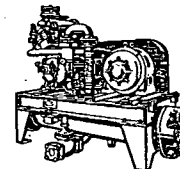
Complete Frick Systems, including several that are patented; also refrigeration for use with equipment supplied by others. Thousands of installations attest the value of Frick air conditioning. See Bulletin 504 on typical installations, 505 on engineering details, 522 on unit conditioners, and 146 on air conditioned cold storages.



Unit Air Conditioners, 3, 6 & 7 1/2 Hp.

### FREON REFRIGERATION

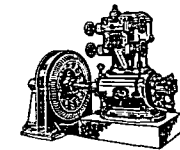
Frick low pressure units, "ECLIPSE" multi-cylinder compressors, and larger enclosed Freon machines provide a complete and efficient line. Unit air conditioners; central systems; plain and finned coils; coolers, condensers, controls; also valves and fittings to suit. Patented Flexo-Seals, pressure lubrication, capacity controls, and built-in dependability make Frick machines your logical choice.



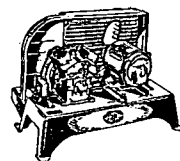
Combined Units with "ECLIPSE" Compressors. Bulletin 100

### AMMONIA REFRIGERATION

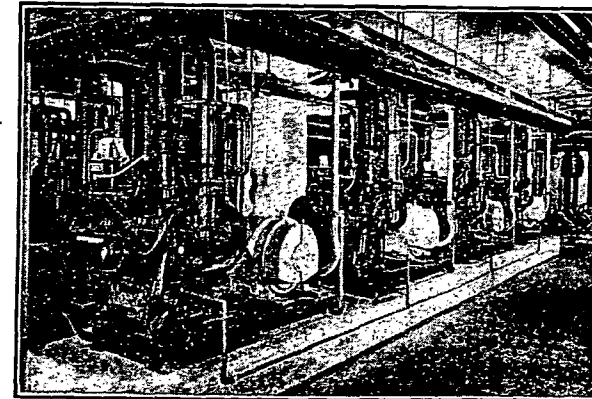
Combined units and vertical enclosed compressors, with 2 or 4 cylinders, in sizes from 2 1/2 to 1000 tons. Also "ECLIPSE" compressors for ammonia and high pressure service, with 3, 6 or 9 cylinders. Ammonia equipment is used with material savings in certain air conditioning work.



Enclosed Ammonia Compressors, 3 in. by 3 in. to 17 3/4 in. by 12 in. Bulletins 112, 516 & 651.



Low Pressure Refrigerating Units, Open Drive or Accessible-Hermetic Types. Bulletin 97.



Eight 9-Cyl. "ECLIPSE" Compressors Air Condition the Two 11-Story Buildings of The American National Insurance Co. at Galveston



Air System Equipment • Refrigerating Machinery  
Gas and Oil

## The Ready-Power Co.

11231 Freud Ave., Detroit 14, Mich.

# READY-POWER

AIR CONDITIONING AND REFRIGERATION EQUIPMENT  
SAVES AS IT SERVES

District Offices or Representatives

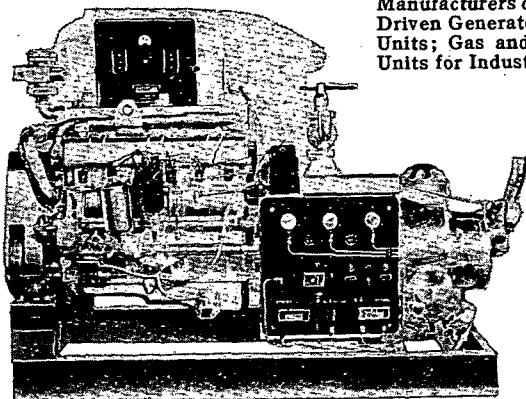
ATLANTA  
BOSTON  
CHICAGO

CINCINNATI  
DALLAS  
DETROIT

PHILADELPHIA

PITTSBURGH  
LOS ANGELES  
NEW ORLEANS

NEW YORK  
SEATTLE  
ST. LOUIS



Manufacturers of Gas and Diesel Engine  
Driven Generators and Air Conditioning  
Units; Gas and Diesel Electric Power  
Units for Industrial Trucks.

Ready-Power Engine Driven Compressor Units are designed and built to meet the need of (1) Low operating cost air conditioning and refrigeration employing NATURAL GAS fuel and (2) Air Conditioning and refrigeration where electric power is not available or high in cost. It is particularly adaptable to portable equipment for cooling airplanes, before take-off, for pre-cooling perishable food shipments by rail or truck, and for installations in refrigerated rail cars and trucks.

### CAPACITY MODULATION

The Ready-Power inherent system of capacity modulation permits operation of the compressor to meet the needs of varying conditions. This assures much better control of temperature and humidity conditions than is possible with the usual "on and off" system generally used with electrically driven equipment.

On units of 15 to 70 ton the capacity modulation is controlled both by varying the engine speed and by unloading the cylinders of the compressor. Since

engine speed can be varied from maximum to less than half of maximum this more than doubles the usual advantages obtained from unloading.

On the smaller units, the capacity modulation is controlled entirely by engine speed variation.

All capacity modulation is automatically controlled.

### UP TO 70 TON RANGE

Unit capacities range up to 70 tons for air conditioning and multiple unit installations of more than 150 ton are in successful operation.

Compressor units are adaptable for use with evaporative condenser, heat exchanger or radiator cooling of the engine. Water cooled manifolds are standard on some models and available on all models. Engine starting is by either storage battery or a-c Motor.

All units are supplied for operation on Natural Gas, Gasoline, Propane or Butane fuels.

Units of 15 ton and larger are also available for operation on Diesel fuel.

Air System Equipment • Refrigerating Machinery  
Cooling Towers

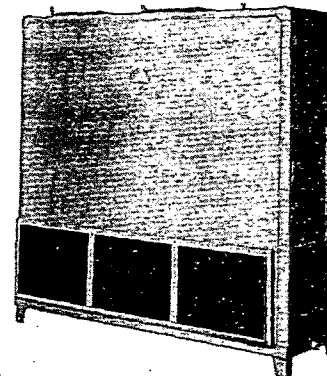
# Refrigeration ENGINEERING, INC.

7250 East Slauson Avenue, Los Angeles 22, California.

Manufacturers of Air Conditioning and Commercial  
Refrigeration Equipment



TRADE MARK REG.



### RECOLD AIR CONDITIONING EQUIPMENT

Sizes from 3.3 to 40 sq ft cooling coil area

Vertical or horizontal units (illustrated)

Bulletin No. AC-502G

Multi-Zone units

Bulletin No. AC-504G

Air Conditioning Coils

Bulletin No. AC-501G

Midget Evaporative Condensers  
(Specifications Sheet)

Hy-Flo Cooling Towers (3 and 5 ton)

Bulletin No. CT-811G

Recold also manufactures a complete line of refrigeration blower coils including Water Defrost and Vapor Defrost systems.

### "DRI-FAN" EVAPORATIVE CONDENSERS AND "DRI-FAN" COOLING TOWERS

Capacities from 3 to 150 tons

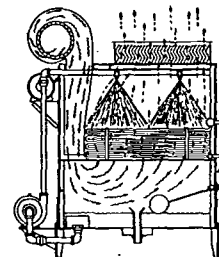
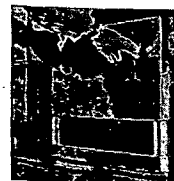


Diagram shows "Dri-Fan" principle. Wavy arrows denote warm inlet air. Dotted arrows show discharge of moist air. Air is forced through instead of drawn through. Fans operate in dry, incoming air stream. This prolongs life of fan and eliminates many service problems. Units are galvanized inside and out. Ingenious panel fastening insures an air tight, water tight housing and yet provides easy access by removing only a few screws.

"Dri-Fan," Evaporative Condenser—  
Bulletin No. EC-410G

"Dri-Fan" Cooling Towers—Bulletin  
No. CT-801G

Patented access doors (left) form a water tight seal without use of gaskets. Doors slide freely, can be opened and closed repeatedly without danger of leaking.



Patented bleed control (right) eliminates small tubes and valves. Funnel catches an accurately determined amount of water. Assures positive, non-clogging action with scale control and minimum water loss.



Write for bulletins and name of nearest distributor  
Refrigeration Engineering, Inc.

7250 East Slauson Avenue Los Angeles 22, California

## Aerovent Fan Company, Inc.



Ash and Blade Sts.  
Piqua, Ohio



Standard Assemblies for Every Air-Moving Requirement

### BELT-DRIVEN AND DIRECT-DRIVEN DUCT

Easily installed in present ducts for hazardous and non-hazardous atmospheres. In sizes 12 to 84 in. with 2, 4, 6 or 7 blades for capacities to 120,000 cfm.

### DIRECT CONNECTED

Heavy-duty units for all industrial applications. Steel ring and panel types. In sizes 9 to 84 in. with 2, 4, 6 or 7 blades for capacities to 120,000 cfm.

### "BI-FLO" DUCT

New divided-duct design for duct or stack installation. Available with new 7-blade Semi-Pressure propeller. Sizes 16 to 48 in. for capacities to 40,000 cfm.

### MANCOOLERS

Four models for any industrial cooling, drying, exhausting or ventilating requirement. Sizes 16 to 48 in. for capacities to 40,000 cfm.

### MATERIALS HANDLING

Reversible rotation and adjustable air discharge for conveying production and waste materials, dust collecting or exhaust. Wheel diameters 19, 26, 33, 40, 51 in.

### VANEAXIAL

Maximum efficiency against resistances to 6½ in. S.P. High-velocity, straight-line air discharge. Sizes 12 to 48 in. for capacities to 77,000 cfm.

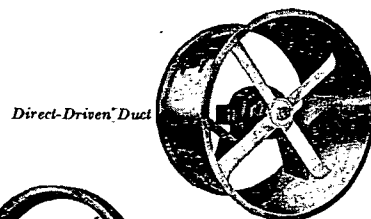
### ROOF VENTILATORS

Three types for all industry exhaust and air supply requirements. All-weather construction for use in all climates. Sizes 12 to 72 in. Capacities to 80,000 cfm.



### CERTIFIED RATINGS

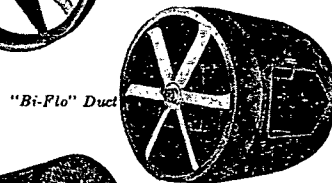
All Aerovent Fans are tested and rated in accordance with the Standard Test Code for Centrifugal and Axial Fans and conform with U. S. Department of Commerce Commercial Standard CS178-51.



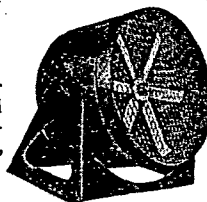
Direct-Driven Duct



Direct Connected



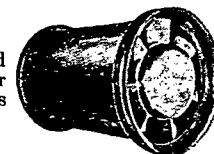
"Bi-Flo" Duct



Portable Utility



Material Handling



Vaneaxial



Roof Ventilators

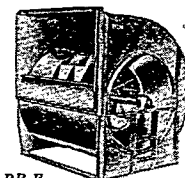
"Specialists in efficiency-engineered air-moving equipment"

Fan Wheels • Large Diameter Propellers • Penthouses • Shutters • Accessories

## Aladdin Heating Corporation

1111 West Ave. 137, San Leandro, Calif.

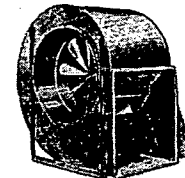
Manufacturers of Centrifugal Blowers,  
Heating and Ventilating Equipment.



BB Fans



FC Fans

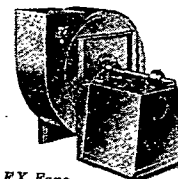


RB Fans

**BB FAN**—Backwardly inclined blade fan with non-overloading horsepower characteristic. Manufactured in 22 sizes, single and double width, all arrangements, 2 classes of construction. Request *Bulletin 605-A, 605-B*.

**FC FAN**—Forward curved fan, slow speed for quiet operation. Manufactured in 22 sizes, single and double width, all arrangements, 2 classes of construction. Request *Bulletin 605-A, 605-C*.

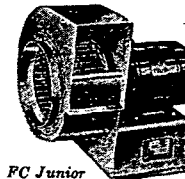
**RB FAN**—Radial blade fan well suited for handling grease or other sticky materials. Manufactured in 13 sizes, single width only, all arrangements, 2 classes of construction. Request *Bulletin 450-B*.



EX Fans



Utility Sets

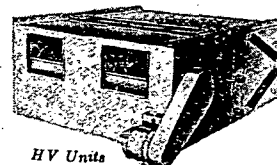


FC Junior Fans

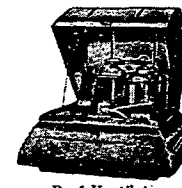
**EX FAN**—Radial blade fan used chiefly for conveying materials, fume exhaust, etc. Manufactured in 15 sizes, single width only, all arrangements, 5 classes of construction, 3 wheel types. Request *Bulletin 461*.

**UTILITY SETS**—Self contained units for a wide variety of ventilating applications. Manufactured in 14 sizes with forward curved rotors, 12 sizes with backwardly inclined blade rotors, single width only. Request *Bulletins 610-A, 611-A*.

**FC JUNIOR FANS**—Self contained direct connected fans with forward curved rotors. Manufactured in 5 sizes with 13 motor speeds, single width only. Request *Bulletin 422*.



HV Units



Roof Ventilator



Type AR Roof Ventilator

**HV UNITS**—Heating and ventilating unit of universal design. Can be furnished with air filters, face and by-pass dampers or mixing box. Manufactured in 7 sizes with unlimited flexibility as to arrangement. Request *Bulletin 510*.

**ROOF VENTILATOR**—Backwardly inclined blade centrifugal type. Manufactured in 13 belt driven and 12 direct driven sizes with steel, aluminum, copper or stainless steel housings. Request *Bulletin 410-A*.

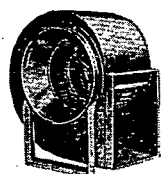
**TYPE AR ROOF VENTILATORS**—Backward inclined blade centrifugal type. All units fabricated from spun aluminum. Available in both direct connected and belt driven models. Request *Bulletin 411*.

## Bayley Blower Company

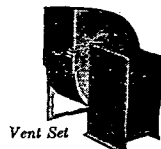
1821 S. Sixty-Sixth Street Milwaukee 14, Wis.  
 Branches in Principal Cities  
 Engineers and Manufacturers of Fans, Washers,  
 Heaters and Other Air-Handling Equipment

### CENTRIFUGAL FANS

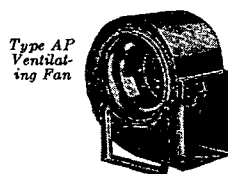
Bayley offers a complete selection of types, sizes and arrangements of centrifugal fans for ventilating, conditioning, industrial, and mechanical draft service, with slow-speed, power-limiting, or medium speed wheels. Made in single or double widths, with capacities up to 300,000 cfm or more. Smaller sizes have reversible housings for convenience and economy.



Type F  
Ventilating Fan



Vent Set



Type AP  
Ventilating Fan

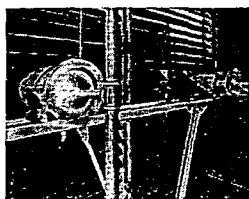
**VENTILATING FANS AND PACKAGED SETS** Type "F" Fans are equipped with wheels having forward-curved floats, effecting a slow-speed characteristic. The floats of the wheels supplied with Type "AP" Fans are backwardly inclined, producing a non-overloading characteristic. Choice of fans is determined by the design conditions of the individual installation.

Compact, unitary Ventilating Sets are manufactured with drive complete, ready to use, direct-connected and belted styles with capacities to 15,000 cfm. These handy units serve a wide variety of applications in ventilation and exhaust, for kitchens, lavatories, gymnasiums, restaurants, garages, halls, hospitals, laboratories, industrial plants, and many other locations. May be used for supply, exhaust or both. They can be equipped with weather-protection hood for outdoor or penthouse installation. Carefully engineered and sturdily built to give long-lasting, efficient service.



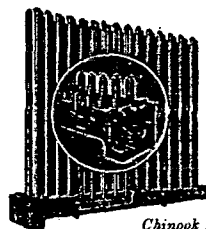
Type EX  
Industrial Fan

**INDUSTRIAL FANS** Bayley Industrial Fans are available in a wide range of sizes and constructions from which to select the unit best fitted for any application in exhausting, conveying, cleaning, drying, blast, draft, or similar duties. Type "EX" is proportioned primarily for medium pressures and capacities usually encountered in materials handling or exhaust. Type "H" is similar, but proportioned for relatively higher pressures and smaller volumes. Designs are adaptable to suit virtually any requirement of temperature, corrosion-resistance or other severe operating conditions.



Turbo Washer

**AIR WASHERS** Because Turbo washers atomize by mechanical means, they cannot clog, hence are admirably suited to handling air contaminated with particulate matter. Standard pressure-nozzle washers also available for use where dust content is light.



Chinook Heater

**BLAST HEATERS** The finless, long lasting iron pipe coils of Chinook Heaters will not clog, therefore maintain full capacity longer. Pipe-within-a-pipe arrangement has single heater for supply and return, cannot short-circuit, and absorbs expansion and contraction without damaging stresses.

## The Bishop & Babcock Mfg. Co.

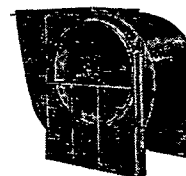
Massachusetts Blower Division

4901 Hamilton Ave.

Cleveland 14, Ohio



S.C.  
(F.C.)



P.F.  
(B.C.)

### SQUIRREL CAGE AND POWER FIXED FANS

Squirrel Cage (forward curve) and Power Fixed (Backward curve) Fans available in a complete range of sizes—single or double width. For all types of commercial and industrial air conditioning and exhaust systems. *Bulletin 101* (P.F.) *Bulletin 105* (S.C.)

### MASSACHUSETTS UNIT HEATERS AND AIR CONDITIONING UNITS

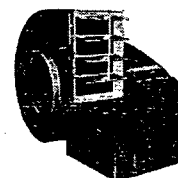


Both floor and ceiling mounting arrangements available. These units are built in sections to facilitate efficient handling and erection. Offered in a wide range of popular sizes with various heating and cooling coil combinations. *Bulletin 112* (Unit heaters) *No. 120* (A.C. Units)



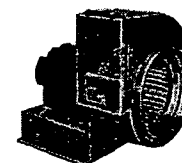
### POWER ROOF VENTILATORS

Propeller fan type features a steel venturi-type inlet orifice, belt or direct drive. Power fixed type has backward curve wheel, belt or direct drive. Both offered in a wide range of competitive sizes. *Bulletin No. 118* (Power fixed) *No. 124* (Propeller fan).



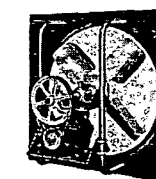
### BELT OR DIRECT DRIVE UTILITY TYPE VENTILATING SETS

Belt drive wheel diameters 7 in. to 30 in., direct drive 6 in. to 13½ in. Both available in popular competitive sizes. *Bulletin No. 109.*



### PROPELLER FANS

New venturi-type propeller fans. Belt drive 24 in. to 48 in. wheel diameters. Direct drive 12 in. to 30 in. wheel diameters. A complete line of accessory items are available. *Bulletin No. 117.*



**UNIVERSAL BLOWERS** (at left). A stock blower assembly made in single or double width, sizes 7 in. to 27 in. wheel diameter and features universal discharge arrangement. *Bulletin No. 110.* **DESIGN 2 A.C. BLOWERS** (at right). Available in single, double or special width. All housing and wheel parts are die formed and are offered as complete assemblies or parts only. *Bulletin No. 115.*



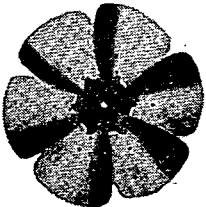
## Bronson Fan Manufacturing Corp.

4560 Worth Street, Los Angeles 63, Calif.

Representatives in Principal Cities

Manufacturers of Propeller Type Fan Blades for Air Conditioning, Heating and Ventilating Equipment.

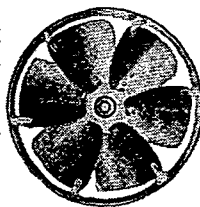
Tested and rated according to *NAFM* and *NEMA* codes.



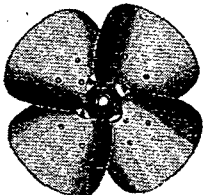
Hi-Static Series

**HI-STATIC SERIES**—Quiet operation against static resistances. Gives high air volumes at reduced fan depth. Diameters 11 in. through 16 in. Neoprene hubs available.

**HI-STATIC SLINGER RING**—Condensate eliminating fan blade for use in air conditioning units where space is a factor. Exceptionally low noise level.



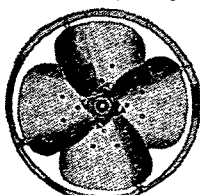
Hi-Static Slinger Ring



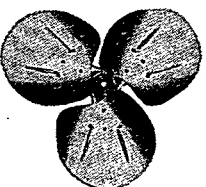
Static Pressure Series

**STATIC PRESSURE SERIES**—For efficient air deliveries against static pressures. Diameters 8 in. through 20 in. Pitches 6 deg to 40 deg. Also in **THREE BLADE SERIES**.

**STATIC PRESSURE SLINGER RING**—Designed to eliminate condensate in air conditioning applications. Ring can be positioned anywhere on fan blade. Neoprene hubs available.



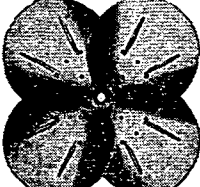
S. P. Slinger Ring



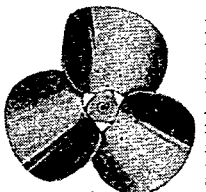
Free Air Three Blade

**FREE AIR THREE BLADE SERIES**—Bright finish aluminum blades, steel spider. High efficiency in free air. Diameters 8 in. through 30 in. Pitches 6 deg to 40 deg.

**FREE AIR FOUR BLADE SERIES**—Wide overlapping blades assure quiet operation. Sturdy construction. Diameters 8 in. through 30 in. Pitches 6 deg to 40 deg.



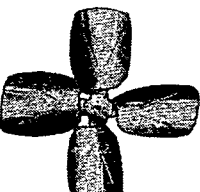
Free Air Four Blade



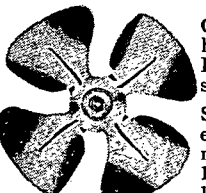
Hurricane Series

**HURRICANE SERIES**—Semi-pressure type for efficient use against low static resistances. Diameters 12, 14 and 16 in. Neoprene bushed hubs available.

**K-D SERIES ATTIC FAN BLADES**—Heavy duty construction. Shipped knocked down. Diameters 24, 30, 36, 42 and 48 in. 35 deg pitch only.



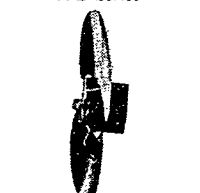
K-D Series



One-Piece Series

**ONE-PIECE SERIES**—Available with hub or pierced for unit-bearing motors. Diameters 6 in. through 12 in. Many special designs.

**SPACESAVER SERIES**—Off-set design enables the blades to rotate around motor for space reduction. Diameters: 18 in., 20 in. Three blade only. Pitches 15 deg to 35 deg.



Space saver Series

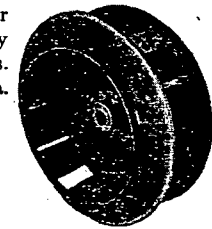
## Brookside Products Company, Inc.

McCordsville, Indiana

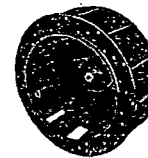
Manufacturers of—

**FANS — BLOWERS — VENTILATING EQUIPMENT**

**POWER-FLO 100-SERIES BLOWERS:** Sturdily built with conical shaped inlet ring welded to blades. Built especially for higher pressure ventilating and exhaust systems. Backwardly inclined for non-overloading and low noise characteristics. Both statically and dynamically balanced. 14 in. to 60 in. dia.



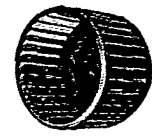
100-Series



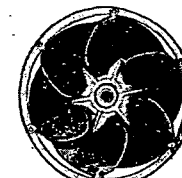
200-Series

**POWER-FLO 200-SERIES BLOWERS:** Ruggedly and efficiently built as well as lighter in weight for lower pressure applications. Backwardly inclined blades for low noise and non-overloading characteristics, also, statically and dynamically balanced. Fabricated of aluminum or steel. Riveted construction throughout. 11 in. to 60 in. dia.

**POWER-FLO 50-SERIES BLOWERS:** Are general purpose blowers for various air moving applications including air conditioning, heating, oil burners, etc. Available in both single and double inlet types, both rotations. All widths in sizes from 3 in. to 10 in.



50-Series



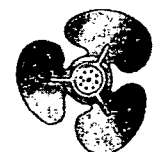
Slinger Type

**M-PEL-AIR FAN BLADES:** Slinger type for air conditioning or offset spider and conventional propeller type fans for ventilating and other applications. All engineered exactly to your specifications free of charge. Slinger rings are all one piece die drawn.



Off Set Type

**M-PEL-AIR "A" SERIES FANS:** Are of one piece construction of aluminum or steel. Available with hub or unit bearing motor piercing. Designed especially for air conditioning and refrigeration industries.



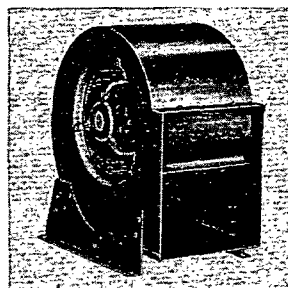
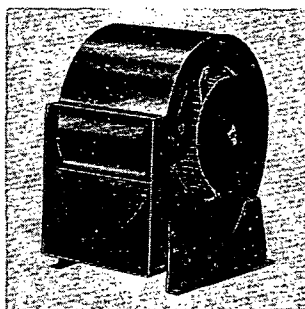
A-Series

# THE *Brundage* COMPANY

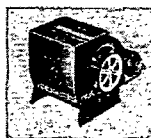
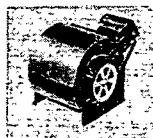
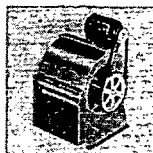
530 N. Park Street

Kalamazoo, Mich.

*Air Conditioning and Furnace Blower Specialists*



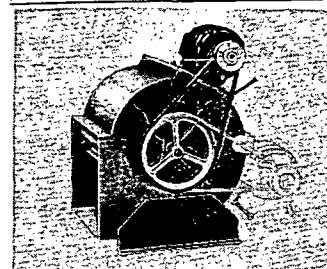
**DIRECT DRIVE BLOWERS.** Save space. Cut costs. And maintain full cfm output with top-quality Brundage Direct Drive blowers. Ideal for modern, compact heating and air conditioning equipment. The Brundage Volume Control Damper insures proper air flow at lowest cost . . . requires no electrical components. With full or three-quarter width wheels. Produced in all discharges.



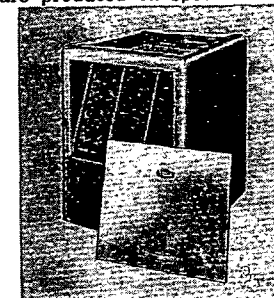
**UX SERIES UNIVERSAL BLOWERS.** Here are all standard and angular discharges your heating or air conditioning equipment may require—in one package. Available with full or three-quarter width wheels, Brundage Universal Blowers are ideally suited to streamlined production facilities where lower inventories are desired.

WRITE FOR DETAILED SPECIFICATIONS AND PERFORMANCE DATA.

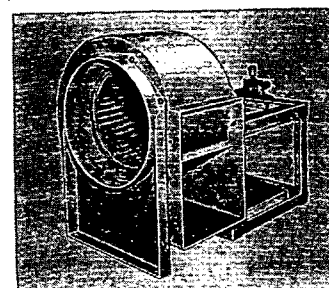
1380



**SERIES "X" BLOWER ASSEMBLIES.** A high-performance unit for all heating and air conditioning applications . . . in top and bottom, vertical and horizontal discharges. A full range of standard sizes from 8 in. to 16 in. built to high quality standards. Special discharge models are produced on special order.

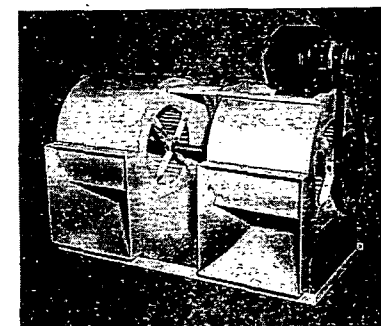


**BLOWER-FILTER PACKAGE UNITS.** 7 sizes, from 400 to 3,500 cfm output. Cabinets are heavy-gauge, cold-rolled steel finished in durable baked enamel. Standard replaceable air filters are easily reached.



**SERIES "S" BLOWER-EXHAUSTERS.** 200 to 2,200 cfm output, very compact. Can be fastened directly to wall and easily made weatherproof. Angle of discharge adjustable to any degree. Precision made of heavy-gauge steel.

**SERIES "T" TWIN BLOWERS.** For distribution of large volumes of air over large areas. Consists of two blower wheels on self-aligning, polished shaft. Heavy scroll housings and rugged metal frame for industrial applications.



WRITE FOR DETAILED SPECIFICATIONS AND PERFORMANCE DATA.

1381

## Buffalo Forge Company

450 Broadway, Buffalo, N. Y.

Unit heaters, Ventilating Fans (centrifugal axial flow and propeller), Air Washers, Drying Equipment, Mechanical Draft Fans, Air Preheaters, Blowers, Exhausters, Air Cleaning Equipment, Spray Nozzles. Write for Bulletins mentioned below, or call the "Buffalo" Engineering Representative in your nearest principal city. "Buffalo", publisher of "FAN ENGINEERING", is ready to work with you on any air problem you may have.



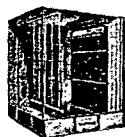
**TYPE "BL" VENTILATING FANS.** These non-overloading centrifugal fans are widely used in large ventilating and air conditioning systems where quiet operation and high efficiency are desirable. Performance is completely stable, from free air delivery to shutoff. Smooth bell-shaped inlet and duct collars with "Buffalo" directional inlet vanes, minimize entry turbulence. The rotor has a curved shroud matching the inlet bell, as well as double backward curved blades for smooth, quiet air flow through the streamlined, full-curvature housing. Capacities from 1000 to 500,000 cfm. Wide choice of arrangements. Write for *BULLETIN F-101*.

**INDUSTRIAL EXHAUSTERS:** All-welded steel plate construction in these heavy-duty fans means smooth rivet-free interior surfaces for minimum friction. Available with interchangeable "AW" Air Wheels for airborne dusts, gases, fumes, or with "MW" Material Wheels for grit, sawdust, grain, stringy materials. Available with heat slingers to handle gases up to 1000 F. in induced draft and other high temperature applications. Write for *BULLETIN 3576*.



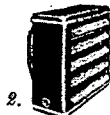
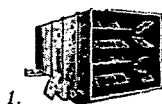
**AXIAL FLOW VENTILATING FANS.** For light-duty (up to 3 in. s.p.) ventilation, exhausting, system boosting, draft and circulation applications, these lightweight fans fit into straight duct runs, taking up no more room than a section of round duct. Extremely quiet, efficient and non-overloading. Available in tubeaxial (without directional vanes) or vane-axial (with directional vanes) models, with direct connected motor-in-housing or with Vee-belt drive and motor out of air stream. Models for high or low temperatures, non-sparking and/or corrosion resistant construction. Write for *BULLETIN 5533-EF*.

**AIR CLEANING EQUIPMENT.** "Buffalo" builds all types of units from Air Washers like the one shown for cleaning, humidity control, heating and cooling to highly specialized units for abating effluent nuisances in the chemical and process industries. More than a half-century of experience in this field is at your service, as well as our complete manufacturing facilities. Write for Bulletins on the industry-proved "Buffalo" equipment to solve any air cleaning or processing problem you may have.



**PC CABINETS (1).** Heavy-duty units for major air conditioning. Compact,

coils and heavy-gauge paneling and tank. *BULLETIN 5703*.



sectionalized construction permits easy installation and servicing. Vertical floor or flat suspended models for any or all air conditioning functions. Equipped with "Buffalo" Fans and Pumps, Aerofin

**UNIT HEATERS (2).** "Buffalo" breezeo-Fin Heaters operate on as little as 2 lbs steam, have high-radiation one-piece copper-finned tubes and efficient "Buffalo" Breezeo Fan for quick, economical heat where needed. Write for *BULLETIN 3137-E*. Also, a wide selection of heating and ventilating units, with or without filtered intake and by-pass dampers, suspended and floor models for large areas.

## Alan E. Burden Co., Inc.

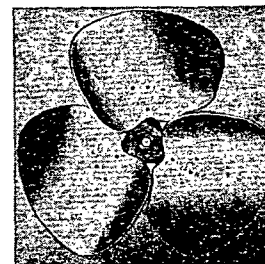
Manufacturer of Propeller Type Fan Blades

1940-50 Pontius Ave., Los Angeles 25, Calif.

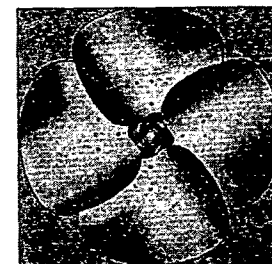
### For Air Conditioning Refrigerating and Heating Applications

All Burden Fan blades are individually inspected after leaving the production line for bore size with "go and no-go" gauges, to a tolerance of plus or minus one  $\frac{1}{1000}$ th of an inch. Each fan blade is individually gauged on a special machine for contour and alignment, then statically and dynamically balanced with Mechanical, Audio Vibration Equipment.

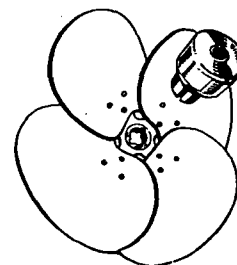
A modern, completely equipped laboratory makes possible exhaustive performance tests. Expert engineering counsel is available for requirements involving unusual applications. A laboratory at the factory is equipped for both routine and special testing when necessary.



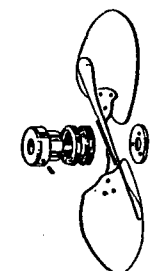
**BURDEN 3 BLADE FANS.** Furnished clockwise and counter-clockwise. Diameter range, 10 in. to 24 in. with variations of pitch of from 6 deg to 42 deg in increments of 1 deg. Hubs front or back. Standard spiders cadmium plated. Blades aluminum, commercial bright.



**BURDEN 4 BLADE FANS:** Furnished clockwise and counter-clockwise. Diameter range, 10 in. to 30 in. with variations of pitch of from 6 deg to 42 deg in increments of 1 deg. Hubs front or back. Spiders cadmium plated. Blades aluminum, commercial bright.



**BURDCO REVERSIBLE, INTERCHANGEABLE HUBS:** Designed for special Burden blades produced with uniform size openings. Hubs produced in six bore sizes can be quickly adapted to front or back and keyed firmly into place with a positive locking device. They are adaptable to 3 or 4-blade fans, clockwise or counter-clockwise in all variations of pitches.



**BURFLEX HUBS:** Are similar to the Burdco reversible, interchangeable type with the added feature of a specially designed noise insulating grommet, constructed to fit over the hub in applications where lessened vibration and dampening of sound are desired. Insulated hub absorbs motor noise. Information sent on request.



# Century Fan & Ventilator Co., Inc.

45-55 Cedar St., Stamford, Conn.

Plants in Stamford, Burrville, Torrington, Conn.

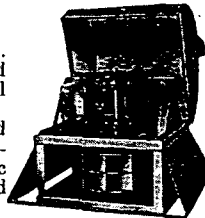
PROPELLER FAN EQUIPMENT • PADDLE WHEEL TYPE  
BLOWERS • MULTIVANE & BACKWARDLY CURVED  
VENTILATING BLOWERS • INDUCED DRAFT  
FANS • GRAVITY VENTILATORS



## CYCLONE ROOF FAN

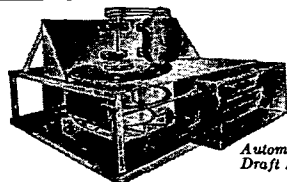
Compact, symmetrical and low in height for modern buildings. Its high efficiency, large volume capacity, slow operating speed and quiet performance make it ideal for schools and hospital buildings.

Shipped complete with motor, driver, fan, framework and housing. Housing of galvanized steel, aluminum, copper, lead-coated copper and stainless steel to withstand atmospheric conditions. Conforms to code ratings of PFMA, NAFM and ASHVE.



Capacity Table

| Fan Size | Fan Rpm | Motor Hp | Fan Tip Speed | Cfm F.A. | Cfm 1/4" | Cfm 1/2" | Cfm 3/4" | Cfm 1" | Cfm 1 1/4" |
|----------|---------|----------|---------------|----------|----------|----------|----------|--------|------------|
| 16       | 1140    | 1/4      | 4460          | 1565     | 1460     | 1310     | 1120     | 1020   | 755        |
|          | 960     | 1/4      | 3760          | 1320     | 1205     | 1050     | 855      | 730    |            |
| 19       | 1070    | 1/4      | 5040          | 2610     | 2500     | 2340     | 2220     | 2030   | 1770       |
|          | 900     | 1/4      | 4230          | 2380     | 2200     | 2100     | 1895     | 1620   | 1310       |
| 22       | 850     | 1/2      | 4675          | 3680     | 3520     | 3355     | 3190     | 2945   | 2580       |
|          | 750     | 1/2      | 4120          | 3385     | 3280     | 3120     | 2790     | 2510   | 1880       |
| 25       | 790     | 1        | 4960          | 4680     | 4460     | 4220     | 3910     | 3705   | 3290       |
|          | 600     | 1        | 3760          | 4055     | 3660     | 3260     | 2740     | 2270   | 1630       |
| 28       | 620     | 1 1/2    | 4390          | 5670     | 5335     | 5015     | 4705     | 4145   | 3520       |
|          | 540     | 1 1/2    | 3820          | 5000     | 4615     | 4160     | 3785     | 2965   | 2050       |
| 31       | 510     | 2        | 3595          | 4745     | 4325     | 3800     | 3315     | 2430   |            |
|          | 590     | 1        | 4840          | 7160     | 6800     | 6620     | 5930     | 5510   | 4920       |
| 34       | 500     | 1 1/2    | 3085          | 5000     | 4415     | 3820     | 3290     |        |            |
|          | 440     | 1        | 4330          | 8600     | 8360     | 8160     | 7990     | 7500   | 6680       |
| 37       | 500     | 1 1/2    | 3815          | 7640     | 7335     | 7065     | 6800     | 6185   | 5060       |
|          | 410     | 1        | 4710          | 10920    | 10640    | 10320    | 9550     | 8830   | 8080       |
| 43       | 400     | 2        | 3995          | 9130     | 8770     | 8400     | 7680     | 6870   | 5920       |
|          | 345     | 1 1/2    | 4390          | 13920    | 13460    | 13000    | 12470    | 11630  | 9720       |
| 50       | 350     | 3        | 3785          | 12240    | 11600    | 11020    | 10250    | 8960   | 7080       |
|          | 300     | 3        | 4390          | 17900    | 17120    | 15890    | 14900    | 13530  | 12070      |
| 56       | 300     | 2        | 3770          | 15440    | 14470    | 13100    | 11830    | 10300  | 8500       |
|          | 285     | 3        | 4240          | 23060    | 22280    | 21550    | 20150    | 18800  | 16950      |
| 62       | 285     | 2        | 3745          | 20660    | 19830    | 19060    | 17730    | 16140  | 14100      |
|          | 230     | 3        | 4400          | 27030    | 25800    | 24700    | 23100    | 21800  | 19000      |
|          | 240     | 2        | 3750          | 23900    | 22860    | 21490    | 20050    | 18200  | 14900      |



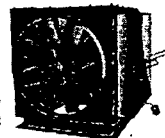
Automatic Draft Inducer

## CENTURY AUTOMATIC DRAFT INDUCER

Installed in boiler breeching. Maintains draft of pre-selected intensity. Eliminates high stacks. Completely automatic and quiet operation. Approved by "Underwriters Laboratory".

## CENTURY MID DRAFT FAN

For low and high pressure heating plants using oil, stoker or gas-fired boilers. Creates perfect uniform draft regardless of weather. Installed in breeching in any position. Rated in conformity with test codes of PFMA, NAFM, and ASHVE.



Mid Draft Fan

### Mid Draft Fan

Send For Complete Catalog

| Size | Hp  | Max. Fan Rpm | Cfm  | Sp inch | Oil Gal per hr |
|------|-----|--------------|------|---------|----------------|
| 14   | 1/4 | 1725         | 960  | 3/4     | 12             |
| 14   | 1/4 | 1725         | 1080 | 1       | 14             |
| 18   | 1/4 | 1200         | 1600 | 1 1/4   | 20             |
| 18   | 1/4 | 1450         | 1850 | 1 1/2   | 23             |
| 18   | 3/4 | 1650         | 2160 | 1 3/4   | 27             |

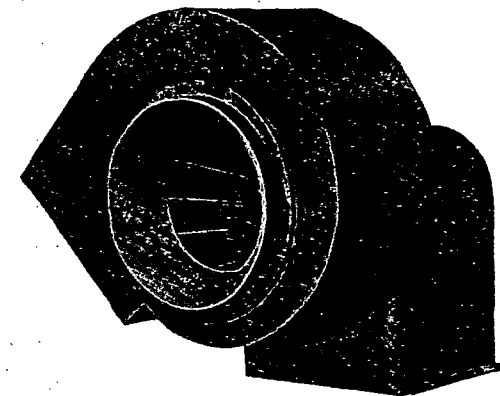
# CHAMPION BLOWER & FORGE CO.

Lancaster, Pa.

Address Correspondence to Div. 9

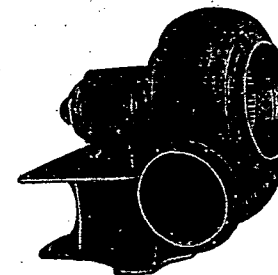
Manufacturers of Blowers, Ventilating Fans and Exhaust  
Fans for handling air, material and fumes

Representatives in Principal Cities

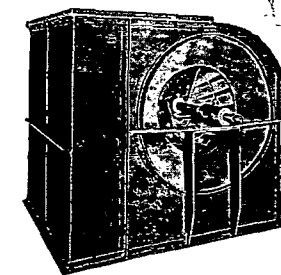


CHAMPION TYPE "D" VENT SETS

For general ventilation of all types equipped with backward curved non overloading wheels up to 30 in. diameter, furnished complete with electric motor, adjustable drive and weather proof covers if required.



Champion Cast Iron Housed Fans of various types for fume hood exhaust and for handling corrosive gases. Can be equipped with either plain steel or non ferrous blast wheels, interior of housing and wheel can be covered with special corrosive resisting coating.



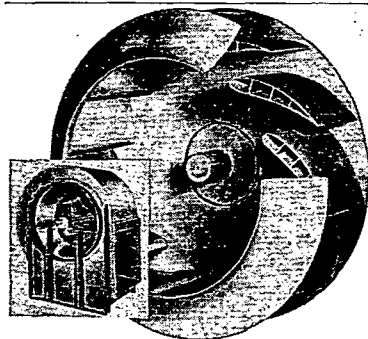
Champion Forward and Backward Curve Ventilating Fans and Exhaust Blowers manufactured in sizes up to 60 in. dia. Fans also furnished in all standard arrangements with Ball, Bab-bitted or Water Cooled Bearings as required.



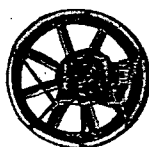
# CHICAGO BLOWER CORPORATION

9865 Pacific Ave., Franklin Park, Ill. Gladstone 5-4780-Write for Bulletins

|                         |                    |                      |                      |
|-------------------------|--------------------|----------------------|----------------------|
| ALA., BIRMINGHAM        | IOWA, BETTENDORF   | N. M., ALBUQUERQUE   | PA., PHILADELPHIA    |
| ARIZ., PHOENIX          | IOWA, DES MOINES   | N. Y., ALBANY        | PA., PITTSBURGH      |
| ARK., LITTLE ROCK       | KANS., WICHITA     | N. Y., BROOKLYN      | TENN., KNOXVILLE     |
| CALIF., LOS ANGELES     | KY., LOUISVILLE    | N. Y., BUFFALO       | TENN., MEMPHIS       |
| CALIF., SAN FRANCISCO   | LA., SHREVEPORT    | N. Y., ROCHESTER     | TENN., NASHVILLE     |
| COLO., DENVER           | LA., NEW ORLEANS   | N. Y., SYRACUSE      | TEXAS, AMARILLO      |
| CONN., NEW HAVEN        | MD., BALTIMORE     | N. C., CHARLOTTE     | TEXAS, DALLAS        |
| FLA., JACKSONVILLE      | MASS., BOSTON      | OHIO, CINCINNATI     | TEXAS, HOUSTON       |
| FLA., MIAMI             | MASS., SPRINGFIELD | OHIO, CLEVELAND      | TEXAS, LUBBOCK       |
| FLA., PONTE VERDA BEACH | MICH., DETROIT     | OHIO, COLUMBUS       | TEXAS, SAN ANTONIO   |
| GA., ATLANTA            | MICH., MUSKEGON    | OHIO, DAYTON         | UTAH, SALT LAKE CITY |
| ILL., CHICAGO           | MINN., MINNEAPOLIS | OHIO, TOLEDO         | VA., RICHMOND        |
| ILL., ROCKFORD          | MISS., JACKSON     | OKLA., OKLAHOMA CITY | D. C., WASHINGTON    |
| IND., FORT WAYNE        | MO., KANSAS CITY   | ORE., TULSA          | WASH., SEATTLE       |
| IND., INDIANAPOLIS      | MO., ST. LOUIS     | ORE., PORTLAND       | WASH., SPOKANE       |
| IND., SOUTH BEND        | NEBR., OMAHA       | PA., HARRISBURG      | WIS., MILWAUKEE      |



New aerodynamic blade design

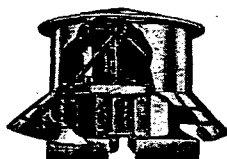
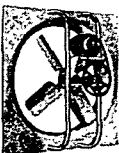


**Axial Airfoil Fans** for removing fumes, vapors in dangerous locations. 1100 to 105,000 cfm. *Bulletin AA-101.*

**Axial Mushroom Roof Exhausters** for industrial, commercial ventilation. 870 to 47,800 cfm. *Bulletin CAM-102.*

**Gyra-Flo Roof Exhausters**—Extremely quiet for schools and hospitals. 830 to 29,750 cfm. 61 to 88 db. *Bulletin GPE-103.*

**Centrifugal Fans** for heating, ventilating, air conditioning, all drive styles. 600 to 750,000 cfm. *Bulletin C-102.*

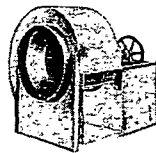


**Propeller Fans** for commercial, industrial, business, home ventilation. 1200 to 24,100 cfm. *Bulletin CEF-103.*

**Steel Plate Fans** for removing dust, materials or high temperature air, gases. 200 to 50,000 cfm. *Bulletin SPE-103.*

**Turbo-Pressure Blowers** for oil or gas burners in industrial furnaces, ovens. 80 to 5500 cfm. *Bulletin CTB-102.*

**MD Fans** for commercial ventilation. Direct or belt drives. 300 to 17,000 cfm. *Bulletin MD-102.*



## NEW AIRFOIL CENTRIFUGAL FANS REDUCE NOISE LEVELS 65 PER CENT

Quieter Operation, Greater Efficiency for industrial, commercial and all other heating, ventilating and air conditioning applications.

- Efficiencies in excess of 90 per cent.
- Steep pressure characteristic curves.
- Noise level ratings lower than other type wheels.

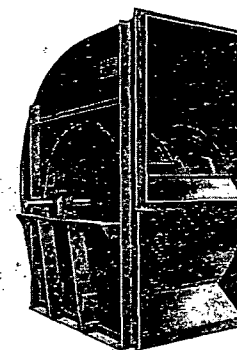
Certified ratings. All drive arrangements; directions of rotation and discharge. 600 to 1,000,000 cfm to 32 in. sp. Class I to V construction. Wheels 12 to 143 in. diameter. *Bulletin A-102.*

# CLARAGE

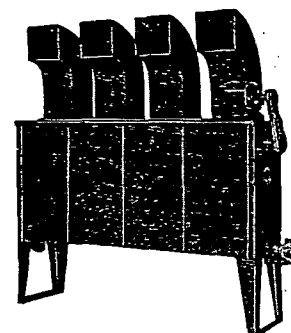
CLARAGE FAN COMPANY  
Kalamazoo, Mich.

Air Handling and Conditioning Equipment  
Application Engineering Offices in All Principal Cities

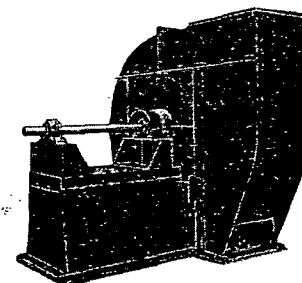
For nearly a half century Clarage has been a leading manufacturer of equipment and units for ventilating, exhausting, cooling, air cleaning, humidifying and complete conditioning. Clarage equipment is designed to meet all types of industrial, commercial and public building requirements. For other equipment in the complete Clarage line see "Air Conditioning—Central Systems."



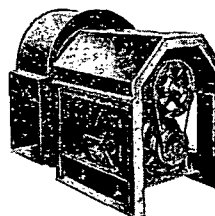
Clarage Fans for ventilating and air conditioning are offered in many different standard types and arrangements. Capacities range from 200 to 725,000 cfm.



Clarage Unit Heaters are available for either floor or suspended installation. 23 sizes range from 24,000 to 1,160,000 Btu. They can be operated on either steam or hot water.



Clarage Industrial Fans (shown above) range up to 130,000 cfm, 18 in. sp, and 60 in. inlet diameter. Can be constructed for special applications.



Clarage Ready Units (left) are furnished complete ready-to-run. V-belt or direct connected. Capacities to 12,000 cfm.

We welcome your inquiry on any air handling or conditioning problem. Contact our nearest branch office, or write us at Kalamazoo, Michigan.

## DeBothezat Fans Division

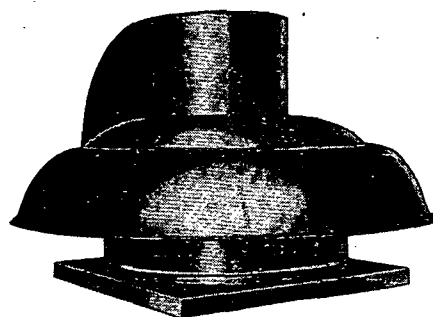
American Machine and Metals, Inc.

Main Office and Factory—East Moline, Illinois

SALES ENGINEERING OFFICES IN ALL PRINCIPAL CITIES

CONSULT YOUR TELEPHONE DIRECTORY UNDER "FANS" OR "VENTILATING EQUIPMENT"

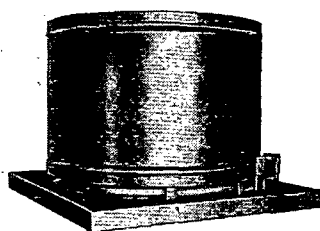
### FOR CONTROLLED VENTILATION



Centrifugal  
Roof Ventilator

Centrifugal Roof Ventilator is ideal for schools and hospitals where whisper-quiet operation is a must. It runs at low speeds and moves large volumes of air efficiently against static pressures. Capacities up to 32,980 cfm.

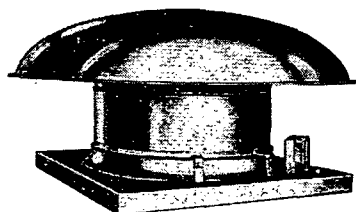
Vertical Discharge Roof Ventilator exhausts oil or grease-laden air straight up at high velocity. It keeps harmful residue off the roof and thus prolongs roof life. Capacities up to 48,925 cfm.



Vertical Discharge  
Roof Ventilator

Power-Flow Roof Ventilator is most popular of all for general usage. It is a ruggedly built unit in an aerodynamically correct, weatherproof housing. Capacities up to 43,070 cfm.

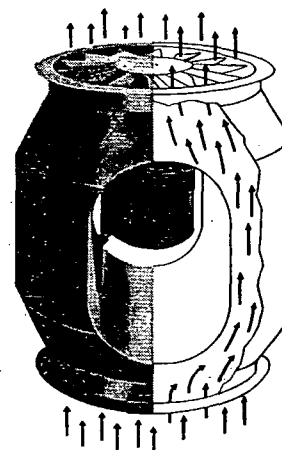
All three DeBothezat roof ventilators are low in silhouette and distinctively profiled... blend well with modern architecture. Write for separate catalogs, mentioning units by full name.



Power-Flow Roof Ventilator

Certified Capacity Ratings. All performance ratings are the output of the completely assembled unit... obtained from wind tunnel tests as per *Standard Test Code for Power Roof Ventilators*... and conform to U. S. Department of Commerce Standard 178-51.

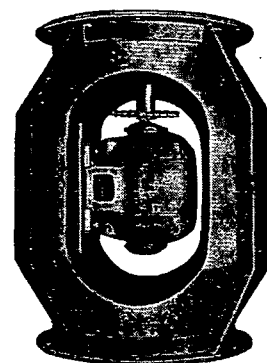
### FOR FUME REMOVAL



Bifurcator Fan

### BIFURCATOR FAN

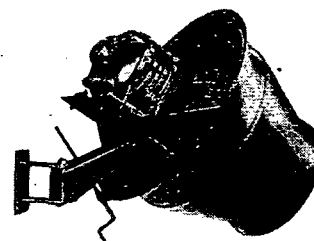
Bifurcator Fan exhausts hot, corrosive or flammable fumes. Motor is mounted in a through-ventilated chamber and destructive fumes are by-passed (bifurcated) around it. Bifurcators install directly in the duct, in any position from horizontal through vertical. Fan wheels 12 in. through 48 in. in diameter, with capacities up to 54,200 cfm. Write for Catalog.



Induced Draft Bifurcator

### INDUCED DRAFT BIFURCATOR

Induced Draft Bifurcator provides controlled draft for boilers and furnaces, eliminating the need for tall costly stacks. For high-pressure boilers delivering up to 60,000 pounds of steam per hour and for low-pressure boilers up to 190,000 EDR. Write for Bulletin.



"Hy-V" Air Jet

### "HI-V" AIR JET FOR SPOT COOLING AND GENERAL VENTILATION

"Hy-V" Air Jets blow a directed stream of cooling air as far as 60 feet without ducts. Write for Bulletin. Additional bulletins are also offered on Axial-Flow Vent Sets and Panel Vent Sets.

## Garden City Fan Company

332 South Michigan Avenue

Chicago 4, Illinois

Representatives in principal industrial cities.

Manufacturers of Design "B" Multiblade—Non-Overloading—Hi-Static Cycloidal Standard Steel Plate and Small Exhaust Fans. Wheels designed in forward curved, backward curved and radial bladed types, adaptable to commercial and industrial applications. Suitable for cooling, evaporating, drying, air-conditioning, material conveying and disposal, processing foodstuffs and animal or mineral products and by-products, induced draft, paint spray and fume removal, packaged steam generators, and requirements for fan and blower systems. Standard Steel Plate fans also produced for high temperature operation 300 F to 1600 F, N.O.L. fans to 600 F, and Design "B" Multiblade fans for temperatures to 800 F.

Non-Overloading Fan illustrates an angular up discharge position. Fan interior coated with resistant paint. Backward curved fan blades.

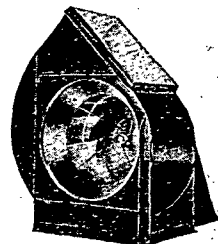
Large Design "B" Multiblade Fan for temperatures to 800 F, showing insulated cup and air-cooled fan shaft. Forward curved fan blades.

Hi-Static Cycloidal Fans—used for systems handling and conveying many materials. Specially designed fan blade reduces power requirement and operates at slow speed.

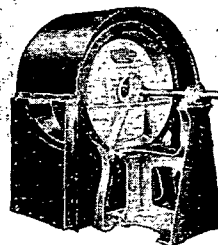
Small Exhaust Fans—steel plate housing shown. Available with cast iron housing and direct-connected motor. Wheels, 9½ in. thru 16 in. O.D.

High Temperature Fans to 1600 F. Insulated or uninsulated housings. Air-cooled shaft with ball bearings.

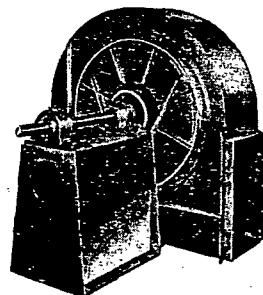
Engineering data, information, and catalogs, available upon request.



Non-Overloading Fan



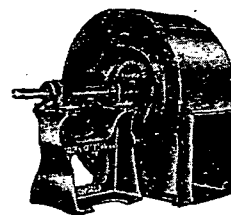
Design "B" Multiblade Fan



High Temperature Fan



Small Exhaust Fan



Hi-Static Cycloidal Fan

## General Blower Company

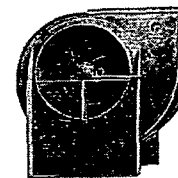


Plant

8602 Ferris Ave., Morton Grove, Ill.

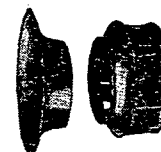
Offices

Sales Offices in Principal Cities



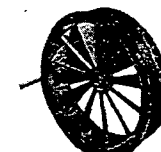
A

General Centrifugal Fans for complete range of volumes for heating, ventilating and air conditioning. Type SS (seal seam) housing construction.



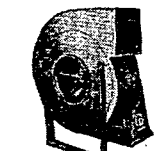
C

For Industrial applications requiring heavier construction, General offers the type W (Welded) housing construction.



B

General Backward Blade and Forward Curved fan wheels and inlet cones are assembled of spun parts for smooth quiet air movement. Ask for *Bulletins BB102* or *FC-105* for particulars.



E

General Propeller Fans supplied with either cast aluminum or steel blades from 10 in. to 72 in., with direct or belt driven arrangement. *Bulletin PF101*



H

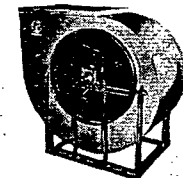
Inlet vane controls of General design are offered for manual or automatic operation.

Material handling Exhausters convey air borne particles caused by grinders, polishing or cutting. General Steel Plate Exhausters are suitable for high temperature air recirculation. *Bulletin MX-104*

General Util-A-Vent sets of FC or BB wheel construction recommended for low cost air handling requirements for ventilating and industrial needs. Direct motor connected units for up to 12 in. fan wheels. Belted units up to 36 in. *Bulletin UVS-103*

For removal of fumes and foul air where no duct system is required, General offers the Automatic Propeller type Roof Ventilator having vertical discharge. *Bulletin PF-101*

General Power Roof Ventilator, of low silhouette design having type BB centrifugal fan wheel meets architectural design requirements. Aerodynamic design provides quiet efficient operation. *Bulletin RV-101*



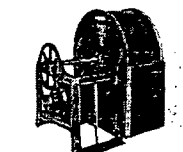
B



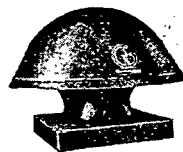
C



D



G



I

ALL GENERAL FANS TESTED ACCORDING TO NAFM STANDARD TEST CODE.



## Hartzell Propeller Fan Co.

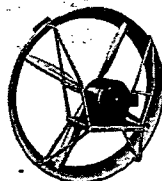
DIV. OF CASTLE HILLS CORP.

Piqua, Ohio

Engineering Offices In Principal Cities

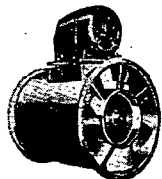
### PROPELLER TYPE FANS

Standard fans (shown) in single-propeller, two-propeller and multi-blade models, diameters from 12 in. to 60 in. Also Low Noise Fans, 24 in. to 60 in., and a special high pressure fan which operates efficiently against pressures as high as 3 in. water gauge. All can be supplied in direct-drive, belt-drive, pulley-drive or extension shaft construction—ring or panel mounted. Cast aluminum-alloy propellers.



### VANEAXIAL BLOWERS

For use in duct systems, against very heavy pressures. Direct-drive in six sizes, 18 in. to 42 in. Belt-drive in 10 sizes, 12 in. to 54 in. Air deliveries to 88,000 cfm. Special high-temperature models move air at elevated temperatures, and air containing mild acids and alkalis, without danger of premature failure of belts and bearings. All-welded construction. Dynamically-balanced cast aluminum alloy impellers.



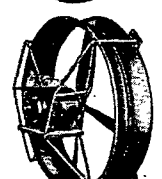
### DUCT FANS

Standard duct fans are prefabricated duct sections which can easily and quickly be bolted into place in any duct system. Direct or belt-drive, 12 in. to 60 in. Bi-Pass Duct Fan has motor in tunnel out of air stream; for high temperature applications (up to 550 F with special heavy duty construction) and for moving corrosive fumes.



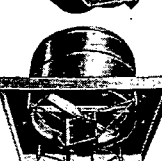
### REVERSIBLE FANS

Move air in either direction with the same high efficiency. Can be reversed manually or automatically. For many cooling and drying processes and for ventilating jobs where intake may be desired under some conditions and exhaust under other conditions. Available in 28 in., 36 in. and 44 in. fans diameters, in duct section or double-ring construction.



### ROOF VENTILATORS

The Vertijet (shown) or the Automatic Airjet attain unusual efficiency and economy through extreme simplicity of design. Lids open automatically when the fan is on, close weather tight when it goes off. Other ventilators include a Rotary Ventilator and a new Reversible Roof Ventilator which also meets all the requirements for a blackout unit.



**OTHER HARTZELL VENTILATING EQUIPMENT:** Centrifugal blowers, man and materials cooling fans, intake air units, unit heaters, aluminum and plastic adjustable-pitch fans for cooling tower and heat exchanger applications and mine ventilation.

## ILG Electric Ventilating Co.

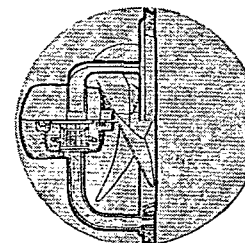
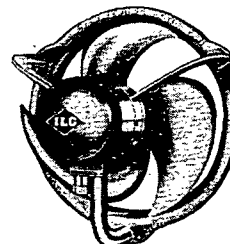
2880 North Crawford Ave., Chicago 41, Ill.

Offices in more than 40 Principal Cities



### ILG PROPELLER FANS, CENTRIFUGAL FANS, ROOF VENTILATORS

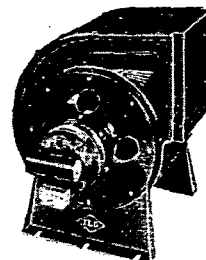
Tested and rated by NAFM, PFMA and ASHVE code. Capacities guaranteed.



Type "X" Explosion Proof Fans carry UL certification of suitability for all Class I, Group D hazardous applications.

Type "TA" Tubular Duct Fans for pressures up to 0.8 in. Easily installed duct section for vertical or horizontal use.

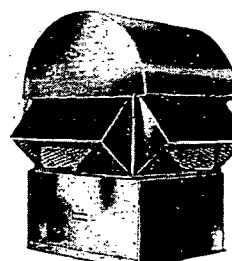
**ILG DIRECT-CONNECTED SELF-COOLED MOTOR PROPELLER FANS**—Exclusive self-cooling feature: motor covered for protection against corrosive and contaminating exhaust air, but cooled by a vent, the entrance of which is outside the exhaust area. Motor never "gums up" from contact with foul air . . . saves on power costs . . . practically no maintenance required. Direct drive assures permanent alignment. Exceptionally quiet operation. Wide range of sizes.



Volume Blower Type "B" left—Small volume, low pressure, quiet running. Cast iron base. Universal discharge positions, 7 capacities.

Volume Blower Type "P" left—For exhausting dust, fumes, vapors. Four discharge positions, 7 capacities.

**ILG DIRECT-CONNECTED CENTRIFUGAL FANS, NEW AIRFOIL TYPE BC** above, far left—Motor load is constant for wide range of volume and static pressure changes. Direct drive design with motor partially recessed, 10 sizes. Belt-drives in 12 sizes.



**TYPE LSQ**—Direct-connected propeller fan type featuring low silhouette, low maintenance and high capacity, 5 sizes up to .6 in. static pressure.

**TYPE RVS**—Centrifugal fan type, ideal for low volume requirements. 9 sizes up to .5 in. static pressure. 17 in. high above curb. Optional without damper, Type RAS, 13 in. high above curb.

**ILG PRV POWER ROOF VENTILATORS**—Centrifugal fan type, shown above left, for exhaust from vertical flues or duct systems. Direct drive, self-cooled motor. Non-overloading, backward curved wheel. 10 sizes. Up to 1½ in. Static Pressure.

## JOY MANUFACTURING CO.

General Offices: Henry W. Oliver Building, Pittsburgh 22, Pa.

### MANUFACTURERS OF VANEAXIAL FANS

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CALIF., SAN FRANCISCO 3 1155 Harrison St.  
COLO., DENVER 2 1626 Wazee St. (Schloss & Shubart)  
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IDA., KELLOGG North 1 Division St.  
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QUEBEC, MONTREAL 1275 Hodge St.

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Cie. (Marocaine) Joy, S. A. Rue de Verdi  
NORTHERN RHODESIA, N'DOLA  
Joy-Sullivan (Africa) (Pty.) Ltd.  
PERU, LIMA Casilla 3111  
SOUTH AFRICA, JOHANNESBURG  
1 Steele St., Steeledale

AND MORE THAN 500 DISTRIBUTORS THROUGHOUT THE WORLD

### SERIES 1000 AXIVANE\* INDUSTRIAL AND COMMERCIAL FANS

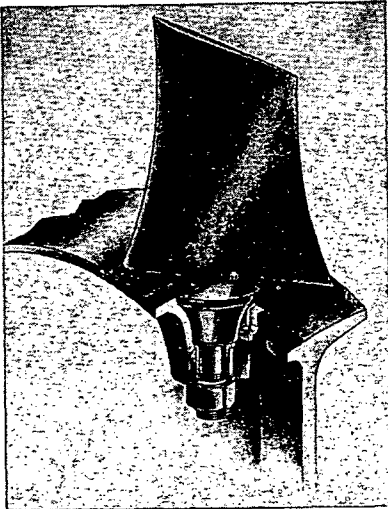
Joy Series 1000 adjustable blade AXIVANE\* Industrial fans are available in 136 sizes ranging in volume capacity up to 200,000 cfm with pressures up to 11 in. W. G. Housing diameters range from 18 in. to 84 in. For complete specifications, construction details, and selec-

tor charts giving pressure-volume range for each fan, write for bulletin number J-611.

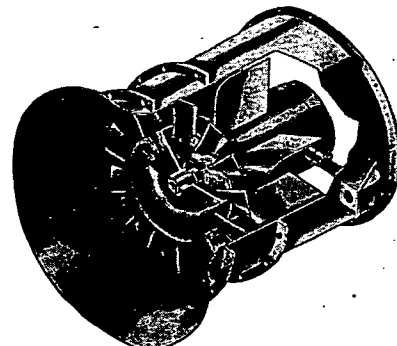
Joy AXIVANE\* Series 1000 fans are efficient, quiet, compact, flexible, and easy to install.

#### ADJUSTABLE BLADES

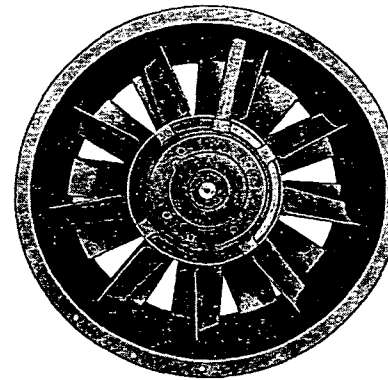
Joy AXIVANE\* Industrial Fans have the extra performance flexibility of adjustable blades. Adjustable blades are standard equipment on all Series 1000 fans. The factory blade setting can be quickly changed to provide either a wide pressure range for any particular volume or a change in a volume simply by loosening



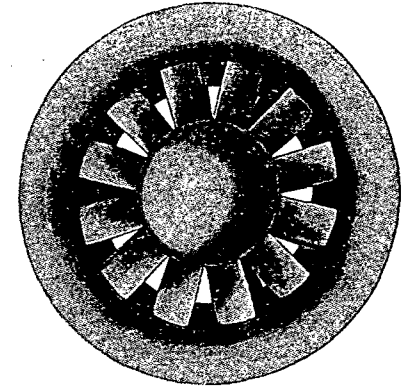
Blades are adjustable on the job by loosening one lock nut



Cutout drawing showing location of motor and compact construction



Rear view, showing vanes and motor



Front view, showing simplicity of construction

ing a lock nut with a wrench, setting the blades uniformly with the indicator, and retightening the lock nut. A permanent stop prevents setting blades in a position likely to overload the motor. Minimum blade settings are limited by the fan housing.

Adjustable blades permit on-the-job correction for unpredictable duct resistance or for poorly installed duct work.

#### MORE EFFICIENT

Stationary straightener vanes, located immediately behind the rotor, partially recover the rotative energy imparted to the air by the rotor, and re-establish axial flow to the air leaving the vanes. This eliminates excess turbulence at the point where the air enters the duct system and increases efficiency by decreasing pressure loss.

The Joy AXIVANE\* fan utilizes an aerodynamically efficient blade and stationary vane design.

#### QUIETER OPERATION

For equal weight and space the Joy AXIVANE\* fan is quieter than a centrifugal type fan of equal volume and pressure. The streamlined airflow from an AXIVANE\* fan makes sound insulation a simple and inexpensive operation when required for the ventilation and air conditioning of quiet spaces such as hospitals, auditoriums, radio stations, etc., where insulation against system noise must be used.

#### MORE COMPACT

Joy AXIVANE\* fans are built around the motor, the fan housing becoming an actual part of the duct system. This produces a more compact design than is

possible with a centrifugal fan. An AXIVANE\* fan, installed on an in-line connection with ventilation ducts, parallel to and close by an overhead structure, may require 70 per cent less space than a conventional belt-driven centrifugal fan. The compactness of a Joy AXIVANE\* fan assures a maximum of net operating or rentable area. Fan rooms are virtually eliminated.

#### EASIER TO INSTALL

The Joy AXIVANE\* Series 1000 fan develops a greater volume and pressure per pound of fan and motor because of its compact, in-line construction. This light weight permits a simplicity of installation that minimizes installation costs and total weight by eliminating heavy foundations, complex duct offsets and elbows, drives and guards. AXIVANE\* fans can be installed quickly and easily, even by relatively inexperienced or unskilled labor.

#### MATCHED ACCESSORIES

Inlet bells, screens, and fan supports are accessories designed to fit all AXIVANE\* fan housings. In ordering, it is only necessary to state the model number with or without the accessories as desired. If required with accessories, these will be furnished to fit the fan model ordered without special number.

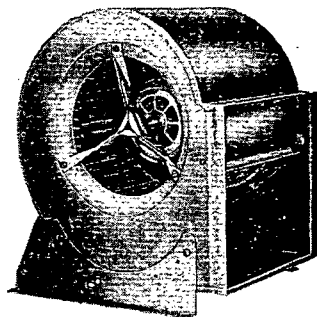
No matter how carefully a duct system is planned, an incorrectly selected inlet bell will reduce fan efficiency by increasing intake turbulence. This excess turbulence will also increase the noise level of the fan. When a fan takes its air directly from the weather, a plenum, a fan room, or from a duct system larger in circumference than the fan housing, a bell should be used.

\* Reg. U. S. Pat. Off.

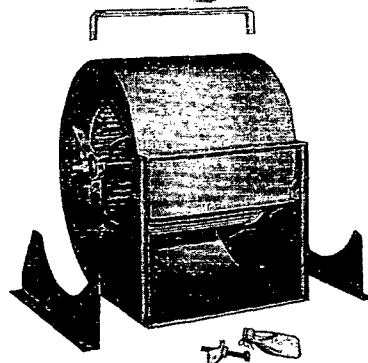
## The Lau Blower Company

2004 Home Avenue, Dept. J, Dayton 7, Ohio

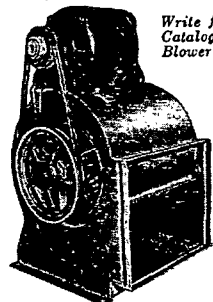
In Canada • The Lau Blower Company of Canada, Ltd., Kitchener, Ont., Canada  
Manufacturers of Exhaust and Portable Fans, and Air Conditioning Blowers



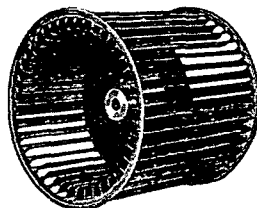
LAU all new \*ELECTRO-WHEEL BLOWER: Two unobstructed air inlets on wheel sides plus compact motor design gives more air delivery with less power load. Stationary shaft with rubber mountings reduces vibration to a minimum. Rugged tripod mountings give greatest shipping strength without impeding air flow. Air deliveries from 500 to 1500 cfm, static pressure from .5 to 1.25 in. (water gauge),  $\frac{1}{4}$  hp motor. Available in 115 and 230 volt ac. Housing supports optional. Pre-punched holes in housing unit make any discharge angle possible.



LAU Econo-Pak Blowers cover most applications for residential air-moving equipment; effect savings up to 10 per cent by eliminating special blowers for each application; reduce blower inventories by simplified order procedures, quick handling of model changes, lower handling costs, up to 26 $\frac{1}{2}$  per cent reduction in warehouse space. Three Basic Sizes each in 2 widths, with all features of Standard Series A Blowers. Package Includes blower wheel, housing with cut-off, housing supports, motor mount (not attached), all hardware. Exclusive Lau-Pak Bearings without oil cups require no lubrication. Adjustable Discharge, any one of 5 positions.



Write for LAU Blower Catalog 707. Mention all Blower items of interest.



LAU Standard Blower Assemblies (Series A), heavy-gauge steel housing assemblies, entire unit die-formed. Capacity range 350-22,000 cfm. Motor Mounting adjustable for any motor location. Housing Base heavy 16-gauge steel, rigid. Discharge Outlet improved design, construction. Belt special composition for blower operation. Shafting 2-stage centerless ground, burnished. Bearing Bracket 3-point suspension; same bracket used for all discharge angles. Lausteel Pulleys employed; V.S. motor pulley allows speed variations up to 30 per cent. Center Suspended Wheel. Embossing of Scroll Sides reinforces venturi inlet and discharge. Bearings highest grade self-aligning porous bronze sleeve type. Plastic Thrust Washer absorbs shocks.

LAU Spun Wheels, Center Suspended Riveted Wheels, S.I. and D.I. Weld Wheels, a complete wheel line. Spun Wheels center disc construction; baked enamel, Ruspruf, or hot-dip galvanized

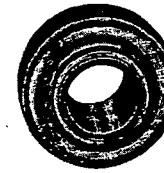
## The Lau Blower Company

2004 Home Avenue, Dept. J, Dayton 7, Ohio

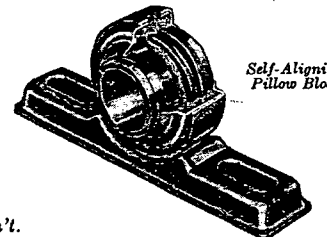
In Canada • The Lau Blower Company of Canada, Ltd., Kitchener, Ont., Canada  
Manufacturers of Exhaust and Portable Fans, Air Conditioning Blowers



Lau Series A Bearing



Lau-Pak Gold Seal Bearing



Self-Aligning Pillow Block

LAU Series A and Lau-Pak Gold Seal Bearings are noted for their high performance and longer life. Series A is a self-aligning, self-oiling bronze bearing held in housing under uniform spring pressure; bore sizes  $\frac{5}{8}$ ,  $\frac{3}{4}$ , 1 and  $1\frac{1}{16}$  in. Lau-Pak Gold Seal Bearings require no additional lubrication; ample supply of plastic petroleum is sealed in housing; bore sizes  $\frac{5}{8}$ ,  $\frac{3}{4}$ , 1, and  $1\frac{1}{16}$  in.

LAU Self-Aligning Pillow Blocks are low-cost, light-weight, oil-tight steel housings with porous bronze bearings. Hold much more oil than cast iron types. Durex bushing feeds oil to shaft by capillary action. Spring keeps spherical surface of bearing and ring in close contact. Long bolt slots permit interchanging with other makes of pillow blocks. Bore sizes available are  $\frac{5}{8}$ ,  $\frac{3}{4}$ ,  $1\frac{1}{16}$ , 1, and  $1\frac{1}{8}$  in.

con't.

finish; standard steel or Power Lock hubs. Center Suspended Wheels, blades double-riveted to end rings, are welded to center disc, diameters 18 in.-30 in.; standard steel or Power Lock hubs. S.I. and D.I. Weld Wheels, individual blades of correct length, width, pitch; baked enamel, Ruspruf, or plated; diameters  $4\frac{1}{2}$  in.-9 in.; widths  $2\frac{1}{4}$  in.-9 in.

Lausteel Variable and Constant Speed Pulleys are in balance and true-running. Lausteel Variable Speed Pulleys available in three standard bores:  $\frac{1}{2}$ ,  $\frac{5}{8}$ , and  $\frac{3}{4}$  in. Diameter  $3\frac{1}{4}$  in. OD. Allow speed variations up to 30 per cent for many drive combinations. Lausteel Constant Speed Pulleys available in diameters of 6 in. to 10 in., inclusive. Suitable for both "A" and "O" section belts. Lau also offers cast iron pulleys in diameters of 11 in. to 14 in.

LAU Niteair\* Exhaust Fans for residential, commercial, and industrial use. Niteair\* Rancher, for homes with low-pitched roofs, pulls air up through ceiling opening; four sizes: 24-30-36-42 in. Niteair\* Panel Unit in standard and heavy-duty models, with four blades properly pitched for greatest air movement; five sizes: 24-30-36-42-48 in. All Lau Fans carry PFMA Certified Ratings and UL Approval; also regular manufacturer's warranty.

\* T. M. Reg. U. S. Pat. Off.



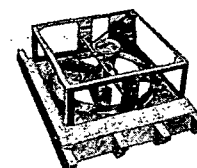
Variable Speed Pulley



Constant Speed Pulley

LAU Blower Catalog 707 contains full information on Pillow Blocks and Pulleys.

Niteair\* Rancher



Niteair\* Panel Unit

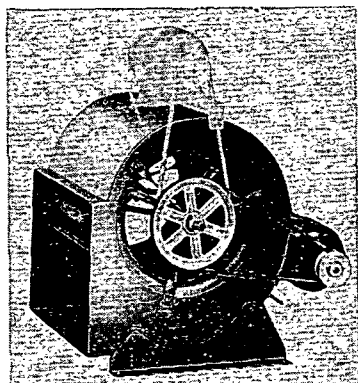
LAU Fan Catalog gives you complete details. Write for it.



## Morrison Products, Inc.

A 33 Year Firm

East 168 Street and Waterloo Road, Cleveland 10, Ohio



Belt Drive Blower

### MORRISON COMPLETE BLOWER ASSEMBLIES AND PARTS

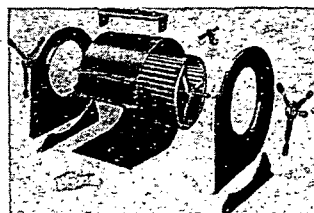
Made exclusively for original equipment manufacturers of heating, ventilating and air conditioning products.

#### MORRISON BLOWER WHEELS

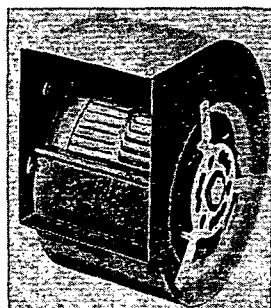
Are double width-double inlet in standard diameters from 10 in. to 20 in. and 6 in. to 20 in. wide.

#### ONE-PIECE BLADE CONSTRUCTION

Three-piece balanced assembly—one-piece blade and two pressed end rings of



Exploded View-Belt Drive Parts



Direct Drive Blower

deep drawn steel. Never any loose blades. Spot welded for lasting strength and quiet operation.

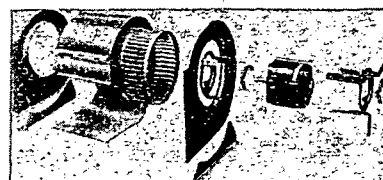
#### MORRISON PARTS

for manufacturers who want to build their own blower assemblies and thus save approximately 50 per cent of their Blower Dollar investment.

#### COMPLETE ENGINEERING SERVICE

Shop drawings, certified performance data, cost analysis.

Morrison Catalog No. 603 Belt Driven Blowers, and Catalog No. 604 Direct Drive Blowers mailed upon request.



Exploded View-Direct Drive Parts

## nyb THE NEW YORK BLOWER COMPANY

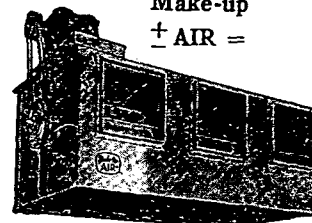
SALES OFFICES • 3145 SOUTH SHIELDS AVENUE • CHICAGO 16

FACTORY, LAPORTE, INDIANA

Representatives in Principal Cities

FANS • BLOWERS • UNIT HEATERS • MAKE-UP AIR UNITS  
HEAVY DUTY HEAT SURFACE

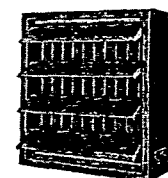
Make-up  
+ AIR =



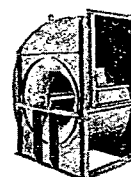
M15—15,000 cfm



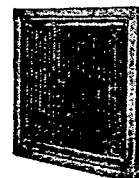
Propeller Fan



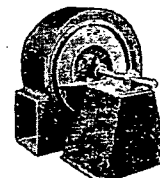
Unit Heater



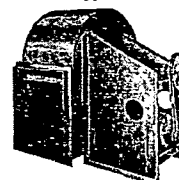
IPL Fan



Steelfin



Type GI



General Purpose Fan

M15—A unit that delivers, warmed, filtered, outside air to industrial spaces to replace exhausted air and balance minus pressure. Corrects drafty conditions and uncontrolled infiltration. Made in 4 sizes from 5,000 cfm to 20,000 cfm. Described in Bulletin 523.

IPL Centrifugal Fans—Capacities up to 101,000 cfm. Slow speed wheels offered from 7½ to 73 in. Capacities up to 123,000 cfm. Quiet operating (IPL) medium speed wheels with non-overloading horsepower characteristics for heating, ventilating and air conditioning or industrial applications. Wheel diameters from 18 in. to 73 in., with any speed or discharge required. Class I, II, III or IV construction. Write for Bulletins 543 and 544.

Steelfin Hot Blast Heating Surface—Extra heavy duty, fin-and-oval tube, all-steel, welded construction. A hot dip metallic coating over all, including headers, affords perfect bonding and conductivity. Suitable for continuous heating service on steam pressures up to 150 lb. Bulletin 492.

nyb Propeller Fans—Deliver large volumes of air at low resistance and low current consumption. All wheels are machine balanced for smooth, vibrationless operation. Made in two types and eight basic sizes. Wheel diameters from 12 in. to 48 in. Direct or belted drive. Capacities from 400 cfm to 23,500 cfm. Ask for Bulletin 541.

nyb Unit Heaters—Heavy duty, welded steel, fin-and-tube heating element. Suitable for continuous heating service on steam pressures up to 150 lb or more. 10 sizes with capacities from 30 Mbh to 490 Mbh. Bulletin 522.

Type GI Industrial and Heat Fans—For dust and gas removal, conveying of materials and handling hot gases. Housings, drives, and discharge arrangements to meet any requirement. Wheel diameters from 10 in. to 66 in. Capacities from 450 cfm to 60,500 cfm. Details and engineering data in Bulletin 521.

General Purpose Fans—Portable, self-contained units for Class I industrial and ventilating applications. Recommended for ease of installation, low maintenance and space saving features. Made in three types and eight basic sizes. Capacities 400 cfm to 18,000 cfm. Bulletin 545.

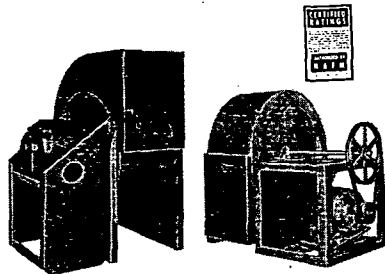


# The Peerless Electric® Company

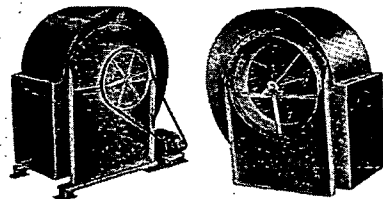
W. Market Street • Warren, Ohio

REPRESENTATIVES IN PRINCIPAL CITIES

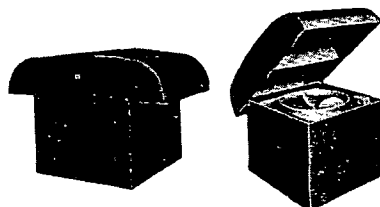
Industrial and Commercial Ventilating Equipment



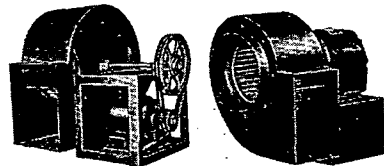
**BACKWARD CURVE BLOWERS**—In sizes from 12½ in. to 49 in.; self-limiting hp characteristics; *NAFM* standards; dynamically balanced wheel; heavy cast-iron hub; nothing in air stream; quiet entry, passage and exit; job-matched motor; convertible discharge; belt drive or direct drive.



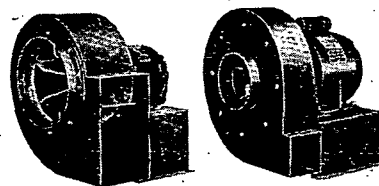
**ARRANGEMENT 3**—12 in. through 48 in. wheel; clockwise or counterclockwise rotation; convertible discharge; single or double width; motors and drives available; vibration bases optional; ball or sleeve bearings furnished.



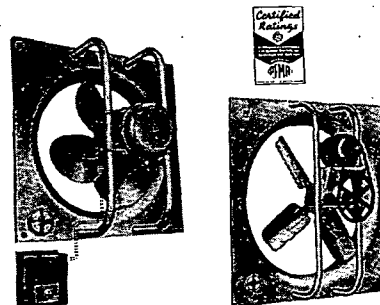
**POWER ROOF VENTILATORS**—Direct or belt drive; 12 in. to 48 in.; 600 to 25,000 cfm; complete with disconnect switch; totally enclosed motor; automatic shutters; inside insulation; 16 gauge steel housing; baked enamel finish.



**UTILITY BLOWERS**—Belt or direct drive with clockwise or counterclockwise rotation; ¼ through 7½ hp; motors in all current characteristics; convertible discharge; arc-welded housing; sleeve or ball-bearing construction; weatherproof drive covers optional.



**RADIAL BLADE BLOWERS**—¼ to 2 hp; slow and high-speed units; self-cleaning wheel; ball or sleeve bearing motors; discharge as specified; base and housing of heavy-gauge steel.



**INDUSTRIAL EXHAUST FANS**—Vertical or horizontal mounting; totally enclosed motors; adjustable motor base; continuous duty; ball-bearing construction; cfm rating from 470 to 29,350; mount with 4 or 6 lag screws.

# PROPELLAIR® Div.

ROBBINS & MYERS, INC.

1947 Clark Boulevard  
SPRINGFIELD, OHIO

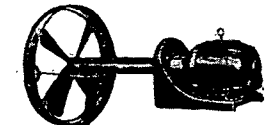
HEAVY-DUTY INDUSTRIAL VENTILATING  
EQUIPMENT

OFFICES IN PRINCIPAL CITIES



For Ducts,  
Walls, Windows, Hoods,  
Roof Ventilators

Propellair  
Direct-  
Connected  
Fans

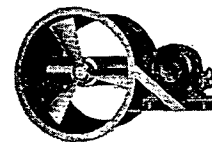


For Heat, Moisture, Fumes,  
Dust, and Gases

Propellair Extended-Shaft Fans

For use wherever motors may operate within the air stream, from free air to medium and relatively high resistance. A compact, durable design with fan having two to six blades. Sizes: 12 in. to 60 in. Capacities: 1,020 to 85,000 cfm. Type "CD."

This design locates motor outside air stream when fan is installed in duct at right angle turn, elbow, "Y," or offset. Simple installation usually can be supported by duct without auxiliary bracing. Drive shaft is enclosed and sealed within steel tube. Sizes: 12 in. to 60 in. Capacities: 1,020 to 78,800 cfm. Type "CE."



For Heat,  
Acids, Alkalies—Fumes,  
Gases, Dust

Belt-Driven  
Propellair  
Tube-Axial  
Type

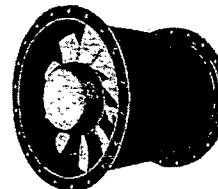
A complete fan unit in short duct section ready for installation in lines from 20 in. to 60 in. diameter. Type "CS" may be used for severe acid or alkaline conditions, explosive fumes and gases. Type "CSV," for excessive temperatures, circulates outside air through belt and fan shaft tubes to keep drive and bearings cool. Capacities: 5,075 to 78,000 cfm.

Power Roof Ventilator

Propellair  
Sky-Blast®



Dependable and economical power roof ventilators. Butterfly dampers open wide the instant fan is started, close automatically as fan coasts to a stop, offer virtually zero resistance as heat, fumes, moisture, dust shoot high into air. Rain is prevented from entering by fan when operating. Drainage shed prevents leakage when dampers are closed. Sizes: 16 in. to 60 in. Capacities: 2,800 to 78,000 cfm.



Propellair  
Vaneaxial  
Fans

A compact, highly efficient pressure fan using standard steel drum sections incorporating standard *NEMA* frame motors in direct drive models. Also available in belt-driven ratings with motor outside the air stream. Cast aluminum airfoil propeller and guide vanes for maximum efficiency and durability. Available in 20, 24, 30, 36, 48, and 60 in. diameters in belt and direct driven models. Capacities from 3410 to 85,000 cfm.

Airfoil Principle  
Entrance Ring



Airfoil-Section Blades

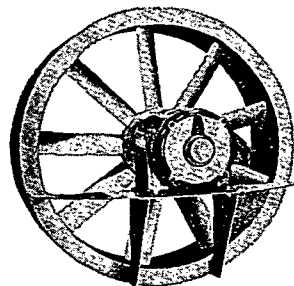
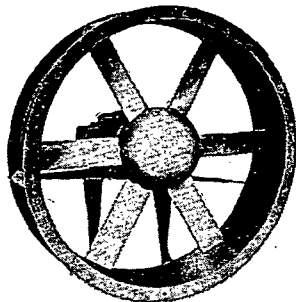
Propellair fans have airfoil-section blades with variations of pitch, curvature, and thickness to compensate for different lineal speeds of points at various radii. Air movement is uniform over whole fan area. The Propellair curved entrance ring eliminates eddy currents; helps efficient Propellair blades deliver highest pressure and volume.

# Reed

## Unit-Fans, Inc.

1001 Saint Charles Ave., New Orleans, La.

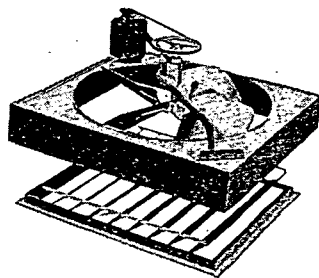
Manufacturers of Industrial, Direct-Drive Axial Flow Fans, Belt-Drive Exhaust Fans, Window Fans, Attic Fans and Portable Air Circulators



### REED INDUSTRIAL AXIAL-FLOW FANS

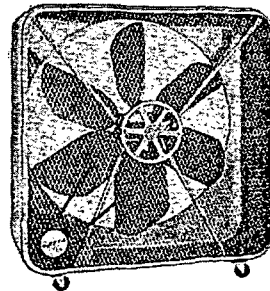
The Reed APD Industrial Fan line consists of heavy-duty axial-flow direct-connected fans capable of operating against static pressures up to 3 in. water gage, with air delivery ratings from 1,000 to 100,000 cfm. Cast aluminum air foil blades of unique design make it possible to vary the number of blades and their angle of attack, thus providing the necessary flexibility to custom-build to specific requirements.

The basic line consists of four groups of sizes, namely 9 in. through 18 in., 21 in. through 27 in., 30 in. through 36 in., and 42 in. through 60 in. These groups are further subdivided in 3 in. steps. Totally enclosed ball-bearing motors, either single or three phase are standard, but special motors are furnished on request. Fan frames are of heavy hot-rolled steel, electro-welded throughout.



### REED PACKAGED ATTIC FANS

Seven stock sizes ranging from 24 in. to 48 in. blade dia. Corresponding free air cfm ratings of from 5,000 to 18,600. Simply and quickly installed with hanging brackets on rafters. Completely automatic shutters.



### REED PORTABLE AIR CIRCULATORS

Supplied in 5 stock sizes; 22 in., 26 in., 30 in., 36 in., and 42 in. blade dia. Wire guards front and back, four hard-rubber casters at bottom of fan case. Completely vibrationless, two-speed and reversible. Ideal for commercial and industrial spot-cooling.

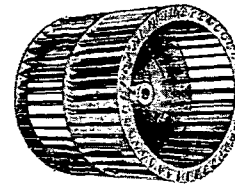
## Revcor

249 Edward Street

Carpentersville, Illinois

Phone: HAZEL 6-4819

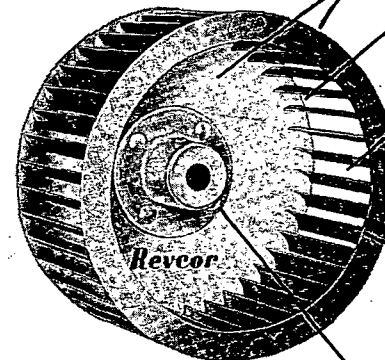
ENGINEERS AND MANUFACTURERS OF SINGLE AND DOUBLE BLOWER WHEELS AND HOUSINGS



Two single inlet blower wheels welded together back to back and having a common hub make up the REVCOR DOUBLE INLET BLOWER WHEEL. Any two REVCOR single inlet wheels of the same diameter and of the same or varying widths can be assembled to make the double inlet blower wheel.

Heavy gauge backplate and inlet ring assure rigid support for blades and hub.

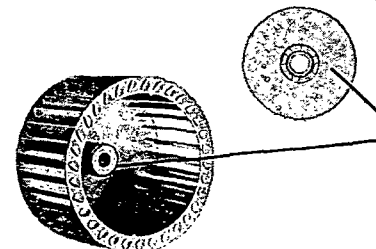
Individual blades of correct number, curvature, depth, and blade angle to deliver the greatest amount of air both efficiently and quietly.



FULL WIDTH blades with a blade tip diameter substantially the same as the outside diameter of the wheel enable REVCOR BLOWER WHEELS to deliver the MAXIMUM AIR AND PRESSURE FOR THE SPACE DIMENSIONS REQUIRED.

Blade tips projecting through slots in the backplate and ring are bent toward the blade curvature to securely lock the backplate and ring between the bent tip and the shoulder at each end of the blade. Tips may be spot welded for greater strength when required for special severe applications.

Cast hubs are attached to the backplate with 4 or 6 rivets. Hubs can be mounted either inside or outside of the wheel.



SIZES: 1 1/4 in. to 12 3/4 in. Diameter; wheel widths from 5/8 in. Special Sizes of Single and Double Inlet Blower Wheels can be made to your specifications.

Hubs machined from bar stock are attached to the serrated center hole in the backplate by curling the hub material on to the backplate. The hub material is then pressed into the serrations in the backplate to key the hub to the wheel to prevent loosening. Hubs can be mounted either inside or outside of the wheel.

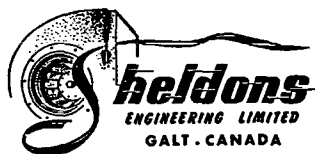
MATERIALS: Steel. Also available in Aluminum, Brass and Stainless Steel.



AVAILABLE: Sheet Metal Housings for all Revcor Wheels

### FREE REVCOR CATALOG

Containing technical details, diagrams, specifications, and sizes of Revcor Blower Wheels. Write direct to: REVCOR, 249 Edward Street, Dept. R, Carpentersville, Illinois



SALES OFFICES: MONTREAL, OTTAWA, TORONTO, HAMILTON, LONDON  
AGENTS: HALIFAX, ST. JOHN, N.B., WINNIPEG, CALGARY, EDMONTON, VANCOUVER

Fan Manufacturers For More Than 60 Years  
Member Canadian Fan Manufacturers' Association.

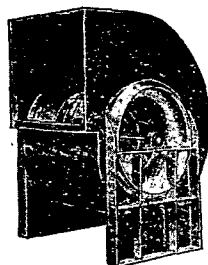
### AIR HANDLING APPARATUS

for every industrial, commercial, mining and processing need

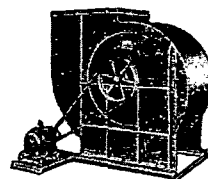
For more than 60 years this Company has been well and favorably known in Canada as manufacturers of high-quality air-handling equipment. SHELTON products are accepted as "EQUAL" to any other similar apparatus produced on the American Continent.

Inquiries invited for specifications and full information on SHELTON Fans, Blowers, Exhausters, Heating, Ventilating and Air-Conditioning Apparatus, and allied equipment required on your Canadian projects.

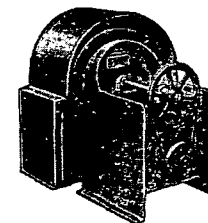
Air Conditioning Units • Keith and Silavent Fans • Utility Sets • Forced Draft Fans • Induced Draft Fans • Airscrew Fans • Axial Flow Fans • Medium Blowers and Exhausters • Mill Exhausters • Dust Separators and Collectors • Dust Filters • Centrifugal Blowers • Unit Heaters • Drying Equipment • Chemical Plant Fans • Mine Ventilating Fans •



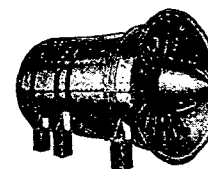
Silavent Fans



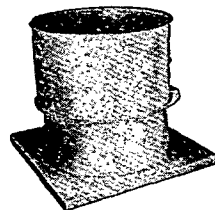
Keith Fans



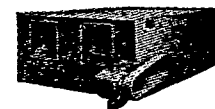
Utility Sets



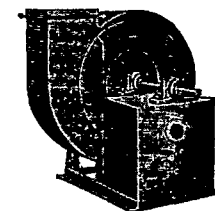
Axial Flow Fans



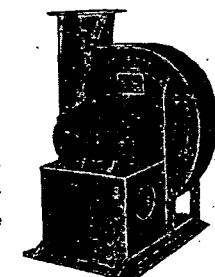
Roof Ventilators



Air-Conditioners



Mill Exhausters



Pressure Blowers

Complete engineering data and catalogs available upon request



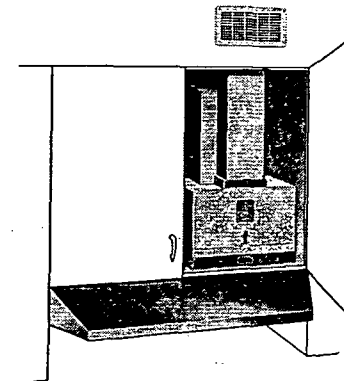
### Trade-Wind Motorfans, Inc.

7755 Paramount Blvd.  
Riverside, Calif.

Representatives  
In All Principal  
Cities. Carried in  
Stock By Many  
Electrical Jobbers

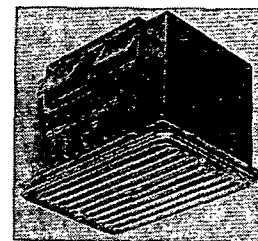
### CABINET VENTILATOR

At left, Model 3501 for kitchen cabinets, shown with optional Stationary Hood.



**SUPER CLIPPER MODEL 3501.** 550 cfm kitchen ventilator installs in cabinet directly over stove. The dual inlets, one directly over the stove, the other at ceiling level are equipped with cleansable metal filters. The unit has twin blowers, isolated and radio shielded 140 watt motor, 4-speed switch control and built-in back draft damper. Three optional hood styles are available. Finished in choice of copper or stainless steel, the Stationary Hood comes in standard sizes from 30 in. to 48 in. The Expansion Hood adjusts from 30 in. to 54 in. The stainless steel Fold-Under Hood comes in 39 in. or 42 in. sizes.

### CEILING VENTILATORS

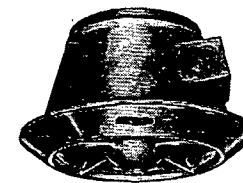


Trade-Wind ceiling ventilators are designed for small rooms such as kitchen, laundry, den, ticket booths, offices and photographic darkrooms. They come in complete "unit package" assembly, requiring only the application of a discharge duct for installation. Units are Underwriters' approved and listed and carry a (pro-rata) five year guarantee.

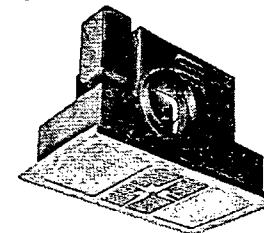
**CLIPPER MODEL 2501.** Shown above. 425 cfm for 2000 cu ft room. Dual centrifugal blowers. 130 watt motor. Interchangeable horizontal or vertical discharge, complete with grille and 4-speed switch.

**CLIPPER MODEL 1501.** 300 cfm for 1000 cu ft room. Dual centrifugal blowers. 105 watt motor. Interchangeable horizontal or vertical discharge, complete with grille.

**CLIPPER MODEL 1201.** 100 cfm for bathrooms only. 50 watt motor. Horizontal discharge, complete with grille. Optional time delay switch available.

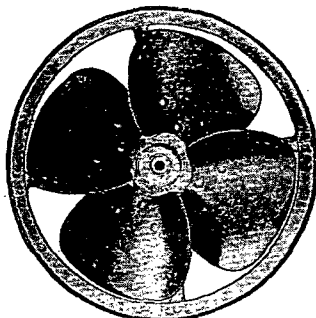


**AXIAL FLOW MODEL AF-7M.** Compact 300 cfm axial flow ventilator for ceiling or wall in 100 cu ft room. It can be installed between joists in ceiling or between studs in the side wall. No elbows are required for vertical discharge. 50 watt motor. Available with aluminum or ivory grille.

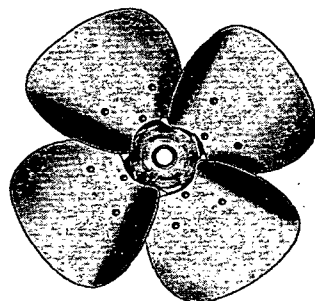


**VENTILATOR/LIGHT MODEL 1701.** 100 cfm for bathrooms. 50 watt motor, horizontal discharge. Features modern Alba-lite glass grille, with two light sockets. Unit is prewired to external switch box. May be connected to single or double switch. Optional time delay switch available.

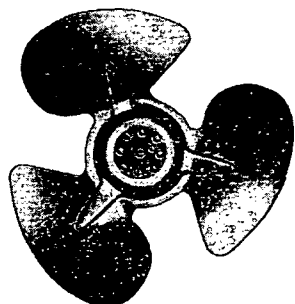
THE  
**TORRINGTON**  
MANUFACTURING COMPANY  
TORRINGTON, CONNECTICUT  
VAN NUYS, CALIFORNIA • OAKVILLE, ONTARIO



"Slinger Rings" for Assembled Fans



"P" Series Airstocrat Fan Blades



New "LU" Series One-piece Airstocrat Fan Blades

"Slinger Rings" for Assembled Fans—A rolled ring, L-shaped in cross-section, with riveted construction. Designed to adapt all popular sizes of assembled Airstocrat fan blades for application in eliminating condensate from room air conditioners. Design allows considerable flexibility as to diameter, location of ring on periphery of blade, etc., without expensive tooling.

"P" series AIRISTOCRAT fan blades—This fan blade has outstanding pressure characteristics and is widely used in room air conditioning units—many times with slinger rings. It is available in heavy gauge construction in all diameters and in light gauge construction on certain diameters for special applications.

New "LU" Series One-Piece AIRISTOCRAT Fan Blades—An extremely quiet and very efficient one-piece fan designed especially for refrigeration and air conditioning applications. This quality product is hand-set to assure accurate forming and alignment. Made of aluminum, pierced for all unit-bearing motors. Sizes: 7 $\frac{3}{4}$ , 8 $\frac{3}{4}$ , and 10 in. diameters.

Torrington Airotor Blower Wheels are light, sturdy and inexpensive—incorporate new principles of design and construction, which insure rigidity and concentricity. Single Width—Single Inlet wheel is of simple four-piece construction. No rivets or welds are used; concentric rib serving as backing for blade strip is formed at same time as hub socket, insuring trueness of wheel. Rigid radial ribs prevent deflection by thrust. Three thicknesses of metal in rims make for maximum strength. Excellent for many heating and ventilating uses. Manufactured in both aluminum and steel in 1 $\frac{1}{2}$  in., 2, 3, 3 $\frac{3}{8}$ ,

The Torrington Mfg. Co.

4 $\frac{1}{4}$ , 4 $\frac{3}{4}$ , 4 $\frac{7}{8}$ , 5 $\frac{1}{8}$ , 5 $\frac{1}{4}$ , 5 $\frac{3}{4}$ , 6 $\frac{1}{8}$ , 7 $\frac{1}{8}$ , 7 $\frac{3}{8}$ , 8 $\frac{1}{2}$ , 9 $\frac{1}{8}$  and 11 in. diameters. Clockwise or counterclockwise rotation. Same sizes available in DA type double width, double inlet wheels.

Torrington Airotor Blower Wheel—Double Inlet—Spider End Plates. Has blades punched and formed in a single strip, rigidly held by flanged single piece end rings. Hubs are rigidly mounted by peening. Wheels of 2 $\frac{1}{2}$  in., 3, 3 $\frac{3}{8}$ , 7 $\frac{3}{8}$ , and 11 in. diameter are available at present. Additional sizes now being developed.

"E" Series AIRISTOCRAT Fan Blades—Outstandingly high efficiency is the chief characteristic of this fan blade. It delivers more air for any given horsepower. Size for size it looks bigger, more powerful.

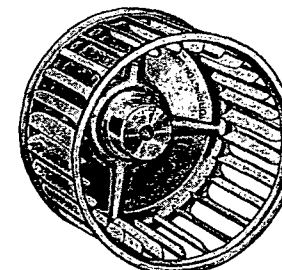
Convincing proof of the superior performance of this fan may be found in the NEMA and NAFM tables prepared as a guide to selection. The catalog containing these tables and specifications will be mailed upon request.

Specifications: Three-blade models in 10 in., 12, 14, 16, 18 and 20 in. diameters; four-blade models 8 in., 10, 12, 14, 16, 18, 20, 22 and 24 in. diameters. Five pitches in most sizes. Aluminum blades, steel spider and hub.

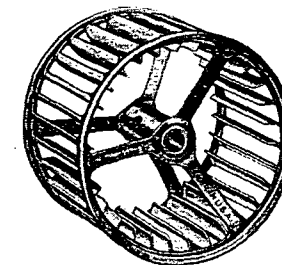
Neoprene Hubs for Shaded Pole motors—designed to minimize the transmission and amplification of motor noises by the fan blade. These hubs are currently available in  $\frac{1}{4}$ ,  $\frac{3}{16}$ ,  $\frac{3}{8}$ ,  $\frac{1}{2}$ ,  $\frac{5}{8}$  in. diameters for Torrington propeller fans up to and including 12 in. diameters.

AIRISTOCRAT "M" Series—Master Ventilating (Attic Fan) Blades—Three outstanding features of this new design are: (1) Extremely high efficiency, which gives maximum cfm per horsepower; (2) knockdown construction which drastically lowers shipping costs; (3) quiet operation—a point of major interest to the consumer.

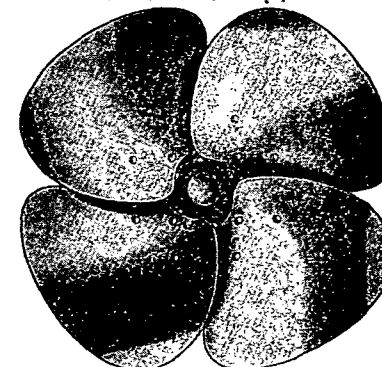
This all steel four-blade fan is manufactured for domestic application exclusively, in 24, 30, 36, 42 and 48 in. diameters, in 40 deg pitch only.



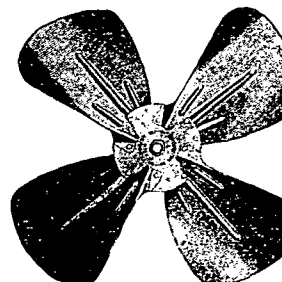
Airotor Blower Wheel—Single Width—Single Inlet  
Patents 2,231,062; 2,272,695 Des. 126,043



Airotor Blower Wheel Double Inlet—Spider End Plates



4-Blade Airstocrat Fan "E" Series



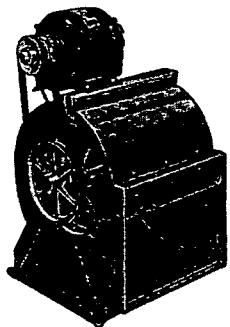
4-Blade Airstocrat Attic Fan "M" Series

## Viking Air Products Division

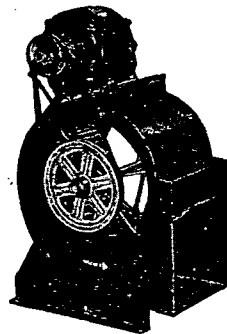
of National-U. S. Radiator Corporation

5601 Walworth Ave., Cleveland 2, Ohio

Heating, Cooling and Ventilating Blowers for Furnace and Air Conditioner Manufacturers



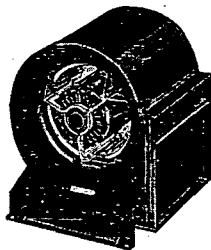
Belt Drive Blowers



Universal Foot Blowers

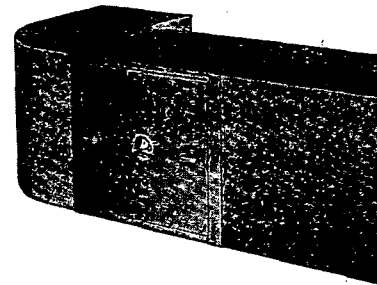
In addition to standard (Top Horizontal, Bottom Horizontal, Upblast and Downblast) positions, motor can be mounted and outlet located in any specified position.

Both Belt Drive and Direct Drive Blowers are available without foot mounted. Lock-on feet provided which you can mount in any position on your own production lines.



### New Direct Drive Blowers

Equipped with  $\frac{1}{8}$ ,  $\frac{1}{4}$  or  $\frac{1}{2}$  hp motors. New 6-point motor mount test-proven to resist shipping abuse. Mount by feet in standard positions or by outlet in any other position. Brackets available if you choose to buy and mount motors at your plant.



### Universal Duct Blowers

Designed to be mounted in duct work in any position required to boost air movement for heating, cooling and ventilating.

New 16 page "Viking Blower Assembly Work Book"—For use in specifying sample model blower assembly you need for testing with your air conditioner, cooling tower, and evaporative cooler.

### Contents:

1. Air Selector Table for determining cfm
2. Blower Capacity Table
3. Speed Ranges of Variable Pitch Pulleys
4. Dimensions of Blowers in all positions
5. Motor Location Grid for 9 in., 11 in., 13 in. blowers... with acetate template guide
6. Belt size table for all motor positions
7. Effect of side and rear wall clearance on performance
8. Effect of blower outlet and furnace drum clearance on efficiency

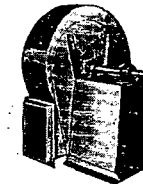
## Western Blower Company

Main Office and Plant: 1800 Airport Way, Seattle 4, Washington

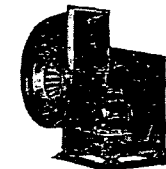
Sales Offices in the Principal Cities West of Rocky Mountains



Turbine Multi-Blade Fans



Mill Exhausters



Pulley Driven Utility Sets

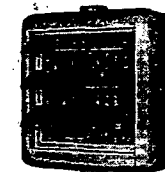
**Turbine Multi-Blade Fans**—forward curved blade, Type TR, or backward curved blade, Type "S," fans for heating, ventilating, mechanical draft, etc. *Bulletins No. 30 and 31.*

**Mill Exhausters**—single or double for material conveying exhaust systems, direct connected or V-belt driven. *Bulletin No. 32-3.*

**Pulley Driven Utility Sets**—V-belt driven, slow speed, quiet operating, for general utility duct ventilating systems. *Bulletin No. 31.*



RB Volume And Pressure Fans



Western Unit Heaters

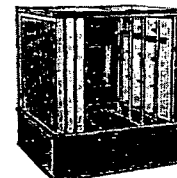


Centrifugal Exhaust Fans

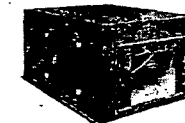
**RB Volume And Pressure Fans**—radial blade type either direct connected or V-belt driven for ventilating and conveying applications. *Bulletin No. 39.*

**Western Unit Heaters**—vertical or horizontal, for general heating and drying applications. *Bulletin No. 53.*

**Centrifugal Exhaust Fans Series 59**—for general exhaust systems. Complete packaged units. *Bulletin No. 59.*



Air Washers



Volume Heaters



Spirovane Propeller Fans

**Air Washers**—for cleaning, cooling, humidifying and dehumidifying. *Bulletin No. 30.*

**Volume Heaters**—with one or more centrifugal fans for heating, ventilating and air conditioning. Available in vertical or horizontal cabinet units. *Bulletin No. 54.*

**Spirovane Propeller Fans**—furnished either direct connected or V-belt driven for commercial or industrial ventilation. *Bulletin No. 50.*

**Olympic Heat Exchangers**—Converters, Side Arm Heaters, Immersion Heaters, Oil Heaters, and Condensate Coolers.

*Bulletins as listed above furnished upon request*



## Westinghouse Electric Corporation Sturtevant Division

Heating, Ventilating, Dust Control and Fume Removal Equipment, Electronic Air Cleaners, Mechanical Draft Equipment

Hyde Park

Offices in Principal Cities

Boston 36, Mass.

### AIR HANDLING PRODUCTS

**Centrifugal Fans**—General purpose and Heavy Duty centrifugal fans are highly effective in both commercial and industrial service. Capacities up to 480,000 cfm and pressures up to 32 in. w.g.

**Axial Flow Fans**—Axiflo fans are designed to operate against resistance, are available for either vertical or horizontal airflow. Widely used in industrial heating, ventilating and fume removal.

**Ventilating Sets**—Series 900: direct connected units for maximum efficiency at popular motor speeds. Manufactured in six sizes up to 3200 cfm. Series 1000: compact V-Belt driven units for large capacity and quiet operation. Twelve sizes up to 14,400 cfm.

**Air Handling Units**—For year-round air conditioning, also available for heating and ventilating or ventilating only. They feature sectional construction, various types of coils, and accessories to give combinations to suit the application and space. Capacities to 23,000 cfm.

### HEAT TRANSFER PRODUCTS

**Heat Transfer Surfaces**—Sturtevant cooling and heating coils are available for Freon, chilled or hot water and steam. Steam coils are of standard, heavy duty steam, and steam-distributing types.

**Air Blenders**—For both winter and summer conditioning of individual rooms, air blenders mix conditioned air from a central system with recirculated air.

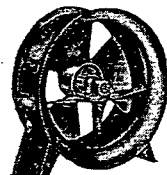
**Surface Dehumidifiers**—For central plant air conditioning, these sprayed coil units are available with chilled water or direct expansion coils. Capacities to 115 tons of refrigeration and 45,000 cfm.

### UNIT HEATERS

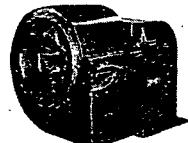
**Industrial Heaters**—For heating of manufacturing areas, warehouses, garages and general industrial and commercial buildings. Also for continuous duty heating in industrial processes and steel, paper and rubber manufacturing. Capacities to 2,500,000 Btuh and 25,000 cfm. **Propeller Fan Heaters**—Available for steam, hot water and gas-fired applications in horizontal and downblast models. Capacities range from 20,000 to 400,000 Btuh.



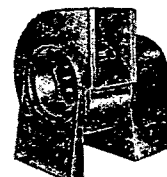
Silentzone Centrifugal Fan Design 10



Axiflo Fan Design 2 A



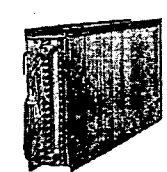
Direct-Connected Ventilating Set



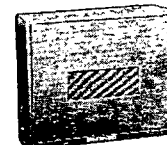
V-Belt Ventilating Set



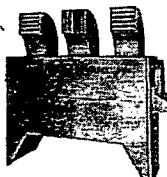
Air Handling Unit Type AH



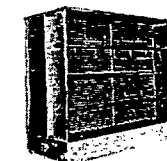
Direct Expansion Type EA Evaporator Coil



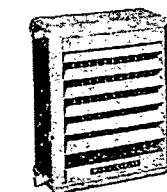
Air Blender



Industrial Heater



Surface Dehumidifier



Horizontal Speedheater



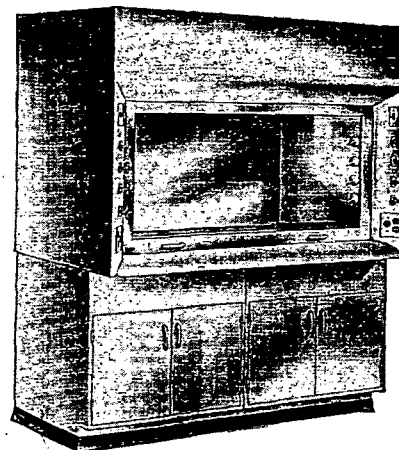
Downblast Speedheater

## Kewaunee Manufacturing Company

5119 South Center Street, Adrian, Michigan

Representatives in principal cities.

Products: AIRFLOW control fume hoods—CONVENTIONAL fume hoods—SPECIAL purpose hoods—C.B.R. SYSTEM laboratories and components—LABORATORY EQUIPMENT—wood-metal construction—HOSPITAL casework—EDUCATIONAL equipment—LABORATORY SINKS and SERVICE FIXTURES.



Catalog No. 3604 (Stainless steel interior)  
(72 in. long, 38 in. wide, 84 1/4 in. high)

Safe operation for personnel protection and comfort is paramount with Airflow fume hoods. Aerodynamically efficient, modern design enables Airflow hoods to operate at lower face velocities. Gently curved, streamlined entrance shapes at the hood face decrease turbulence—increase efficiency.

Airflow hoods operate at 50 lineal feet per minute minimum face velocity, thereby effecting reductions in cost of operation for heating and cooling systems. Automatic bypass results in constant-volume exhaust regardless of sash position. Hoods are available in various sizes in addition to those listed below. Interior lining materials include stainless steel, Kemstone and Transite. Exterior of hoods is carbon steel with acid resistant painted finish.

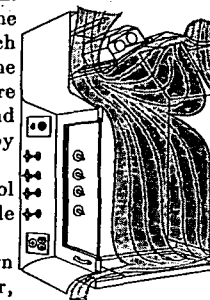
| Recommended Min. Face Velocities and Total cfm |                     |                              |           |
|------------------------------------------------|---------------------|------------------------------|-----------|
| Length of Hood                                 | Overall Dimensions  | Min. Face Velocity @ 1/4" sp | Total cfm |
| 4 ft                                           | 49" x 38" x 84 1/4" | 50 fpm                       | 375       |
| 5 ft                                           | 61" x 38" x 84 1/4" | 50 fpm                       | 500       |
| 6 ft                                           | 72" x 38" x 84 1/4" | 50 fpm                       | 625       |
| 8 ft                                           | 96" x 38" x 84 1/4" | 50 fpm                       | 875       |

### Automatic bypass-constant volume hoods especially adaptable for air conditioned laboratories.

The bypass is completely open in the down position of the sash. Air enters through the bypass and purges the interior of the hood. Use of the bypass limits the maximum air velocity such that disturbing air currents cannot be induced within the hood. This bypass is positive and completely automatic—there are no moving parts, controls or linkages to require service and maintenance. Operation of the bypass is controlled solely by positioning of the sash.

Booklets on "Airflow Fume Hoods" and "Airflow Control Fume Hoods Characteristics and Applications" are available without charge or obligation upon written request.

The Kewaunee Manufacturing Company's two modern plants in Adrian, Michigan, are equipped to design, engineer, and manufacture nuclear laboratory equipment, and scientific laboratory furniture. One of our field engineers will gladly visit you, upon request, to discuss the requirements of the job you have in mind and to offer any service possible without cost or obligation.



Sectional view with sash down.



## E. H. Sheldon Equipment Company

Muskegon, Michigan

### SHELDON INDUCTION FUME HOODS

Manufacturers of Laboratory Equipment for Schools, Industry, and Hospitals.

SHELDON'S *induction* hoods are designed for use in air-conditioned laboratories or in any situation where it is necessary to conserve room air.

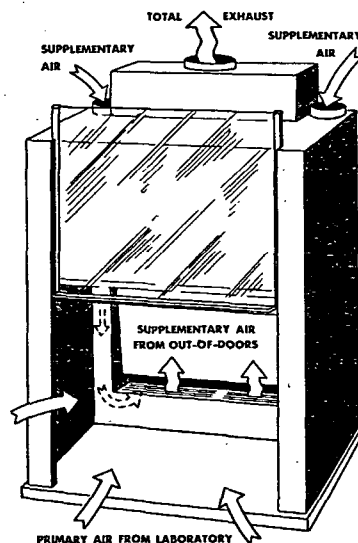
By injecting regulated volumes of "out-door" air into the working areas of the hood to supplement the primary airflow from the laboratory, the following controlled conditions may be achieved:

1. Sufficient volume of air passes through the working areas of the hood at the face velocity required to insure complete evacuation of fumes from the system. The exhaust system of the Sheldon induction-type hood handles the same *volume* of air that the exhaust system of the conventional hood handles at a face velocity of 70-80 linear feet per minute.

2. At the same time, air movement from the room into the hood has a low enough velocity to minimize turbulence within the hood and assure quiet operation, and to prevent objectionable drafts in the work area, and excessive drain on the heating, cooling, and air-conditioning systems of the room. The difference between the exhaust volume and the volume of intake from the room is provided by adjusting the supplementary-air supply.

3. Sufficient volume of air flows into the hood from the room to carry generated fumes into the fast-moving, high-volume evacuation air currents, and also to insure optimum laboratory air changes.

If air movement from adjacent parts of the building to the laboratory is desired, a condition of negative pressure in the laboratory may be induced by lowering the supply-fan capacity or increasing the exhaust-fan capacity. Also, even if the front sash is closed, the hood will purge of fumes because a definite part of the exhaust capacity is still being supplied



mechanically and passes through the hood.

Except for minimum filter requirements, provided for in the hood design, supplementary air seldom needs to be treated, since it does not enter the room.

The following table gives the velocity, velocity pressure and total entrance loss for both exhaust and supply for various lengths of hoods with duct sizes as shown in diagrams below. These values are for volumes as shown. These values are based on exhaust fan capacity capable of producing a face velocity of 75 lfm with only the exhaust fan operating and with a supply fan capable of introducing  $\frac{3}{4}$  the exhaust capacity and producing a face velocity of 25 lfm with both fans operating.

## E. H. Sheldon Equipment Company

Muskegon, Michigan

### SHELDON INDUCTION FUME HOODS

Manufacturers of Laboratory Equipment for Schools, Industry, and Hospitals.

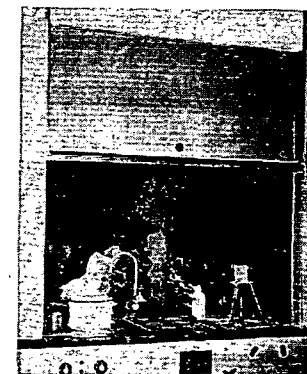
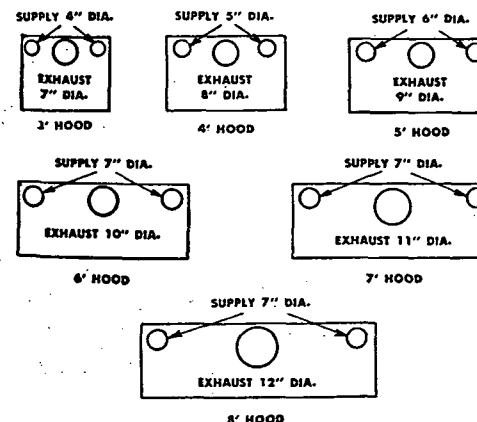
| EXHAUST @ 75 L.F.M. face Vel. |      |      |      |               | SUPPLY @ $\frac{3}{4}$ of exhaust |      |      |               |
|-------------------------------|------|------|------|---------------|-----------------------------------|------|------|---------------|
| Hood Length                   | cfm  | Vel  | V P  | Entrance Loss | cfm                               | Vel  | V P  | Entrance Loss |
| 3'                            | 487  | 1800 | 0.20 | 0.30          | 324                               | 1800 | 0.23 | 0.34          |
| 4'                            | 690  | 2000 | 0.25 | 0.37          | 460                               | 1800 | 0.20 | 0.30          |
| 5'                            | 900  | 2000 | 0.25 | 0.37          | 600                               | 1650 | 0.17 | 0.26          |
| 6'                            | 1087 | 1900 | 0.23 | 0.42          | 724                               | 1400 | 0.13 | 0.20          |
| 7'                            | 1275 | 2000 | 0.25 | 0.44          | 850                               | 1600 | 0.16 | 0.24          |
| 8'                            | 1500 | 2000 | 0.25 | 0.44          | 1000                              | 1800 | 0.20 | 0.30          |

\* Total negative static developed by the hood.

The conversion factor to obtain entrance loss from velocity pressure is 1.5 for 3 ft, 4 ft and 5 ft hoods, and 1.75 for 6 ft, 7 ft and 8 ft hoods.

\*\* Total positive static developed by the hood.

The conversion factor for all hoods for the supply air static is 1.5. These statics should be added to the duct resistances when computing fan sizes.



5' Hood operating under the above conditions.

The duct stubs are located on the top of the hoods as shown. The supply air can enter from below when building conditions require such arrangement. The values given in the table for various lengths of hood are for average conditions.

Consultation is solicited without obligation on other or unusual conditions. Since the hoods use a definite volume of "conditioned" air, their requirements should be considered very early in the

work of designing and specifying heating and/or conditioning plants.

Sheldon engineers welcome new problems arising out of recent production and development programs. A laboratory at Muskegon is maintained for this purpose. A list of satisfied users of a wide variety of industrial installations is available upon request.

Contact the Muskegon office for the field engineer nearest you.



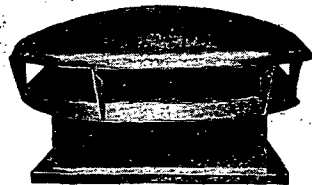
## Allen Cooler & Ventilator Inc.

Rochester, Michigan

Representatives in Principal Cities

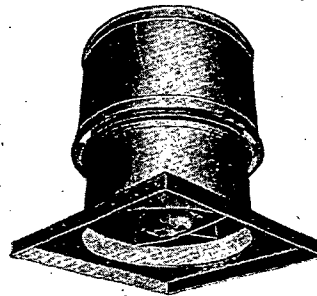
See Sweet's Catalog  
for Further Details

Write to Factory  
for Catalog



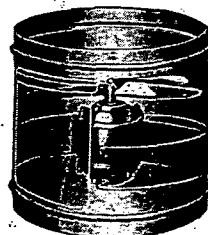
### LOW SILHOUETTE ROOF FAN

Allen "I-Line" Roof Fan is designed to meet the architect's demand for an attractive low silhouette and the engineer's demand for high efficiency. This is accomplished by use of a circular spun steel hood, and venturi, with baffle so arranged in relation to the propeller as to provide maximum efficiency with minimum over-all height. Its appearance and quiet performance recommend it for new or old construction, such as schools and offices as well as industrial plants. It is easy to install (no extra base required) and it is easy to lubricate and clean. Available with *Direct Drive* (450 to 34,000 cfm) or with *Belt Drive* (4,000 to 20,150 cfm).



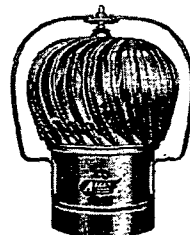
### VERTICAL DISCHARGE FAN

Allen Type "VD" Roof Fan is designed for use where extremely high discharge velocity prevents the tendency of fumes to short circuit back through building openings. Fabricated of prime zinc-coated iron sheet, welded construction throughout. Automatic wing dampers open with air blast, close weathertight when not operating. Available with *Direct Drive*, with motor readily accessible, or *Remote Drive*, with motor in outside housing and enclosed V-belt drive.



### STAXAUSTER FAN

Allen Staxauster is a simple, compact, sturdy unit that can be used to convert all types of roof ventilators into powerful exhaust or air supply units. It is available in many sizes with either *Direct Drive* or *Remote Drive* for handling corrosives and/or high temperature air.



### TURBINE VENTILATOR

Allen Type "C" Turbine Ventilator is wind driven and economically removes heated air, fumes and dust. It is made of heavy-gage coated iron or of special non-ferrous metals, and is easy to install and maintain. Many thousands of Type "C" Turbines are in use in industry.

## AirXpeler EXHAUSTERS

Write for special  
engineers bulletin

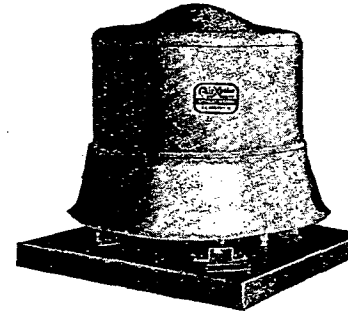
## C. L. Ammerman Co.

110 North Second St., Minneapolis 1, Minn.

Exhausters Powered or Gravity  
Underfloor and Overhead Systems

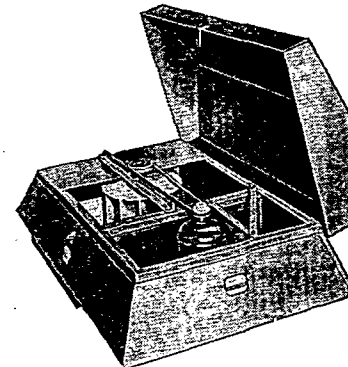
See Sweet's file  
for further details

### BACKWARD CURVE DIRECT CONNECTED



"BCD" Non-Overloading Roof or Wall Exhauster. Designed for optimum performance at lowest possible velocities, reduces noise level to an absolute minimum. Motor directly connected to dynamically balanced wheel eliminates costly maintenance.

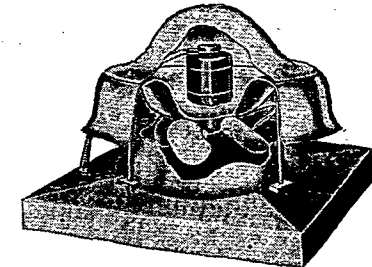
### BELTED ROOF EXHAUSTER



"BCB" Lo-Boy Non-Overloading Centrifugal Wheel. Capacity table offers a selection of 16 wheel sizes—204 constant speed combinations with tip-speeds as low as 2000 fpm. Unit is exceptionally low in height. Standard construction consists of welded structural steel frame, heavy 16 gauge mild steel. Storm band and motor cover is 18 gauge.

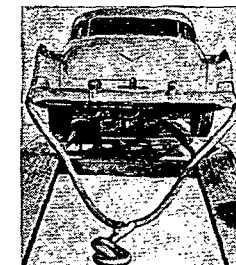
Patents No. 2571513-26666378. Others Pending

### POWER ROOF EXHAUSTER



"PB" or "PFAS" Lo-Boy Wall or Roof Units. Efficient and quiet operation for low static pressures up to  $\frac{1}{2}$  inch. Rubber grommets are installed around all points where metal contacts metal. Powered fresh air supply units on "PB" exhausters with reversed pressure blade to bring fresh air in under power.

### DISAPPEARING EXHAUST SYSTEMS



Under the Floor and Overhead exhaust systems for all makes and models of cars and trucks. Will accommodate flexible metal hose up to six inches in diameter. Write for Bulletin No. 650H.

## THE G. C. BREIDERT CO.

P.O. Box 1190, San Fernando, Calif.

Representatives in Principal Cities of the United States

### MANUFACTURERS OF VENTILATORS FOR EVERY NEED!

There is a Breidert Air-X-Hauster for every ventilation problem. Breidert guarantees **POSITIVE VENTILATION UNDER ANY WIND CONDITION**, barring internal negative pressures!

#### FOR ROOF VENTILATING:



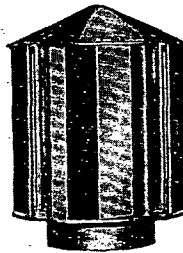
Patents applied for



Old Method  
of Testing



Breidert Method  
of Testing



Patent # 2269428

#### THE NEW BREIDERT POWAIR-X-HAUSTER—

The latest addition to the Breidert line of Air-X-Hausters is this low silhouette power unit. Its unusually large capacity against high static resistance is made possible by horizontal discharge. The top-mounted motor is kept cool and trouble free by ingenious use of outside air. Continues to operate by gravity action when power is off!

#### FOR CHIMNEYS

Breidert Air-X-Hauster Chimney Tops overcome sluggishness caused by down drafts... have produced excellent results on Industrial, Commercial and Residential applications.

In every case where Breidert Air-X-Hausters were properly installed they have never failed to function as advertised.

Write for Free Engineering Data Book containing detailed specifications and installation data and certified capacity ratings.

• Pittsburgh Testing Laboratories

#### THE ORIGINAL BREIDERT AIR-X-HAUSTER—

A gravity flow ventilator, stationary with no moving parts. Widely used on all types of factories, commercial buildings and residences. Breidert Air-X-Hausters pioneered with published certified capacity ratings based on tests\* made with wind blowing in all directions as shown. Only such tests can guarantee the capacities a ventilator will deliver under actual operating conditions.

#### FOR GAS APPLIANCES

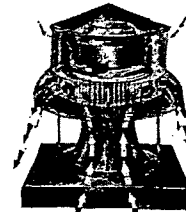
The Breidert L. S. Vent Flue Cap assures positive ventilation with complete safety. Pilot lights cannot be blown out, barring internal negative pressures!

## The Gallaher Company

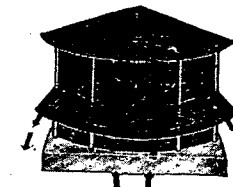
4108 Dodge Street, Omaha 3, Nebraska

Representatives in Principal Cities of USA and in Canada by Canada Fans Ltd., Montreal

Manufacturers of AIR-VAN® and AIR-MAX® Power Roof Exhausters



Pat. 2188241 2526290  
Pat. Pending

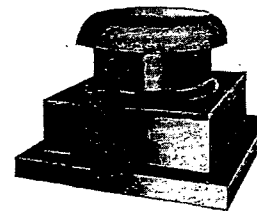


#### Series 1, 2, 3, 4, AIR-VAN® Direct Drive

Capacities 150-11,700 cfm. Static Pressure to 4 in. Low installed silhouette design with motor out of airstream for protection against fumes. Exclusive Gallaher scroll effect design. Shipped as complete package ready for installation. Series 1, 2, and 3 have forwardly curved wheels with blades at varying angles. Series 4 has backwardly curved non-over-loading wheels. Choice of wheels allows buyer to tailor-make unit and select exact capacity desired. Ratings are certified by an independent laboratory.

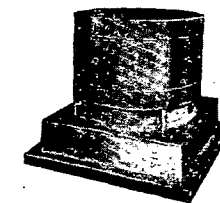
#### Series 5 AIR-VAN® Belt Drive

Capacities 1,000 to 65,000 cfm. Static Pressures to 4 in. The one belt driven power roof exhauster with guaranteed high static pressures and air volumes. Motor out of airstream. Patented scroll effect design. Shipped as complete package including base. Does not require extra height for unobstructed discharge. Extremely heavy construction. Certified ratings by an independent laboratory. Weatherproof under extreme conditions.



#### AIR-MAX® Downblast Model C

Capacities 1,000 to 44,000 cfm. Static Pressures to 1/2 in., and more on special order. Designed to handle relatively dry air at minimum horsepower. Low silhouette. Economical direct connection to duct system without field assembly. Fully blackout. Certified Ratings. Can be furnished for summer or winter supply as well as exhaust. Propellers incorporate latest features in air foil design—four or six blades. Can be replaced without buying new wheel.



#### AIR-MAX® Upblast Model CU

Capacities 1,000 to 44,000 cfm. Static Pressures to 1/2 in. and more on special order. Designed for upward discharge. Special clam shell type dampers give weatherproof protection when units are not in operation. Units have low silhouette characteristics of all Gallaher units. Sturdy construction throughout. Damper stops prevent locking in the open position.

Units can be supplied in Aluminum, Copper, Monel, Stainless Steel, and in any resistant finish.

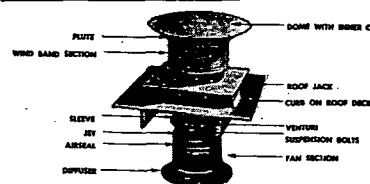
For complete catalog information including certified rating tables, and all pertinent selection and installation data, write The Gallaher Company or contact its representatives.

# GENIE-AIR Subject to Magic Control GENIE-AIR

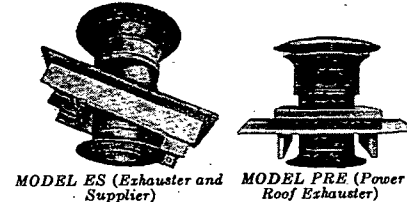
4273 So. Broadway

Multi-Functional Powered Roof Ventilators

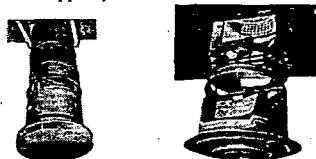
Los Angeles 37, Calif.



MODEL ER (Exhauster and Recirculator) Patent No. 2700331 Other patents pending



MODEL ES (Exhauster and Supplier) MODEL PRE (Power Roof Exhauster)



MODEL RS (Recirculator and Supplier) DELUXE MODEL ERS (Exhauster, Recirculator and Supplier)

Unit selection table dependent upon roof height (To be used with all models except Power Roof Exhausters)

| Max. Roof Height—To | 12' | 14' | 16' | 18' | 20' | 22' | Over 22' |
|---------------------|-----|-----|-----|-----|-----|-----|----------|
| Genie-Air Unit Size | 15  | 17  | 19  | 21  | 25  | 31  | 38       |

GENIE-AIR Performance Data For All Models

| Unit size | cfm   | Fan rpm | h.p. | Phase | Voltage | Drive | Weight |     |
|-----------|-------|---------|------|-------|---------|-------|--------|-----|
|           |       |         |      |       |         |       | PRE    | ER  |
| 15-10     | 1000  | 1140    | 1/8  | 1     | 115     | DD    | 70     | 80  |
| 15-14     | 1400  | 1140    | 1/8  | 1     | 115     | DD    | 70     | 80  |
| 17-18     | 1800  | 1140    | 1/8  | 1     | 115-230 | DD    | 75     | 85  |
| 17-22     | 2200  | 1140    | 1/8  | 1     | 115-230 | DD    | 75     | 85  |
| 19-27     | 2700  | 1140    | 1/8  | 1     | 115-230 | DD    | 85     | 95  |
| 19-30     | 3000  | 1140    | 1/8  | 1     | 115-230 | DD    | 85     | 95  |
| 21-33     | 3300  | 1140    | 1/8  | 1     | 115-230 | DD    | 100    | 110 |
| 21-37     | 3750  | 1140    | 1/8  | 1     | 115-230 | DD    | 100    | 110 |
| 25-41     | 4100  | 1140    | 1/8  | 1     | 115-230 | DD    | 150    | 160 |
| 25-47     | 4700  | 1140    | 1/8  | 1     | 115-230 | DD    | 150    | 160 |
| 31-55     | 5500  | 850     | 1/8  | 1     | 115/230 | BD    | 260    | 300 |
| 31-65     | 6500  | 750     | 1/8  | 1     | 115/230 | BD    | 260    | 300 |
| 31-80     | 8000  | 750     | 1/8  | 1     | 115/230 | BD    | 265    | 305 |
| 38-10     | 10850 | 900     | 1/8  | 3     | 220/440 | BD-DD | 310    | 360 |
| 38-13     | 13000 | 545     | 1/8  | 3     | 220/440 | BD    | 315    | 365 |
| 38-14     | 14400 | 1140    | 1/8  | 3     | 220/440 | DD    | 315    | 365 |
| 38-16     | 16800 | 1140    | 1/8  | 3     | 220/440 | DD    | 320    | 370 |

GENIE-AIRS exhaust, recirculate, supply or mix recirculated and supply air—any 1,2,3 or all 4 functions with the same unit.

MODEL ER exhausts in summer and recirculates in winter. During the recirculating cycle the butterfly dampers, which seal the opening between the roof jack collar and sleeve section, remain in closed position and the heated air trapped at the roof line is recovered through the opening between the venturi and jet and returned to the occupied area; thus improving the efficiency of the heating system and reducing operating costs as well as initial costs. The cycle of operation may be changed at any time through a three-position switch or thermostat. In new design the amount of heat normally required can be greatly reduced when used in conjunction with these units. This model, with slight modifications, can also provide for supply of fresh air.

MODEL ES either exhausts or provides for supply of fresh air merely by reversing fan rotation through a three-position switch.

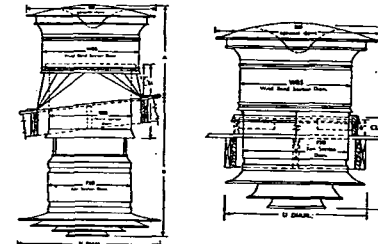
MODEL PRE is a typical power roof ventilator. This unit is equipped with butterfly dampers, which prevent heat loss in winter. Domes are optional.

MODEL RS recirculates or supplies; also, any proportion of recirculated and supply air may be obtained by varying the opening between the venturi and jet thru a manually, pneumatically, or electrically-operated mechanism. Filters are optional.

DELUXE MODEL ERS provides all four functions listed above. Filters are optional. Raise the sleeve or fan section for recirculated or exhaust air and close it for supply. The sleeve or fan section is raised or lowered by: (1) gear ratio motor and rack assembly, controlled either by a three-position switch or thermostat or (2) manual mechanism. This model available in sizes 31 and 38 only.

NOTE: Cfm delivery of all models has been calculated on the basis of the static pressure through the unit. As the percentage of cfm delivery is reduced when fan blade rotation is reversed, specify on which cycle of operation the greater cfm is required. Units having larger capacities or special combinations of fan blades, motor sizes and speeds are available on special order.

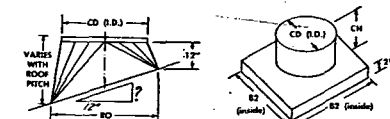
## Dimensional Data



Models ER, RS, ERS

Models ES and PRE

Type 1 and Type 2 roof jacks, as illustrated below, are furnished with all Genie-Airs. Any model may be installed in either type of roof jack; however type 2 is preferred because of its simplicity of installation. In either case, CD dimension plus 2 in. must be held vertically clear downward through the full length of equipment below the underside of roof. Unit sizes 31 and 38 require support in addition to the roof jack. Support is to be furnished by others. See suggested method for framing or support.



Type 1 Roof Jack

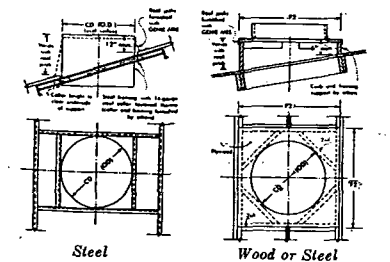
Type 2 Roof Jack

The Following Dimensions Are to Be Used With Type 1 Roof Jack:

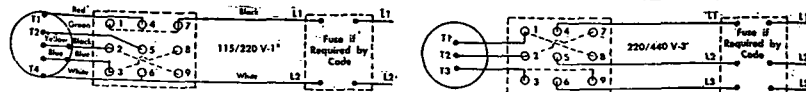
| Genie-Air<br>Size | Models ER, RS,<br>and ERS |     |     | Models PRE |    | Models E |    |
|-------------------|---------------------------|-----|-----|------------|----|----------|----|
|                   | A                         | *SL | *B  | A          | *B | A        | *B |
| 15                | 27                        | 27  | 37  | 27         | 16 | 27       | 17 |
| 17                | 29                        | 27  | 38  | 29         | 16 | 29       | 17 |
| 19                | 29                        | 27  | 38½ | 29         | 16 | 29       | 17 |
| 21                | 35                        | 27  | 39½ | 35         | 16 | 35       | 17 |
| 25                | 39                        | 27  | 43½ | 39         | 17 | 39       | 17 |
| 31                | 42                        | 27  | 51½ | 42         | 18 | 42       | 17 |
| 38                | 44                        | 28  | 52½ | 44         | 19 | 44       | 18 |

\* Dimensions (in inches) Based on 12 in. Roof Jack Height But May Be Varied.

## SUGGESTED METHODS FOR FRAMING OR SUPPORTING SIZES 31 & 38



## SUGGESTED ELECTRICAL SWITCH WIRING USING 3-POLE DOUBLE-THROW SWITCH



See our complete catalog in A-E-C Catalog File or write to above address.

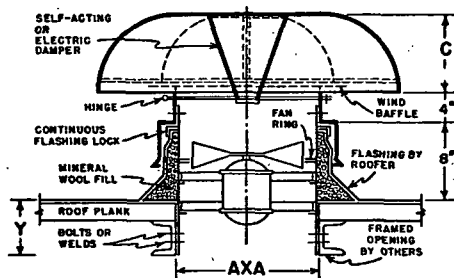
## Hirschman-Pohle Co., Inc.

Since 1908

200 Lent Ave. . . . LeRoy, N. Y.

Sales Representatives in Principal Cities

Manufacturers of all types of Power and Gravity Roof Ventilators

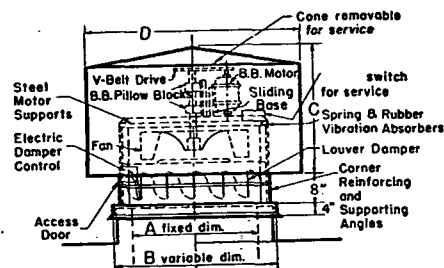


Minimum Overall Height

(So Desirable for Modern One-Story School Buildings)

|                  |        |     |     |     |        |     |     |     |     |
|------------------|--------|-----|-----|-----|--------|-----|-----|-----|-----|
| Roof opening "A" | 10"    | 12" | 15" | 18" | 20"    | 24" | 30" | 36" | 42" |
| Cowl height "C"  | 5 1/4" | 6"  | 7"  | 8"  | 9 1/4" | 11" | 12" | 14" | 16" |

The Hirschman Type "CAF" Electric ventilator shown has been designed in response to a demand for the absolute minimum in overall height above the roof line, and as standard construction uses our INSULATED DOUBLE SHELL STEEL CURB of any of the several types for any kind of roof deck. Fan and motor assembly available for a wide range of capacities at the lower static pressures. The companion Type "CA" gravity or pressure relief ventilator (not shown) uses the same general construction minus the fan and motor. Either type subject to numerous modifications to meet the needs of any building project.



Our Type "LA" STATICK Power ventilator designed for efficient exhaust at either low or high static pressure, using non-overloading backward curved blade centrifugal fan, available in many sizes for almost any required capacity within reason. Note the damper housing above the top of the curb providing ready access to whatever type of damper is used. The Type "LB" STATICK Power ventilator (not shown) uses a similar construction minus the damper housing.

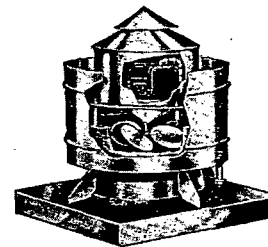
See Sweet's Architectural, Engineering, or Industrial Construction Files.  
Complete data on any or all types gladly furnished on request.

## Muckle Manufacturing Co.

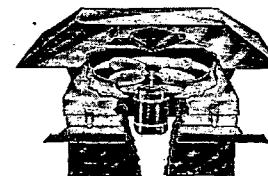
666 Belford Road

Owatonna, Minn.

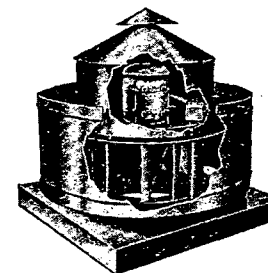
Sales Engineering Representatives in Principal Cities



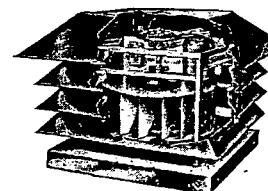
**MUCKLE VENTS**—are ideal for moisture laden applications or corrosive conditions. Motor is located out of the air stream, and housing is hot dipped galvanized after fabrication for maximum protection. Capacities 254 to 10280 cfm. Units very efficient at low static pressures. Constructed from heavy gauge steel, electrically welded.



**MUCKLE LO-SIL**—designed for low silhouette appearance. Largest unit only 25 1/2 in. high. Capacities from 225 to 17,600 cfm. Automatic back draft dampers built in on all models. Vibration separators are provided to eliminate vibration and hum. Totally enclosed, ball bearing motors are directly connected to propeller.



**MUCKLE BC VENT**—Centrifugal backward curved wheel is ideal for operation where static pressures are encountered. Non-overloading, dynamically balanced wheel, directly connected to totally enclosed motor. No maintenance of belts, pulleys, or bearings. Motor is out of air stream for protection. Capacities from 280 to 7650 cfm. Heavy gauge construction.



**MUCKLE BELTED VENT**—offers over 100 different capacities for any specific requirement. High exhaust capacity utilizes low fan tip speed to make unit very quiet in operation. Low in height, compact and symmetrical design, blends well with modern architecture. Heavy duty, ball bearing motors and non-overloading backwardly curved wheels used on all units.

MANUFACTURERS OF POWER ROOF VENTILATORS FOR OVER 15 YEARS  
SEE SWEETS ARCHITECTURAL OR INDUSTRIAL FILE, OR COMPLETE DATA  
FURNISHED UPON REQUEST.

# PENN VENTILATOR COMPANY

Goodman above Allegheny Ave. Philadelphia 40, Penna.  
Representatives and Distributors in Principal Cities.

## Roof Ventilators and Accessory Products for PUBLIC, COMMERCIAL AND INDUSTRIAL BUILDINGS

**DOMEX**—V-belt and direct driven centrifugal fans in a weather-tight spun aluminum housing. Backwardly curved statically and dynamically balanced fan wheels with non-overloading characteristic. Over 40 capacity selections.

**PENN DYNAFAN**—Quiet, steady exhaust against system resistances. Centrifugal fans in sixteen sizes belt-driven at speeds to fill many capacity requirements.

**AIRETTE**—Efficient fans housed in easily installed modern and inconspicuous roof mounted housings. Certified capacities from 9,000 cfm to 40,000 cfm.

**HI-EX**—Straight thru—high velocity—vertical discharge air exhausters—streamlined housings. Certified capacities from 2,400 cfm to 60,000 cfm.

**TURBINE**—Ball bearing turbine ventilators are true rotary, air-driven suction turbines that work automatically and continuously without maintenance or operating expense. Ball bearing action enables the slightest motion of air to move the rotor.

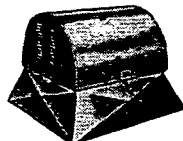
**PULLMAN**—Efficient gravity roof ventilator with large protected outlet area. Large exterior suction band converts passing wind currents into a powerful suction force accelerating the movement of air up through the ventilator.

**RIDGE**—Provides complete ventilation for continuous openings of various lengths. Furnished in many throat sizes and in 10 ft standard lengths. Fabricated to be inconspicuously low and to blend with building.

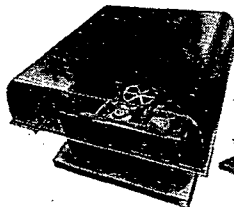
**RECTANGULAR PUL-AIR**—Modification of standard round unit, intended for use where odd size ducts, masonry flues or shafts extend through the roof or openings of irregular areas must be capped with a weatherproof gravity ventilator. They can be furnished in any desired size.



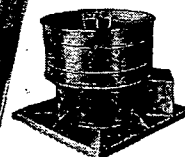
Domex



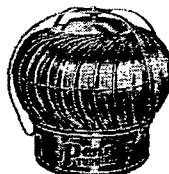
Penn Dynafan



Airette



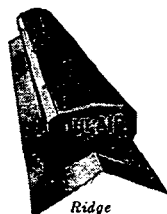
Hi-Ex



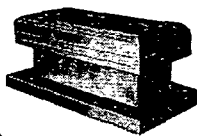
Turbine



Pullman



Ridge



Rectangular Pul-Air

For More Than 25 Years, The Builders Roof-top Line  
Manufacturers of

PROPELLER FAN, CENTRIFUGAL, STATIONARY, and ROTARY  
RIDGE VENTILATORS

See Sweets Architectural or Engineering File or write direct for catalogue.  
Member of Power Fan Manufacturers' Association

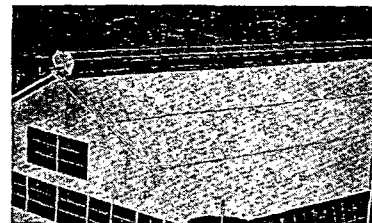
## The Swartwout Company

18511 Euclid Avenue,

Representatives in Principal Cities

Cleveland 12, Ohio

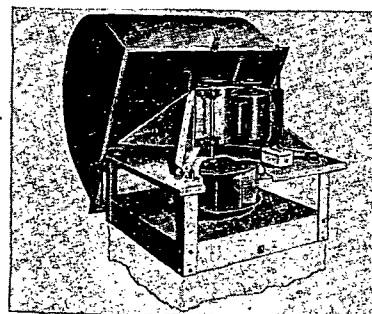
### GRAVITY ROOF VENTILATOR



#### Swartwout-Dexter Heat Valve

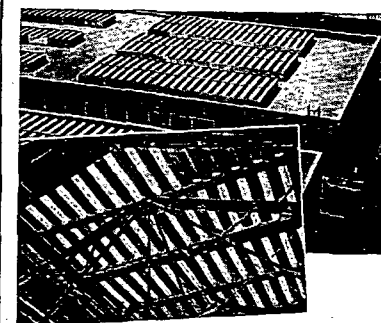
Continuous opening natural draft ventilator particularly effective for ridge of peaked roof, saw-tooth construction or skylights; adaptable to flat or slant roofs. Made in throat opening sizes 4, 6, 9, 12, 15, 18, 24, 30, 36 and 42 in. Ten foot units. Adjustable damper. Weatherproof.

### DUCT EXHAUST VENTILATOR



The Airlift is a centrifugal fan unit for duct exhaust against static pressure. Operates at very low noise levels. Fan has backwardly curved blades completely non-overloading; bottom of wheel flared to form throat overlapping inlet increases efficiency, avoids turbulence. 14 sizes, 138 capacity variations.

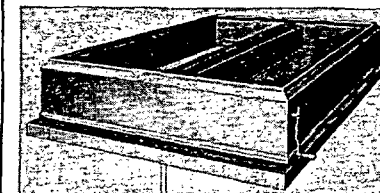
### GRAVITY ROOF VENTILATOR



#### Swartwout Airmover

Compact multiple opening type featuring very short air travel, built in units 10 ft x 7 ft, 6 in. x 32 in. high; 30 sq ft of opening per unit. Used as single units, or single or multiple width runs. Unusual large scale ventilation results possible by roof coverage such as illustrated. Can be adapted to any type of roof. Insert shows "open roof" effect.

### FIRE VENTILATION



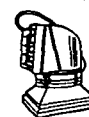
#### Swartwout Fire Valve

Roof unit for release of heat, smoke, gases in event of fire. Two large dampers drop, released by fusible link; provide 46 sq ft free area opening. Only 21 in. high above curb. Weatherproof when closed.

### OTHER SWARTWOUT ROOF VENTILATOR TYPES



ROTARY, gravity



AIRJECTOR, powered



VALVENT, gravity and powered



LOW-LINE, gravity and powered



WHIRLOUT, powered



LOUVERS

See Sweets Architectural, and Industrial Construction Files.

## Western Engineering & Mfg. Co.

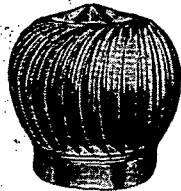
ESTABLISHED  
4112 Glencoe Ave.



1921  
Venice, Calif.

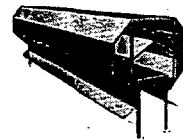
Representatives in Principal Cities

### HIGH EFFICIENCY ROOF VENTILATORS



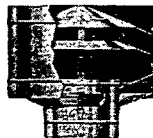
#### Western Rotary Ventilator

High exhaust capacity for relatively small bulk in weight. Remains in continuous motion between gusts, and is stormproof. It cannot backdraft because the throat velocity rises at an increasing rate with the wind speed. Wind tunnel tested. Rigid center support, and vibration absorptive rubber mountings, quiet performance. Enclosed, long-life lubrication, and durable hammertone sea-green finish. Sizes: 6 in. to 48 in. inclusive.



#### Western Continuous Ridge Ventilator

For high volume, low velocity exhaust capitalizing on air movement generated by temperature difference plus induced draft, this ventilator provides a continuous opening of any length desired in 17 throat sizes. The structure is storm and rain proof and is available with or without adjustable dampers and screens. Inherent characteristics qualify this ventilator for use in factories, foundries, mills and similar buildings.



#### Forbes Syphonaire

A highly-engineered stationary type roof ventilator employing a circular wind band that prevents the entrance of outside air. High capacity, rain and storm proof, rugged construction, and low silhouette, obviating the need for guy wires. Wind tunnel tested by aeronautical laboratory. Sizes range from 6 in. to 48 in. inclusive.



#### Westernaire Curb-mounted Fan

For low cost air movement under low static conditions, this unit is designed to meet practically every application involving a roof-mounted exhaust fan. High speed, high velocity for industrial use or slow speed, quiet operation for commercial use. Available in 39 models. 8 in. to 48 in. Can be used in conjunction with any type gravity ventilator.

SEE OUR COMPLETE CATALOG IN SWEET'S ARCHITECTURAL FILE, INDUSTRIAL CONSTRUCTION FILE AND ARCHITECTS AND ENGINEERS CATALOG FILE or write to above address for additional catalog and list of Representatives.



Forbes Econovent Gravity



Western Airout, Gravity



Booster Fan, Powered

## UNITED STATES STEEL



AMERICAN STEEL & WIRE DIVISION, CLEVELAND  
COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO  
NATIONAL TUBE DIVISION, PITTSBURGH  
TENNESSEE COAL & IRON DIVISION, FAIRFIELD, ALA.  
UNITED STATES STEEL CORPORATION, PITTSBURGH  
UNITED STATES STEEL SUPPLY DIVISION,  
Warehouse Distributors, Coast-to-Coast

UNITED STATES STEEL EXPORT COMPANY, NEW YORK

### U.S.S. GALVANIZED STEEL

for high quality results and ease of fabrication

U.S.S. Galvanized Steel Sheets are especially processed for the jobs they have to handle. They are uniform in flatness and surface. They can be bent, cut, stamped, rolled and formed—all with unusual ease of handling. In the production of U.S.S. Galvanized Steel Sheets careful attention is paid to the adherence of the zinc coating. This is done in order that forming operations may not fracture or flake the coating and thereby expose the base metal to atmospheric corrosion and rust.

Because of all these outstanding qualities, U.S.S. Galvanized Steel Sheets permit true bends, tight joints and neat seams, even in forming difficult angles and shapes when working in close and confining places.

#### Other U.S.S. Steels famous for service

U.S.S. STAINLESS STEEL is ideal for use in chemical plants, laboratories, and other places where highly corrosive atmospheres would spell early destruction for less durable materials. Its high resistance to corrosive attack, great strength, ease of cleaning and high resistance to extremes of temperature are definite money-saving advantages.

U.S.S. COPPER STEEL—coated or uncoated, insures increased resistance to



U.S.S. Galvanized Steel Sheets are produced in a wide variety of sizes and forms. Our engineers are specialists in their use and will gladly assist you in their application.

corrosion, and increases life under all conditions of atmospheric exposure.

U.S.S. GALVANIZED PAINTBOND STEEL—for ductwork requiring immediate painting without preliminary treatment or weathering. Paint will not flake. Bonderized surface prevents deteriorating action between paint and galvanized coating. A similar sheet, U.S.S. DULKOTE, is available in the South and the West.



## A-J Manufacturing Co.

3601 E 18th St.

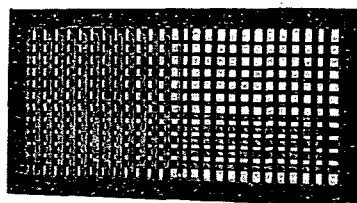
Kansas City 27, Missouri



### REGISTERS

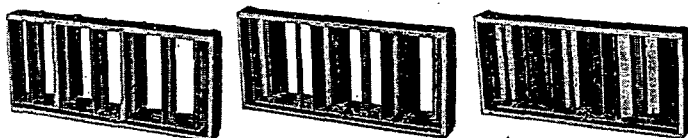
### GRILLES

### DIFFUSERS



Model 400 VH Grille

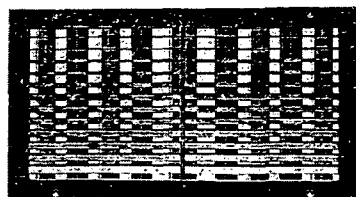
A-J No. 44 Series Dampers are the same dampers furnished with No. 440 Series registers, but are also available as separate units for easy installation in the



Model 44 Damper

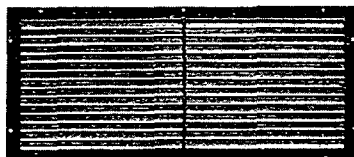
duct behind a grille. They provide positive metered air flow by means of their opposed blades which are controlled by a patented Phillips screw gear drive. Air is distributed evenly over the entire area of the grille. Damper locks at any degree from fully opened to fully closed, as in the photos above. Maximum depth of the unit in full open position is  $3\frac{1}{4}$  in. Sizes range from 8 in. x 4 in. through 40 in. x 12 in.

Model 440 H Register



A-J No. 400 Series Air Conditioning Grilles and No. 440 Series Air Conditioning Registers are available as either single or double deflection units to fit most standard duct sizes from 8 in. x 4 in. through 60 in. x 24 in. Choice of vertical or horizontal bars only, or combination of both with either vertical or horizontal in front. Both the spring tension mounted bank of extruded aluminum face bars and the bank of back bars are individually adjustable. No. 440 Series registers combine any size No. 400 Series grille with a corresponding size opposed blade damper which can be locked in any desired position.

A-J No. 45 Series Return Air Grilles are the matching counterpart for the No. 400 Series grilles and the No. 440 Series registers. Designed for return air intake, they are available with horizontal face bars—straight deflection,

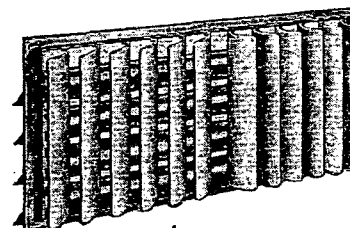
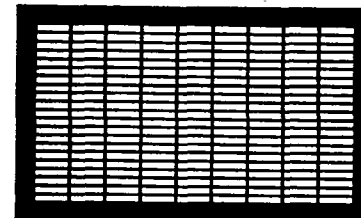


Model 45-D Grille

vertical face bars—straight deflection, and horizontal face bars—35 deg downward deflection. Face bars are of  $\frac{3}{4}$  in. wide extruded aluminum set on  $\frac{3}{4}$  in. centers. Bar deflection is fixed at the factory. Available in all standard duct sizes from 8 in. x 4 in. through 60 in. x 24 in. For positive volume control, can be used with No. 44 Series dampers.

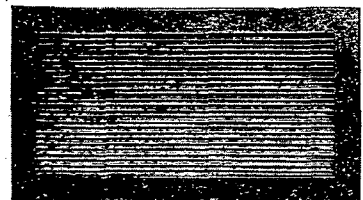
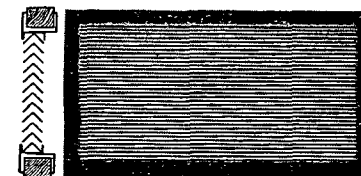
## A-J Manufacturing Co.

A-J Architectural Grilles are available in square meshes of  $\frac{1}{2}$ ,  $\frac{5}{8}$ ,  $\frac{3}{4}$ , and  $\frac{7}{8}$  inches, and in various slotted designs. Made to your order in any size from steel, aluminum, bronze, monel or stainless.

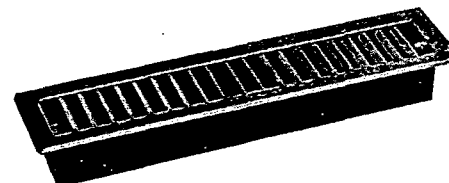


A-J Double and Single Diffusers are furnished with one-half of the vertical curved louvers facing to the right, one-half to the left. In cases where deflection is required in one direction only, louvers will be assembled to direct all of the air to one side only.

A-J No. 70 Series No-Vision Door or Partition Grilles are ruggedly constructed, yet are light in weight and have a free area of approximately 70 per cent. Completely sight proof. Excellent for door or partition installations. Illustration at right shows grille and cut-away view of auxiliary frame.



A-J No. 77 Series Thin Core Grilles are only  $\frac{1}{2}$  in. thick, yet are completely sight proof. Free area is approximately 80 per cent. They were developed to answer the increasing demand for ventilating grilles for panels or partitions, and can be installed in any panel ranging from  $\frac{1}{4}$  in. to  $\frac{3}{4}$  in. thick. Illustration at left shows grille and cut-away view of auxiliary frame.



A-J No. 55 Diffusing Perimeter Registers are designed specifically for installations with perimeter heating systems. Heavy gauge curved vanes are set at the factory to deliver a fan-shaped pattern

of air to cover window areas and cold outer walls. Excellent for installation in stair risers, under kitchen cabinets, in picture window sills, or as side wall outlets with high velocity systems.

FOR COMPLETE SPECIFICATIONS AND PRICES ON ALL A-J PRODUCTS, WRITE FOR  
ILLUSTRATED CATALOG NO. 55



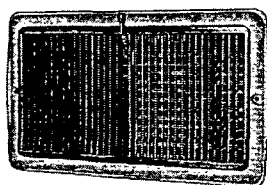


## Air Control Products, Inc.

Coopersville, Michigan

Air Conditioning Registers, Grilles, Ceiling Diffusers  
and Leigh Building Products.

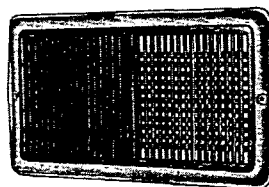
### No. 20 Series Air Conditioning Registers and Grilles



Superbly styled. Two tone finish. Positive control of air stream assured by adjustable vertical front fins plus adjustable horizontal back fins. Both banks of fins are easily adjusted from the face of the register, making it simple to set for heating or cooling.

The front fins are factory set for a multifold horizontal air pattern, an unique Air Control feature. Back fins are set for 22½ deg deflection but may be easily adjusted for any desired up or down flow. Special fin adjusting tool furnished.

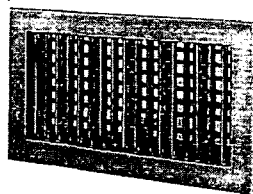
The air flow pattern is not changed by the damper position. Its design provides for perfect volume control, plus ideal air



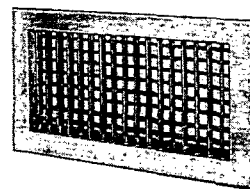
distribution. The volume control damper is formed for rigidity and strength and opens easily to a full 90 deg. An adjustable spring loaded operator makes this register ideal for upside down installation on systems where duct comes down from the attic, or on shallow depth stackheads. Adjusto-stop makes it easy to balance system at the register face. Does not interfere with closing of the damper.

No. 20 Series Sidewall and Baseboard Registers are available in the following duct sizes: 8 in. x 6 in., 10 in. x 6 in., 12 in. x 6 in., 14 in. x 6 in. Sidewall and Baseboard Grilles are available in the above sizes plus the following: 24 in. x 6 in., 30 in. x 6 in.

### MULTI-TROL REGISTERS AND GRILLES



Air Control's Multi-Trol Register line was developed to solve the problem of installation in standard wall construction. Here is a commercial type, adjustable bar register with an opposed action



valve that is so shallow it can be used with standard fittings and duct work, even in ¾ in. risers.

The shallow depth air control valve is achieved by moving the pivot point as

WRITE FOR AIR CONTROL CATALOG NO. 56-AC—COMPLETE ENGINEERING DATA, SIZES

### MULTI-TROL REGISTERS AND GRILLES (Cont.)

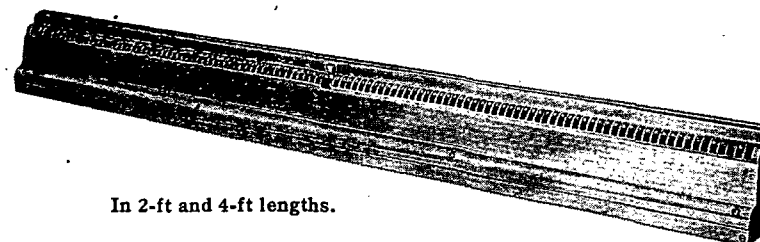
close to the face as possible and closing the louvers practically flat. Louvers are butterfly type and in closed position, air pressure seals the valve and prevents whistling and air leakage. At any degree of opening, air is distributed evenly over the face of the register.

Micro operator gives positive control in any position and opens and closes the largest valve smoothly and easily. On residential installation, the attractive operator key may be left in place if desired.

Face bars are built with an airfoil contour, reducing resistance to a minimum and making units extremely quiet at high velocities. Bars pivot on a round bearing surface. Pivots are rolled over where they extend through the margin—will not pull out. Easily adjusted with deflection key furnished. Bars are full depth, spaced on 0.666 in. centers, the ideal spacing to give positive air deflection and maximum free area.

Beige prime coat finish. A wide range of sizes to 36 in. x 36 in.

### NO. 188 BASEBOARD DIFFUSER WITH BUILT-IN ROTARY DAMPER.



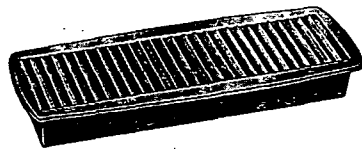
In 2-ft and 4-ft lengths.

With built-in rotary damper the No. 188 assures peak efficiency in air patterns for heating or cooling. Insures uniform velocity at the face, regardless of degree of opening. In 4-ft lengths (29.36 sq in. free area) and 2-ft (14.68 sq in. free area) for single or continuous installation. Sculptured plastic operator.

New Adjusto-Bottom Base Strip cuts

installation time in half. After diffuser is located over the duct, the base strip is withdrawn to duct width, snipped off, and the cut-off inserted into other end of base. No. 186 Return Air Grille in matching design offers 58.72 sq in. free area. Both diffusers and return air grilles may be installed before or after plastering, on sub-floor or finish floor.

WRITE FOR AIR CONTROL CATALOG NO. 56-AC—COMPLETE ENGINEERING DATA, SIZES



**NO. 42 PERIMETER FLOOR DIFFUSER.** One-piece face has no corner seams to mar the beauty of its curved, flowing contours. New, extra wide flanges insure complete coverage of rough cut or irregular floor opening. Smoothly curved vanes and wafer-thin valves reduce resistance, increase free area, and provide more efficient air distribution. Outside walls are blanketed with a layer of warm air—prevents cold drafts from flowing into the room.

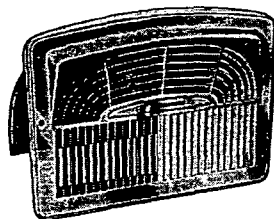
Adjusto-Stop screw stops the valve at any desired opening, balances system at diffuser face—eliminates the need for additional duct dampers. Vanes can be set for any desired deflection without shearing off at ends. Outstanding for use with conventional heating systems, perimeter heating and small-pipe perimeter heating. Standard Oak and Metal-escint finishes.

**OPENING SIZES**—14 in. x 6 in., 12 in. x 6 in., 14 in. x 4 in., 12 in. x 4 in., 10 in. x 4 in., 14 in. x 2½ in., and 12 in. x 2¼ in. Latter two are ideal for narrow, hard-to-fit spaces under kitchen cabinets, in sill of large picture window, under stair risers, etc.

**NO. 265 OUT-OF-THE-WALL PERIMETER BASEBOARD REGISTER.** Solves installation problem where duct does not or cannot enter wall. Adjusto-Stop permits the system to be balanced at diffuser face. Horizontal fins can be adjusted to throw air stream at any angle in relation to wall. Matching No. 262 Baseboard Grilles have same construction, without damper.

WRITE FOR AIR CONTROL CATALOG—No. 56AC—COMPLETE ENGINEERING DATA, SIZES

**NO. 333 RETURN AIR GRILLE.** Answers the problem of centralized returns—easily installed in ceilings, walls, doors. Made of heavy gauge steel, one-piece construction, with angle frame for added stiffness. A single return in one of the larger sizes has enough capacity for an entire heating or cooling system. In 15 sizes from 10 in. x 10 in. to 30 in. x 18 in.

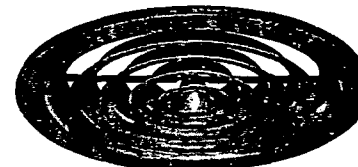


**No. 15 SIDEWALL PERIMETER DIFFUSER.** Scientifically engineered to give a draftless blanket of air over the outside wall from a sidewall location. Two sizes—12 in. x 6 in., and 10 in. x 6 in. Provide complete, rapid diffusion of air when used with conventional duct or loop or radial slab installations. Top section is flared away from diffuser face—prevents air from scrubbing wall. Balancing is easily accomplished at face. Flat-spring linkage holds valve rattle-free in any position. Sponge rubber gasket seals against wall. Beige prime coat or Metal-escint finish.

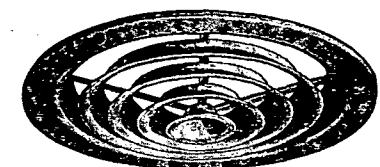
**No. 16 OUT-OF-THE-WALL-DIFFUSER.** Same advantages as the No. 188 or No. 42 series. Ideal for baseboard diffuser, particularly in remodeling. Duct connected through floor; back fits flush with wall. Made in 10 in. x 6 in. and 12 in. x 6 in. opening sizes.

**“E” FRAME FOR NO. 15 DIFFUSER.** Makes conversion of No. 15 Diffusers to baseboard use extremely easy. New style frame blends smoothly with diffuser contours. Made of heavy-gauge steel, finished in beige prime coat or Metal-escint. Sculptured plastic operator.

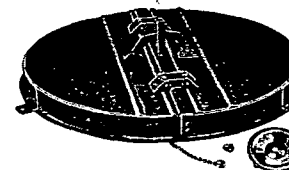
## CEILING DIFFUSERS



**FLUSH TYPE** for installation where projection from ceiling is not desired. Air Flow Rings discharge air in concentric jets for rapid diffusion. Curved contours of ring directs air slightly downward with minimum resistance.



**STEP-DOWN TYPE**, with approximately 30 per cent more free area than Flush. Delivers air downward more directly. Both types suitable for cooling, since air is delivered at ceiling level for gradual settling. Both in 6 sizes, 8 in. to 22 in., finished in Beige prime coat.

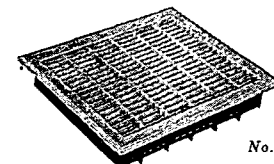


**DOUBLE VALVE DAMPER** gives exact control of air volume, plus even air distribution. Chain operated, permit balancing system at face. For 8-in. to 16-in. Diffusers. Single valve types available for 18-in. and 22-in. Diffusers.



**INSTALLATION RINGS** simplify firm seating of Ceiling Diffusers. Easily screwed or riveted to duct end or blocking. Not used with dampers. In sizes to fit all Air Control Ceiling Diffusers.

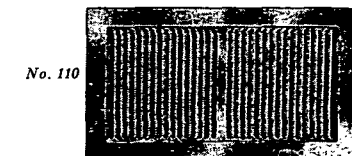
**ADJUSTABLE CEILING DIFFUSER**—adjusts to any pattern from straight downward deflection to flat pattern. 6 sizes from 8 in. to 22 in.



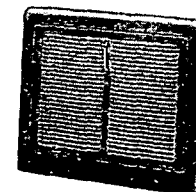
No. 40

**NO. 40 FLOOR REGISTERS** feature famous Rigid-Lock type construction. Each fret is locked to each crossing fret and to margin. Dial-operator valves run the short way of face. Medium mesh (¼ in.) between faces. Same construction in No. 41 Floor Return Air Faces.

**NO. 110 SERIES REGISTERS** with vertical adjustable fins. Provide horizontal control of air stream. Single-shutter damper with sculptured plastic operator, equipped with Adjusto-Stop for balancing.



No. 110



No. 50

**NO. 50 SERIES BASEBOARD REGISTERS.** A gravity-type register with removable face for streak-proof installation. Balanced damper with sculptured plastic operator, stays at any open position. No. 80 Sidewall Gravity Register is styled to match; with damper.

WRITE FOR AIR CONTROL CATALOG NO. 56-AC—COMPLETE ENGINEERING DATA, SIZES

## Air Devices Inc.

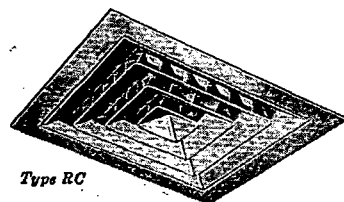
Air Diffusers • Exhausters • Air Filters  
Filter Holding Frames • Industrial Furnaces

185 Madison Ave.  
New York 16, N. Y.



Agents in All  
Principal Cities

### AGITAIR DIFFUSERS

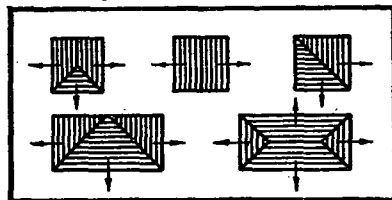


Type RC

AGITAIR square and rectangular air diffusers are available with removable core and three distinct types of mounting frames, attractive in appearance, and practical for all job conditions.

The removable core is a tailor-made diffuser with patented built-in diffusing vanes. The vanes and louvers are assembled in a wide variety of patterns and sizes to suit conditions of each application. Air is discharged in one-two-three or four directions with each side delivering a quantity of air proportional to the area being served. These AGITAIR Diffusers perform efficiently, quietly, draftlessly with rapid temperature equalization.

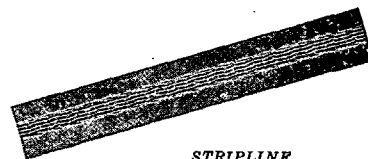
Square or Rectangular in Shape



New method of installing AGITAIR Type "RC" Air Diffusers saves time and labor costs. Only two steps are required to finish installation: 1) attach mounting frame to duct collar. 2) Insert diffuser core and lock in position.

For installation in acoustical ceilings AGITAIR square and rectangular diffusers are made in sizes to conform to standard tile dimensions.

The AGITAIR Diffuser Data Book, available to architects and engineers, will help you design and install air distribution systems. Consult our engineers.



STRIPLINE

STRIPLINE Diffusers incorporate patented built-in diffusing vanes which produce extremely high turbulence and aspiration. Rapid temperature equalization is achieved with maximum allowable temperature differentials between room and supply air. STRIPLINE insures an unvaried distribution of noiseless, draftless conditioned air over a predetermined area. Hot or cold spots are eliminated in the zone of occupancy. Available in two styles and supplied as a continuous decorative unit or in sections.



### CIRCULAR DIFFUSERS

Type "OA" adjustable units employ a radically new means for controlling air direction at 4 different angles of discharge simultaneously without disturbing the position of the spinings. Not only is it possible to produce any angle of discharge from above horizontal to vertical, but each of four 90 deg segments are independently adjustable. Thus, it is possible to blow horizontal from one segment; vertical from a second; 45 deg downward from a third and 20 deg from a fourth if desired. AGITAIR Type "OA" Diffusers are truly adjustable, with or without ceiling.

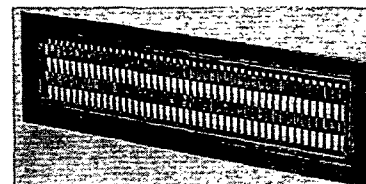
Type "O" are non-adjustable. They are identical to the Type "OA" except for omission of deflectors. Air is discharged horizontally or above—with or without a ceiling.



1624 So. Raymond Ave.  
Air Distribution

Monrovia, California  
Air Control

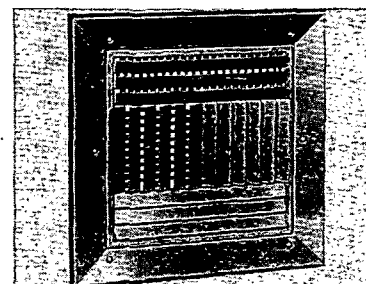
### SERIES LCF SIDEWALL DIFFUSERS:



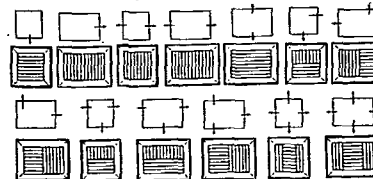
MODEL LCF-RC (Removable Core)

Factory set outlets distributing air in laminar counterflow layers mix supply with room air reaching design conditions in minimum time and space. LCF outlets can be equipped with secondary flexible horizontal vanes which may be reset on job, giving maximum, vertical control with varying length of blow.

### SERIES B60 CEILING DIFFUSERS:

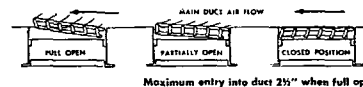
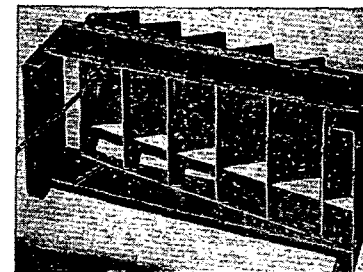


MODEL 4B60-RC (Removable Core)



Patented construction provides proportionately balanced air distribution with controlled total air motion through laminar counterflow core. Square or rectangular air diffusing outlets. Full range sizes and capacities allows maximum mixing of primary and secondary air with distribution of supply air in direct ratio to floor area.

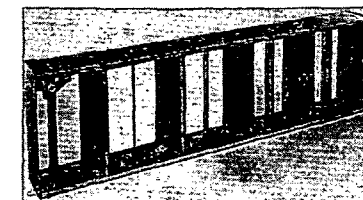
### SERIES AVP-QO Adjustable Air Proportioning Vanes:



Maximum entry into duct 2½" when full open

Balances air distribution for given supply outlet. Quick opening feature extracts air with a 2½ in. maximum entrance into main duct, reducing velocity evenly over outlet face. Full shutoff. Manufactured separately or attached to sidewall ceiling outlet or diffuser. Key or rod operated.

### SERIES OBD-KO Air Volume Control:



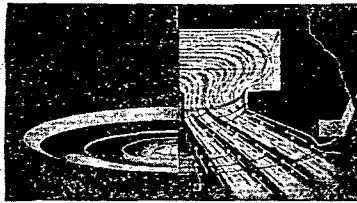
Opposed acting blades; center pivoted. Operate from full open to full closed position. Used directly attached to grille, diffuser or installed as separate unit. Key operated. Friction linkage maintains blades in position when set.

### SERIES ACD DIFFUSER:

For ceiling installation. Patented laminar counterflow core and flexible vanes permit on-the-job adjustments for controlling blow length and ceiling discharge angle.

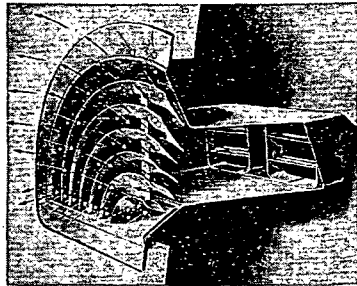
## Anemostat Corporation of America

10 East 39th Street **ANEMOSTAT**® Representatives in  
New York 16, N. Y. **DRAFTLESS Aspirating AIR DIFFUSERS** Principal Cities



### PRINCIPLE OF ASPIRATION

The Anemostat Air Diffuser splits the supply air into multiple, separate air streams and at the same time creates low pressure areas in certain parts of diverging passageways. This causes room air to be siphoned into the device where it is thoroughly mixed with supply air. The mixture is discharged in a series of expanding turbulent air layers and, therefore, readily entrains a large amount of additional room air.



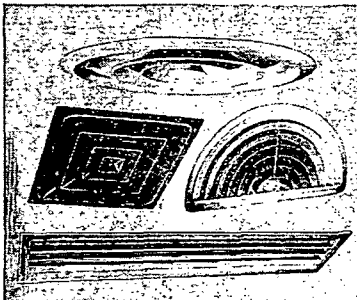
As a result, temperature and humidity are equalized throughout the room and a continuous air motion in the occupancy zone within low acceptable velocity limits is established. Stagnant air pockets are also avoided.

The quantity of room air drawn into Anemostat Air Diffusers depends on the specific design, size and type of the various units and is equal to as much as 35 per cent of the supply air. This effective aspiration distinguishes Anemostat Air Diffusers from all other air outlets.



### SMALLER DUCTS

Aspiration permits the use of greater temperature differentials and higher supply air velocities than customary, which results in savings in the initial cost of fans and ducts and in the operating cost of the system. Duct layouts may be simplified because Anemostat Air Diffusers distribute air evenly in spite of unusual room plans, columns or other obstructions.



### THE COMPLETE LINE

Anemostat Corporation of America has developed air distribution devices and related equipment for every purpose. Circular, semi-circular, square and straightline Anemostat Air Diffusers of various types and sizes for ceiling and wall distribution are available for comfort conditioning and industrial heating, ventilating and air conditioning installations. These are available for both conventional and high-pressure, high velocity systems.

### QUALITY

Anemostat Air Diffusers are scientifically designed according to modern fluid flow theory and manufactured according to modern production standards.

### ANEMOSTAT PATENTS

The Anemostat Corporation of America holds over fifty patents covering the use and design of diffusers in the field of air distribution. The superior functioning of the Anemostat is protected by these patents which are the result of inventive spirit, diligent research and constructive engineering.

### RESEARCH AND ENGINEERING

Anemostat Corporation of America maintains a large, well equipped laboratory manned by experienced scientific and technical personnel for testing purposes and the development of new products. Engineers from all over the world have visited the Anemostat laboratory to witness demonstrations of Anemostat products and their applications to any conceivable problem pertaining to air diffusion. Anemostat has spent over a million dollars in research and engineering and will continue to make substantial contributions to the progress of the science of air distribution.

### EXPERIENCE

Over a million and a quarter Anemostat Air Diffusers are now doing an excellent job in thousands of comfort conditioning and industrial heating, ventilating and air conditioning installations. In addition to applications in commercial buildings, industrial plants, hotels, stores, hospitals, theatres, restaurants and homes, Anemostat Air Diffusers are used in military and commercial aircraft, railroad cars, buses and ships.

### SPECIAL INSTRUMENTATION

Anemostat engineers have developed various instruments for the accurate and convenient testing of the performance of air outlets. The Anemotherm Air Meter, a self-contained, compact, portable instrument, facilitates the balancing and checking of air distribution systems by engineers and contractors. It is now commercially available and is being used with great success by engineers and contractors throughout the country.

### TYPICAL ANEMOSTAT ALL-AIR HIGH VELOCITY INSTALLATIONS



## The Auer Register Co.

6600 Clement Avenue, Cleveland 5, Ohio

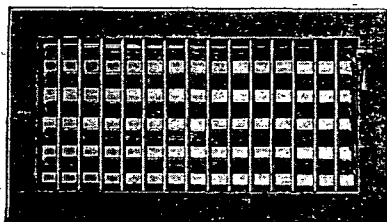
Manufacturers of Registers and Grilles for Gravity and Air Conditioning Systems; Metal Grilles for Radiator Enclosure, Ventilation, Concealment

### AIR CONDITIONING REGISTERS AND GRILLES

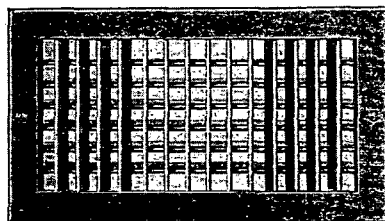
Auer has a complete line for warm air or air conditioning, a wide choice of styles for every purpose. For gravity systems, the Heat-Rite is a quality model, adjustable for up-or-down flow. DuraBilt floor registers and intakes provide extra strength with interlocked cross-bar construction. "Streamliner" registers and grilles for high velocity outlets are made in 8 styles, with single bank of adjustable bars, vertical or horizontal, also with double bank, front

vertical and rear horizontal (or the reverse), also all these types with the addition of multi-louvre valves. Auer Register Book showing entire line sent on request.

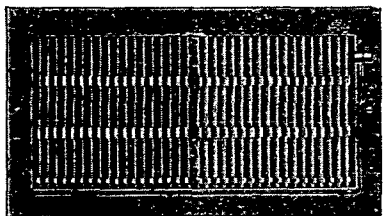
Auer perforated grilles are made in many designs and sizes, in steel (or stainless), aluminum, brass or bronze. Finished or plated as desired. Grille Catalog, "G" gives full scale details, tables of openings and free areas.



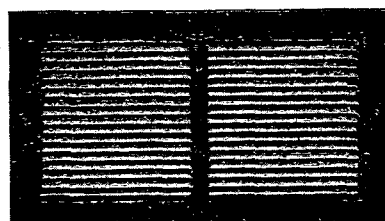
Streamliner Register No. 1005V-HML. Adjustable bars, multi-louvre valve.



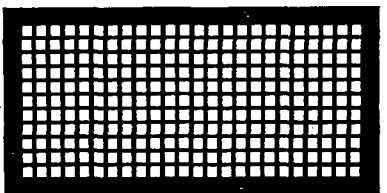
Streamliner No. 1205VH. Double deflection grille, adjustable bars.



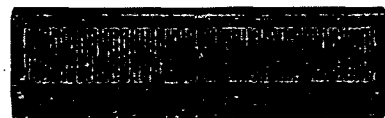
Airo-Flex No. 4432 Register—Multi-louvres adjustable up, straight or down. Grille bars adjustable for right or left flow. Grille to match.



Airo-Flex No. 7032 Register—Grille bars set to direct air downward at 22½ deg, but adjustable for other angles. Single louvre. Grille to match.



5A—Square Lattice Grille



No. 100 Perforaire

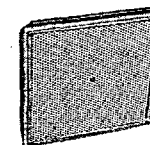
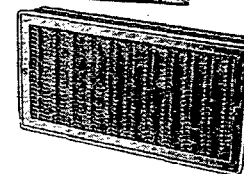
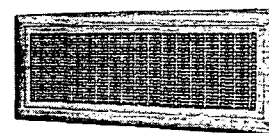
## Barber-Colman Company



**uni-flo®**

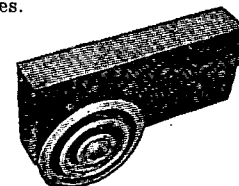
Air Distribution Products  
Rockford, Illinois

Engineered Air Distribution Products and Complete Engineering Data to Meet Any Air Distribution Requirement



### GRILLES AND REGISTERS

Uni-Flo Grilles and Registers provide rapid diffusion, a high rate of aspiration with resultant high air entrainment ratio, low pressure drop, low noise level, simple adjustment of the air pattern, and a pleasing appearance. A variety of frame styles is available to meet sidewall, panel, or exposed duct installation requirements. A removable core feature makes it unnecessary to break the paint or plaster seal for cleaning or decorating purposes.



### HIGH VELOCITY

Uni-Flo High Velocity Air Valves reduce high velocity air to conventional velocities. Installed directly behind grilles or at junction of high velocity trunk duct with conventional velocity branch duct. Uni-Flo High Velocity Control Units, for use at individual diffusers, reduce air velocities, providing maximum attenuation of noise in minimum space. Uni-Flo High Velocity Double Duct Units mix hot and cold high velocity air and reduce it to conventional velocities.

### CEILING DIFFUSERS

Uni-Flo Square and Rectangular Ceiling Diffusers blend with acoustic ceiling tiles, providing air pattern modification without altering outward appearance of diffuser. Venturi-Flo Diffusers, for installation on ceilings or exposed ducts, provide simple adjustment of air patterns from vertical to horizontal. They are available in a complete range of sizes. Line-O-Flo Ceiling Diffusers have distinctive linear design and can be installed individually or in a continuous strip.



### ACCESSORIES

Uni-Flo accessories simplify system balancing; assure uniform air distribution across diffusers and duct sections, reducing noise, turbulence, and pressure losses; and effect savings in ductwork installation and system operation. Uni-Flo Airturbs give sweeping radius performance to square duct corners. Uni-Flo Volocitrol is a balancing device designed to provide even distribution across the grille. The Deflectrol is an air turning device designed for installation at diffuser or branch duct runouts.

## BURGESS-MANNING COMPANY

*Architectural Products Division*

5970 Northwest Highway, Chicago 31

3-Way Functional Ceilings

### A Finished Ceiling that Supplies

1. Radiant Panel Heating
2. Radiant Panel Cooling
3. Acoustic Control

The radiant panel principle of this modern ceiling provides heating and cooling independently of air movement. Heat is conducted from the coils through the aluminum ceiling panels, which are secured directly to the coils. Heat energy is then radiated to or from the entire ceiling to or from every surface and object in the room. Every square inch of the Burgess-Manning Functional Ceiling works—every square inch is heated or cooled as the case may be. Nature's way of controlling human comfort.

Uniform air temperatures are maintained, convection drafts and heat shadows are minimized. Concentrated heat sources and overheated air are eliminated.

Burgess-Manning Ceiling can satisfy a wide range of heat requirements including panel demands of 125 Btu/sq ft/hr.

### THE BURGESS-MANNING CEILING CREATES A NEW STANDARD FOR COMFORTABLE WORKING AND LIVING CONDITIONS.

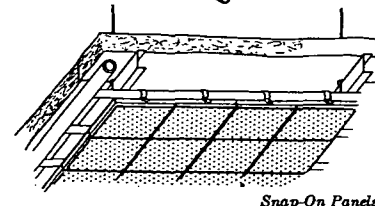
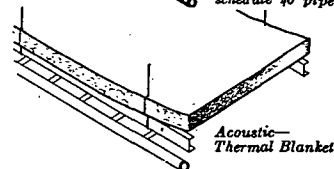
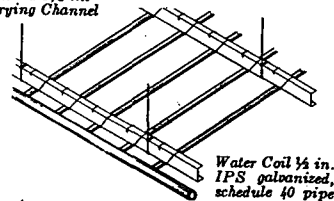
- \* Carries the entire Heating Load
- \* Carries approximately one-half of the entire cooling load. (Air requirements usually limited to latent heat removal and ventilation—reduced air handling equipment and smaller ducts save building cubage.)
- \* Standard controls—instantaneous response to water temperature changes.
- \* Controlled heating and cooling without LAG or OVER-RUN.
- \* Modular system for design flexibility as to layout, lighting, and any system for air distribution.
- \* Unrestricted use of floor area.

### TYPICAL SPECIFICATION

Install Burgess-Manning Ceiling complete with suspension system, heating-cooling coils, acoustic-thermal blanket, perforated aluminum Snap-On Panels standard finish and matching metal edge molding. Each coil is to be provided with threaded nipple ready to accept supply and return piping. Openings to be provided for recessed light troffers, diffusers and sprinkler heads. Supply and return piping, including balancing cocks and air vents to be supplied and installed by others.

For design procedure and performance curves send for Catalog A-129-G.

Standard 1½ in. Carrying Channel

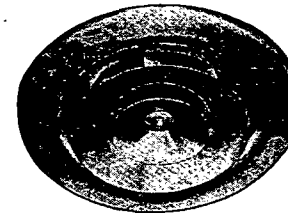


## Charles Demuth & Sons, Inc.

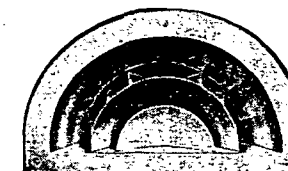
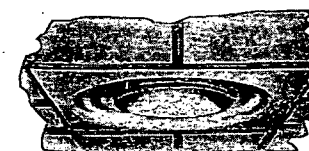
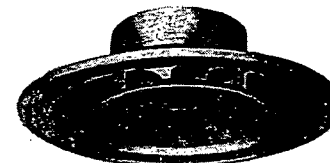
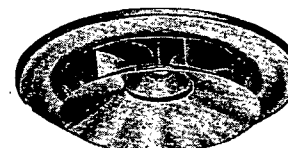
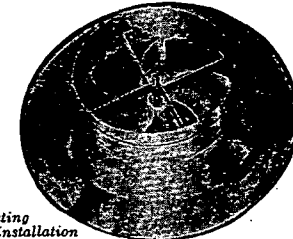
Mineola, N. Y.

### Demuth Draftless Air Distributors

Representatives in Principal Cities



Designed and Patented by Demuth



The DEMUTH DRAFTLESS AIR DISTRIBUTOR consists of a series of curved vanes, mounted on a deflecting cone, to insure 360 deg distribution without the aid of secondary equalizing devices. A second hollow deflecting cone is arranged at a tangent to the primary cone, forming an injection nozzle.

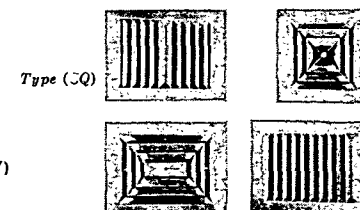
The curved vanes discharge the supply air in turbulent streams, mixing room air with conditioned air, thereby providing constant air motion, uniform temperature and draftless distribution throughout the room.

Secondary air currents, which are created by the turbulence of the discharge air, are drawn into the diffuser by the bottom or secondary cone, mixed with the supply air, resulting in positive aspiration.

Type (SQ) square and rectangular Air Diffusers are made to any size with removable core assembly. Air distribution is from one, two, three or four sides of the diffuser. Made to any air pattern.

### Accessories

Combined lighting is available with the circular type. Volume and Splitter Dampers are available for all types.





# CONNOR ENGINEERING CORP.

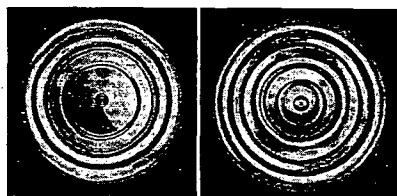
Danbury, Conn.



Representatives in  
All Principal Cities

In Canada: Douglas Engineering Co., Ltd., Montreal, P. Q.

## CONTROLLED AIR DIFFUSION



Type KDA for supply air. Aluminum, sizes 4 to 36 in. neck dia. Capacities 50 to 15,000 cfm per unit.

Type SRD for combination supply and return air. Sizes 6 to 24 in. supply neck dia. Capacities 50 to 2,500 cfm per unit, return neck area 75% of supply.

Kno-Draft Diffusers are geometrically proportional, size for size, insuring like resistance at like neck velocity for any size—a considerable advantage when selecting various size diffusers for a common system.

## Anti-Smudge Cone

Where exceptionally sooty or dusty air conditions are expected or where rough-textured ceilings are employed, the use of this accessory cone is recommended. It furnishes the additional control needed to provide the precise air separation which inhibits smudging.



Diffuser with anti-smudge Cone assembled

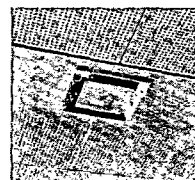
Diffuser and Cone separated

## Square Diffusers

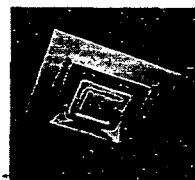
Kno-Draft Square and Panel-type Air Diffusers with built-in volume control and precision circular air patterns are engineered to give the utmost in air distribution efficiency.

Designed for installation in modern acoustical ceilings their simple geometrical lines complement the inherent beauty of the ceiling pattern, creating a uniform effect that is pleasing to the eye.

Utmost flexibility of installation is an outstanding feature of the Panel-type diffuser. By use of special patented flexible tubing the diffuser need not be lined up with duct and may even be installed in adjacent bays. Entire offices, partitions and floor areas may be relocated without moving ductwork.



Integrally stamped Panel Type diffusers shown installed in Acousti-Line ceiling. Sizes available, 4 in. to 6 in. neck dia. with capacities from 75 to 175 cfm.



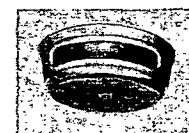
Type KP for installation in acoustical ceilings, 4 in. to 14 in. neck dia. sizes. Capacities from 50 to 1850 cfm.

Kno-Draft Diffusers are covered by U.S. Patents Nos. 2,365,867; 2,369,119; 2,452,259 and others pending; Canadian Patents Nos. 429,208; 443,235.

## HIGH PRESSURE AIR DIFFUSION

In 1949 Connor Engineering Corp. was among the first to supply units for large high pressure diffuser installations. Since that time, the company has been continuously active in the development and use of high pressure systems. High pressure techniques are now applicable to almost every type of proposed or existing structure. High pressure air transmission systems using Kno-Draft high pressure air diffusers are installed and operating satisfactorily in office buildings, hotels, hospitals and schools.

The air outlets are of utmost importance to the successful operation of a high pressure system. Located directly above the occupied areas, they must perform in a completely satisfactory manner if the system is to be a success and its potentialities fully realized. Various high pressure diffusers are required to satisfy all job requirements. Different outlets are necessary for different systems; also, different installations require different methods of air distribution. The illustrations show two of the many types of Kno-Draft high pressure diffusers.



HPC-J High Pressure Diffuser for exposed duct in installation.



Cutaway view of HPR-KA showing internal construction.

The HPC-J was the first high pressure diffuser made by Connor Engineering Corp. The one shown is the result of improvements that have been made over the years. This diffuser was specifically designed for use on exposed ducts in existing department stores and office buildings with particular emphasis on achieving a neat, unobtrusive appearance.

The HPR-KA is one of the most silent high pressure diffusers made. The cutaway illustration shows internal construction including the damper mechanism and sound trap. The damper is a perforated cylindrical type patented by Connor Engineering Corp. It is used in all Kno-Draft high pressure diffusers. The inlet tube and perforated cylinder are fabricated from one piece of corrosion resistant, stainless steel. An adjustable felt-edge piston seals the cylinder. Changes of position increase or decrease the number of perforations exposed and thus vary the air delivery of the unit.

This cylindrical perforated damper has many advantages: it is quiet, simple in construction, self-cleaning, and permits both a complete and positive shut-off together with a wide open position where unavoidable construction dirt can pass through the damper mechanism. The sinuous sound trap is another patented development. It absorbs both low and high frequency noises and the carefully designed contours prevent turbulence and noise generation.

Kno-Draft high pressure units are also available in dual-duct models which feature the same unique construction. Provision is made for operation of the dampering mechanism by pneumatic motors.

## Free Handbooks on Air Diffusers

Complete information on Kno-Draft high pressure diffusers is contained in the newly published Bulletin K-33. This manual also answers many of the questions about high pressure air transmission and contains complete detailed information for designing these systems.

Bulletin K-20A contains complete information on the standard line of Kno-Draft low pressure diffusers. The unique characteristics of these single-jet, high velocity diffusers makes them ideally applicable to low pressure installations. Either of these bulletins may be obtained by writing on your company letterhead to: Connor Engineering Corp., Dept. Y29, Danbury, Connecticut.



Kno-Draft High Pressure Bulletin K-33 gives complete technical data on high pressure systems and diffusers.



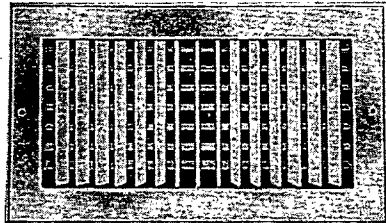
Kno-Draft Adjustable Air Diffusers and their operating characteristics are fully described in Bulletin K-20-A.

See pages 1326 and 1327 for data on Dorex Air Recovery and Air Purification Equipment.



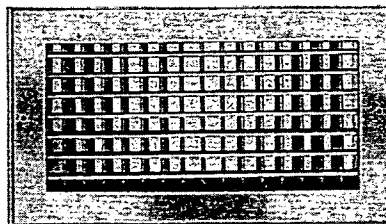
## General Register Corporation

14 Factory St., Cedar Grove, N. J.

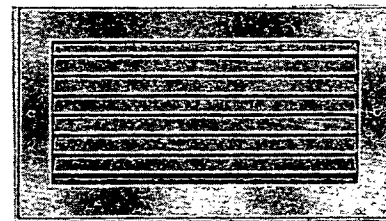


General Register manufactures a complete, quality line of adjustable and fixed supply and return registers and grilles for cooling systems.

Double-deflection register illustrated consists of double-deflection grille with Silentite opposed-blade damper. Front fins may be either horizontal or vertical. Single-deflection type also available.



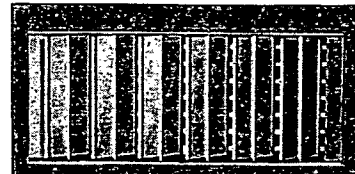
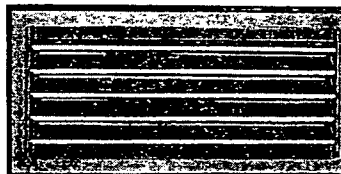
Double-deflection adjustable grilles offer quiet, efficient diffusion. Face fins are hollow, streamlined, sturdy, staked on close-fitting pins to prevent movement after setting. Heavy frames have solid corners and pleasing radius edges. All registers and grilles available with fins on either  $\frac{1}{2}$  in. or  $\frac{3}{4}$  in. centers; supply units furnished with rubber gasket.



Fixed return registers and grilles are of same quality construction as supply outlets, with fins set straight or at 40 deg angle. Registers are furnished with key-operated Silentite damper.

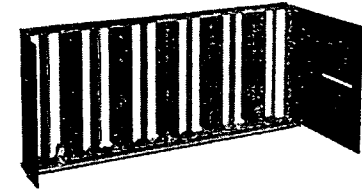
G-R's standard baked prime coat paint is a handsome finish suitable for permanent installation unchanged, or may be readily repainted later.

Simple, inexpensive dampers of the multi-shutter type are available for all General products. Supply registers, with very shallow depth, contain the entire blade structure within the damper housing, whether damper is in open or closed position. Curled edges of rolled blades interlock when closed, providing positive shut-off.



## General Register Corp.

Silentite Volume Damper, outstanding feature of the General line, is supplied with all commercial registers; also furnished as a separate unit. Diagram shows hollow blade construction, made by an automatic precision fabrication process. The streamlined contour eliminates turbulence, allows greatest free air passage. Hollow formation provides for positive gripping of bearings, assuring firm, free action without rattling. Reinforcing rib and double-thick edges produce great durability, also rigidity in longer blades.



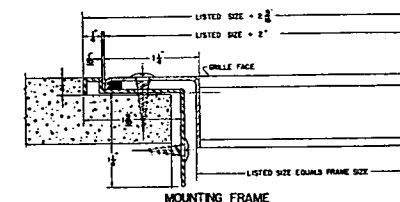
The General line includes a long list of air handling and control devices for ventilating and cooling systems.

The Ductrol consists of a series of individually adjustable deflecting blades staked on close-fitting pins, to divert air from a supply duct into a collar.

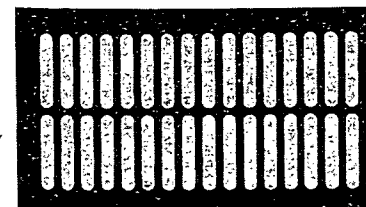
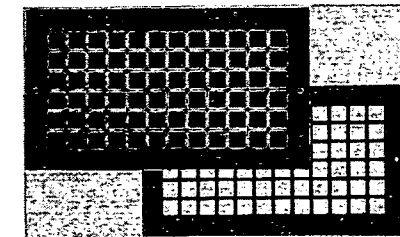


Mounting frames are provided where it is desirable to remove registers or grilles periodically.

Also available is a full line of ventilating grilles for doors and partitions, fusible links for Silentite dampers, angle-iron frames, pulley and chain operators, adjusting keys, and a variety of plated, polished, and lacquer finishes.



Plain lattice stamped grilles can be furnished as exhaust registers with key-operated dampers. Other grilles include Pencil-Proof for schools, and Sanitary, readily suitable for cleaning. Various metals can be supplied, as well as a variety of finishes.

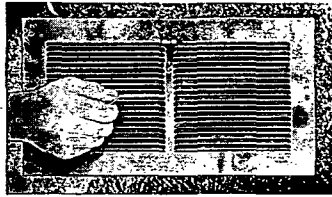




## Hart & Cooley Manufacturing Co., Holland, Mich.

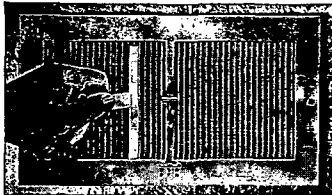
Air Conditioning Registers, Grilles & Diffusers—Warm Air Registers—Damper Regulators—Furnace Regulators—Pulleys—Chain

**No. 74 DESIGN—Economy Type Air Conditioning Register.** Flexible-fin face



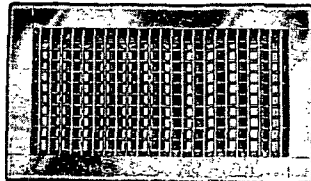
permits any up or down deflection of airflow. Positive valve with volume control for accurately balancing system. Gasket prevents streaking. Side-wall and Baseboard Registers in sizes 8x4 through 14x8. Grilles 8x4 through 30x8.

**No. 75 DESIGN—Multi-deflection.** Flexible-fin face provides for any deflection



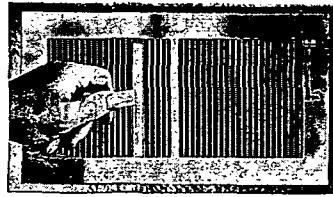
of airflow sidewise. Turning-Blade Valve, an H & C exclusive, turns airflow up, straight or down with 30 per cent less resistance. Instantly adjustable. Gasket prevents streaking. Side-wall and Baseboard Registers in sizes 6x4 through 14x8. Grilles 6x4 through 30x8.

**TRIPL-AIRE Sidewall Registers.** Excellent for commercial type installa-



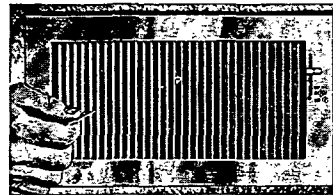
tions. Provide any deflection or combination of deflections desired. Opposed louvers afford absolute volume control. 26 standard sizes up to 36x12... each available in 10 combinations of horizontal and vertical front and secondary face bars and louvers. All key adjusted from front. Maximum size: 36x36.

**No. 76 DESIGN—Ideal Register for Shallow or Horizontal Ducts.** Multi-



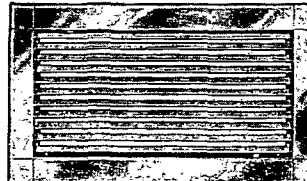
shutter valve (depth  $1\frac{1}{16}$  in. from wall) and flexible-fin face provide for all deflections desired. Any up or down deflection can be maintained with adjusting screw. Sealed to prevent streaking. Sidewall and Baseboard type Registers in sizes 6x4 through 30x8.

**No. 88 DESIGN—Shallow Ducts, Large Installations.** Similar to No. 76 except



that face bars are adjustable in  $2\frac{1}{2}$  in. sections (one moves all in section). Exceptionally good for large installations. Removable handle available to avoid tampering. Sidewall Registers or Grilles 6x4 through 30x24.

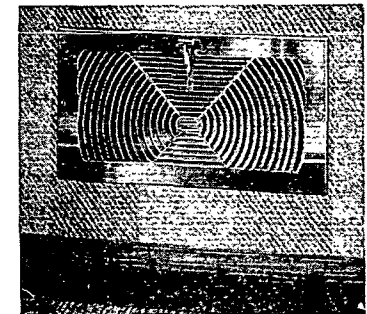
**FIXT-AIRE Return Air Grilles and Registers.** Similar in construction and



perfect complement to TRIPL-AIRE line. Same louver, but face bars (single bank) are fixed in either horizontal or vertical position. Grilles may be had with horizontal face bars set at 22 degree angle for up or down deflection. Maximum one-piece size: 36x30.

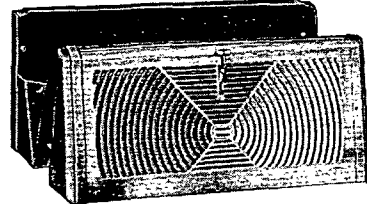


**No. 401 DIFFUSAIRE—For Perimeter Heating or Cooling.** Installed above the baseboard on outside walls, provides an excellent means of blanketing outside wall and window areas with a curtain of warm or cool air. This diffuser disperses air in full 180 degrees spread upward in addition to directing a small portion downward over floor. Adjustable stop on handle permits balancing system at the face. Sizes: 10x6, 12x6, 14x6.



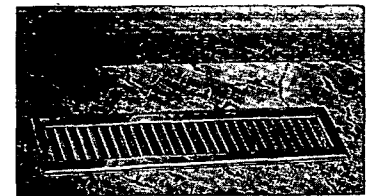
No. 401

**No. 405 DIFFUSAIRE—For Perimeter Installations.** Particularly good for use in established homes. Out-of-wall Baseboard type. No stackhead required. Provides same air pattern as our No. 401 Sidewall DIFFUSAIRE.



No. 405

**No. 411 DIFFUSAIRE—For Perimeter Heating or Cooling.** Floor type. Counteracts downdrafts from windows and cold walls. Opposed louver valves and set-screw adjustment permits accurate volume control for easy balancing of system. Design of louver blades provides even spread of air in fan shaped pattern with minimum resistance. Sizes:  $2\frac{1}{4}$ x10, 12, 14; 4x10, 12, 14; 6x10, 12, 14.



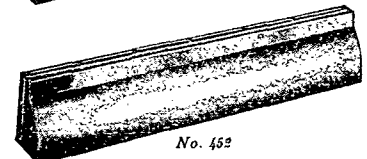
No. 411

**No. 44 Series DIFFUSAIRE—For Perimeter Systems.** Continuous Baseboard type for installations of 8 ft or more. Furnished in 2 ft or 4 ft units, KD. No disassembly or lining up of screw holes necessary. Precision parts snap together without need of tools. Easy to install, easy to clean. Damper available with balancing adjustment.



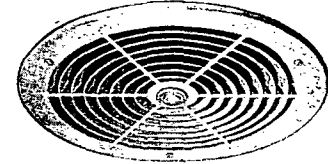
No. 44 series

**No. 452 DIFFUSAIRE—2 Foot Perimeter Unit.** Same construction as No. 44 with additional top perforations for greater volume. Equal to 8 ft continuous type. No cutting of bottom section required. Balancing damper available. Its high throw makes it ideal for cooling as well as heating.



No. 452

**CEILING DIFFUSAIRE—Low resistance eliminates necessity of changing blower in "residential package heating."** Does excellent job on any residential or small commercial heating or cooling installation. 5 popular sizes. Gasket prevents streaking. Damper available.



## Hendrick Manufacturing Company

48 Dundaff Street, Carbondale, Pa.

Sales offices in principal cities—consult telephone directories

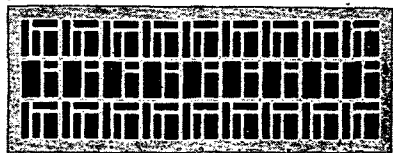
Hendrick Bulators; Hendrick Perforated Metal Grilles; Hendrick Mitco  
Open Steel Flooring, Armorgrids, Shur-Site Treads

### HENDRICK BULATOR

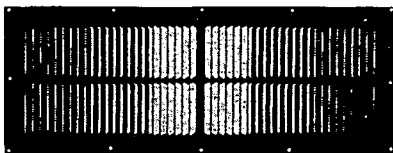
*the dual-unit combination  
of a deflecting vane grille  
and an ornamental grille*

Now you can secure in a single installation all the advantages of an adjustable vane grille—to direct air flow—and an ornamental grille—to harmonize with the decorative scheme—by specifying the new dual-unit Hendrick BULATOR\*. It is a practicable combination that meets both the engineer's specifications for air throw and spread, and the decorative requirements of the architect.

In this dual-unit, the deflecting vanes are not noticeable, although they are mounted just behind the ornamental grille. The vanes are adjustable so that the air flow can be deflected to right or



Photograph taken with deflecting vanes less than an inch behind grille, shows that vanes are not noticeable.



Vertical deflecting vanes, showing how the vanes may be set to produce any desired air stream pattern.

left, up or down, or in a combination of both directions.

For the imposed ornamental grille section of the dual-unit Bulator, Hendrick offers a wide selection of attractive designs, with the essential open area.

#### Tested at Case Institute

To determine the efficiency of the dual-unit, tests were made at the Case Institute of Technology, Cleveland, under the direction of Professor G. L. Tuve, as a result of which, "it was found that at a given air volume, the presence or absence of the 'Mosaic' (design) grille made very little difference on either the air stream pattern or the throw."

A copy of the detailed report on these tests will be mailed on request.

#### How to specify or order Hendrick Bulators

In specifying or requesting quotations on the Hendrick dual-unit Bulator, the following information is required:

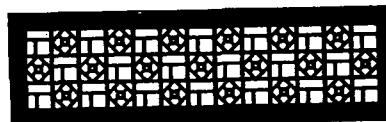
1. The name or description of the desired ornamental grille, as given in the Hendrick Grilles catalog.
2. The metal, gauge and finish of the ornamental grille, that is required.
3. The dimensions of the air duct opening.
4. The type of deflection desired in the deflecting vane section; whether right and left, up and down, or a combination of both.

\* Beauty + Ventilator

### HENDRICK PERFORATED METAL GRILLES

Hendrick decorative grilles are furnished in over a hundred patterns, and in a wide variety of overall dimensions, bar sizes, and number and size of perforations.

Many exclusive Hendrick designs, originally produced to meet an architect's specifications for some particular project, are now available as standard numbers, and facilities for making special designs to specifications make the Hendrick service even more complete. The wide range of patterns permits the choice of a grille that will harmonize with any style of architectural design or period construction.

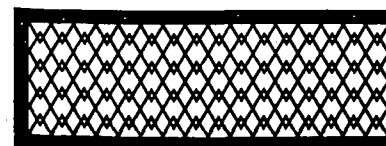


Arglin—63 per cent Open Area

Grilles are fabricated in heavy-gauge aluminum, bronze, copper, Monel, steel, stainless steel, and other commercially rolled metals. With ample open areas and accurate sizes, Hendrick grilles are characterized by clean-cut perforations, fine finish, and freedom from burrs and other imperfections.

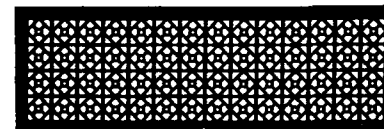


M-No. 2—67 per cent Open Area

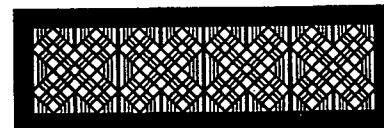


M-No. 3—67 per cent Open Area

They are easy to install, and always lie flat because of a special flattening operation in their manufacture.



Argive—60 per cent Open Area

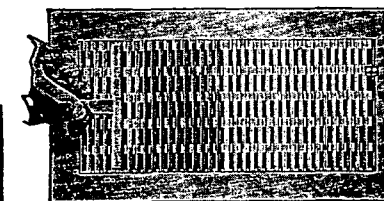


La Crosse—55 per cent Open Area

### AIR CONDITIONING GRILLES AND REGISTERS

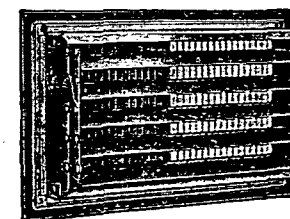
Hendrick air conditioning grilles and registers for directed air flow are made in various meshes, the standard having  $\frac{3}{8}$  in. opening between face bars. All types are furnished with either horizontal or vertical directional bars.

The standard mesh can either be furnished with grille bars permanently set at the factory for straight or directional air flow, or furnished so that the grille bars may be individually adjusted on the job to direct air flow to any desired degree.



Front View

Rear View

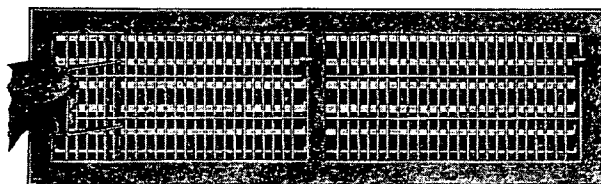


## The Independent Register Co.

ESTABLISHED 1898

3747 East 93rd Street, Cleveland 5, Ohio

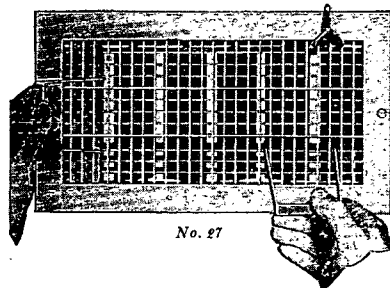
AIR CONDITIONING REGISTERS AND GRILLES



No. 321A-HMV Tandem

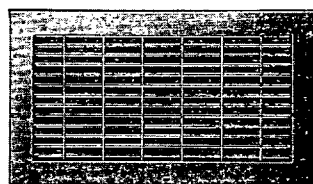
With these grilles, compound deflections of air flows can be obtained with accuracy and certainty. The directional adjustment can be made at the time of installing or after the grille is in position. Each vertical bar on the front may be individually adjusted for air flow right

or left. The HMV valves on the back may be adjusted by the levers in front so as to direct the air flow up or down, or they may be fully closed. If width exceeds 24 in. the valves are made tandem as illustrated above.



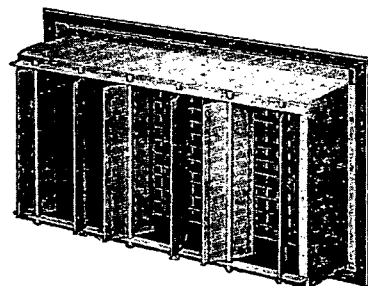
No. 27

Adjustable Vertical Front Bars. Adjustable Horizontal Rear Bars. Key Control opposed blades for volume control attached.



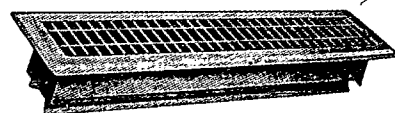
No. 311D-WG Bars Fixed Down

These grilles are designed for commercial installations. Style No. 311-D-WG illustrated has grille bars set permanently at approximately 35 deg. down. Other models available have grille bars set for straight flow.



No. 27 Rear View

Opposed blades for volume control.



No. 60A

For floor installations. Bars are set to diffuse the air up and out to both sides. Famous "Fabrikated" construction, excelling in rigidity, open area and fine appearance. Size shown 24 x 14. Other sizes are made and comply with code requirements of NWAH and ACA.

## Knowles Mushroom Ventilator Co.

Established 1906 All Patents Protected

Main Office and Factory

Upper Montclair, New Jersey

*Nu-Notch*

### NU-NOTCH Specifications

Furnish and install where indicated on drawings or as hereinafter specified (5 in.) (6 in.) (7 in.) (8 in.) (10 in.) (Dome Top) (Flat Top) Nu-Notch Cast Iron Mushroom Air Diffusers with recessed notches for the permanent adjustment of mushroom caps at any desired opening, together with center locking screw feature.

Cast iron mushroom, successfully serving in over 5,000 buildings in U. S. and abroad. Provides correct draft-free distribution of air to each individual in any size auditorium, orchestra or balcony. Close regulation of air—10 different adjustments for all possible conditions. Easily regulated by part turn of cap, and locked in position by tightening head screw with special key—new feature to prevent tampering. Supplied with dome or flat tops, 5 diameter sizes. Easy, permanent anchorage to wood, concrete or monolithic floors.

PROPER auditorium ventilation is now recognized to be a combination of temperature, air motion and distribution, humidity, dust, bacteria, odors, and carbon dioxide. Air motion and distribution is second only to temperature in importance. The Synthetic Air Chart adopted by the ASHVE takes into account all of these factors and makes it possible to arrive at an average which will show the percentage of ventilation obtained in any given installation.

For nearly a half century KNOWLES has devoted itself to one specialized field—the manufacture of air diffusers for auditoriums.

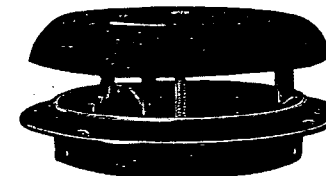
Write for free Guide to Distribution of Air in Auditoriums.

Adaptability of the KNOWLES Mushroom Air Diffuser. In an auditorium seating 2000, requiring 40,000 cfm, it is desired to use 6 in. dia. NU-NOTCH Mushrooms with air velocity of 600 fpm. By referring to the table below, it will be seen that a 6 in. mushroom will exhaust 120 cfm. Dividing 40,000 cfm by 120 indicates 333 units are required.

| Size | Dimensions in Inches |       |       |       |       |       | Net Wgt. Lbs. | Area Sq. Ft. | Cfm at Velocity of |       |       |       |       |       |       |       |       |  |
|------|----------------------|-------|-------|-------|-------|-------|---------------|--------------|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|--|
|      | A                    | B     | C     | D     | E     | F     |               |              | 200                | 250   | 300   | 350   | 400   | 450   | 500   | 550   | 600   |  |
| 5    | 6                    | 7 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 4             | 1.364        | 27.3               | 34.2  | 41.0  | 47.7  | 54.6  | 61.2  | 68.0  | 74.8  | 81.6  |  |
| 6    | 7 1/4                | 1 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 4 3/4         | 1.964        | 39.3               | 49.1  | 59.0  | 68.7  | 78.6  | 88.2  | 98.0  | 107.8 | 117.6 |  |
| 7    | 8 1/4                | 1 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 5 1/4         | 2.673        | 53.5               | 66.8  | 80.2  | 93.5  | 107.0 | 120.6 | 134.0 | 147.4 | 160.8 |  |
| 8    | 9 5/8                | 1 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 6             | 3.491        | 69.8               | 87.3  | 105.0 | 122.0 | 140.0 | 157.0 | 174.5 | 192.5 | 209.4 |  |
| 10   | 11 1/2               | 1 5/8 | 1 1/4 | 1 1/4 | 1 1/4 | 1 1/4 | 8 1/2         | 5.454        | 109.0              | 136.3 | 163.6 | 191.0 | 218.0 | 245.2 | 272.5 | 300.0 | 327.0 |  |

\* The 10" dia. Nu-Notch is the most economically priced Mushroom to use also affording the greatest exhaust area and least duct connections.

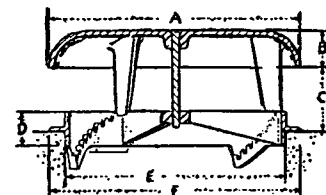
### KNOWLES NU-NOTCH MUSHROOM AIR DIFFUSER



For Auditoriums

MODERN practice shows that 8 cu ft of fresh air per minute per person is ample to keep the air in an auditorium free of odors; and to maintain body heat and to balance the outdoor heat of a warm summer's day, about 20 cu ft per minute per person must be introduced. The accurate amount becomes an engineering problem too extended for this outline.

Of the 20 cu ft per minute per person introduced, 12 cu ft may be recirculated, economizing heat in winter and cooling in summer. If too much air is recirculated, odors will result; and when smoking is to be allowed, much more new air must be introduced.

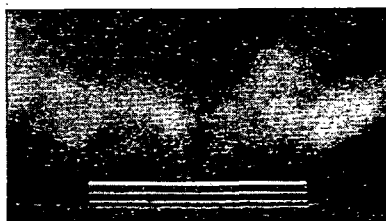


**Lima**

## Register Company, Lima, Ohio

Complete line of floor, baseboard, wall and ceiling diffusers, registers and grilles for heating and cooling.

SOLD EXCLUSIVELY THROUGH HEATING WHOLESALERS AND MANUFACTURERS.



### Proper Diffusion of Air

There is a Lima diffuser designed to assure efficient air distribution over a wide area from any location in the room—floor, baseboard, sidewall or ceiling. Lima's standard sizes of heating diffusers have extra sturdy construction and are equally efficient for cooling as well as heating. Unretouched photo shows front view diffusion pattern of Lima Series 70 Extended Baseboard Diffuser.



### Series 70, Perimeter Extended Baseboard Diffuser with Automatic Pushbutton Damper

Factory set louvers assure uniform diffusion over a wide area. Correct vertical angle eliminates wall scrubbing and allows aspiration of room air down between

wall and air stream. Equally efficient for cooling. Full length spring operated automatic pushbutton damper. Finger tip balancing adjustment. Available in 4-ft and 2-ft sizes. Can be installed in any multiples using joining connector. Permanent medium beige finish.



### Series 75 without damper

This unit is identical in sturdy construction and permanent medium beige finish as the Series 70 but without the automatic pushbutton damper feature, for economy installations where a damper is not required. Available in 4 ft and 2 ft sizes.



### Series 77 Matching Return Air Grille

For use as a return air grille in perimeter extended baseboard installations. This attractive matching unit has the same modern styling, sturdy construction and permanent medium beige finish as Lima Series 70 and 75 diffusers.

### Aspiration of Room Air

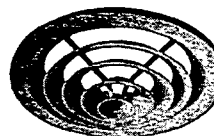
All Lima diffusers are engineered to induce imperceptible aspiration of room air for satisfactory indoor comfort without drafts, in heating and cooling. Photo shows Lima Series 70 side view diffusion pattern with arrows indicating how air within the room is drawn into air stream, setting up induced recirculation of room air. This air pattern holds constant even at low cfm delivery and the velocity remains uniform without whistling, regardless of damper setting.



## Lima Register Company

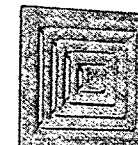
## Air System Equipment • Registers, Grilles And Diffusers

### Series 65 Round Step-Down Ceiling Diffuser



Step-down rings have curved contour without straight edge for proper air diffusion and greater free area. Air stream is deflected outward and slightly downward in all directions without ceiling smudges or drafts. Angle permits aspirating effect with continuous recirculation of room air. Equally efficient for cooling. Spring-loaded butterfly damper, with exclusive balancing control feature. Available in seven sizes.

### Series 60 Square Step-Down Ceiling Diffuser

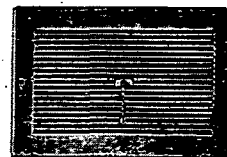


Square design harmonizes with modern tile or block ceilings. Tiers of step-down vanes assure maximum free area with a minimum of resistance and provide effective air diffusion in heating and cooling. Also recommended for return air outlets, especially in perimeter systems, eliminating large, unsightly grilles. Spring-loaded butterfly damper. Exclusive balancing control feature. Six sizes available. Permanent light beige finish.

### Series 45 Wall Diffuser

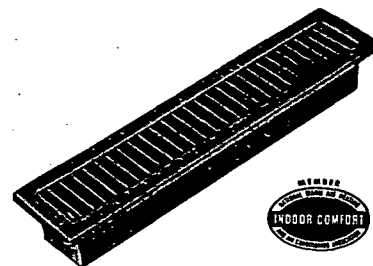
Offers perimeter heating and cooling advantages from side wall. Adaptable for replacing wall or baseboard registers when cooling is being added.

Diffuses air upward and outward so air stream does not strike room occupants. Vertical angle induces aspirating effect of room air.



### Series 40 Floor Diffuser

Spreads a full fan-shaped blanket of air upward and outward to both sides at reasonably high velocity. Pulls air from within the room toward outer wall, setting up induced recirculation of air. This constant aspiration of room air is comfortable and complete without being noticed. Equally efficient for cooling. Five popular sizes are available in a choice of permanent finishes.



See Sweet's Architectural File 29f-Li. For complete catalog contact your local heating contractor or write direct to The Lima Register Company, Lima, Ohio.

## Louvra Manufacturing and Sales Company

Union, New Jersey

Products of Satisfaction

RESIDENTIAL • INDUSTRIAL • SCHOOL • INSTITUTIONAL REGISTERS & GRILLES

Louvra Manufacturing and Sales Company manufactures one of the most complete lines offered. Carefully designed and built to highest specifications. Solid vanes. Resistant to inward corrosion and rust. Maximum free area in all designs. Manufactured of prime steel, aluminum and brass, electro-plated finishes of all types.

1. The Flow Trol, volume controller of air, easily adjusted, complete range in setting. Adjustable tension.

Vision Proof Door louvers available in three types. Core type A, core and flange type B, core flange and reverse frame type C. Maximum free area. (Not shown.)

2. 111-Series. Maximum range four way deflection supply grille. Adjustable face bars.

3. 115-Series. Maximum range single deflection register with protector vanes and adjustable face bars.

4. 116-Series. Maximum range. Four way deflection plus complete volume control and shut off. Adjustable face bars.

5. 111-S-Series. Four way deflection with adjustable range. Back vanes have screw adjustment in and out of air stream without removing face. Available on all series. Face bars adjustable on all types.

6. The 25-75 Lattice Register and Grille in 10 to 14 gauge steel.

7. 103-Series. Conversion-Aire air wall heating or cooling.

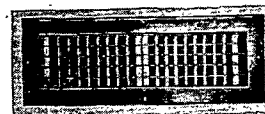
8. 110-Series. Maximum range, single deflection grille. Adjustable face bars.

Positive tamper proof volume control available on all series registers. (Not shown.) Patent Pending.

9. Vane-O-Line. One of the original strip grilles with adjustable vanes.



1.



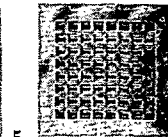
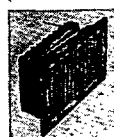
2.



3.

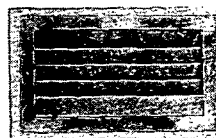


4.



5.

6.



7.



8.



9.

1452

## Register & Grille Mfg. Co.

Incorporated

70 Berry Street,

Brooklyn 11, N.Y.

Sales Offices in principal cities in U. S.

REGISTERS AND GRILLES

HEATING

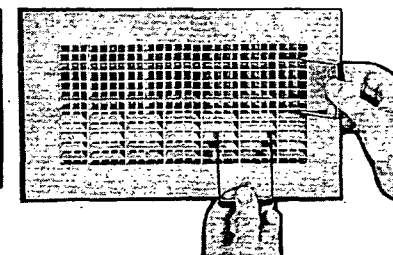
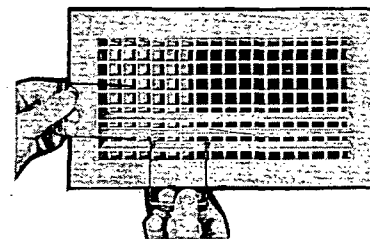
VENTILATING

AIR CONDITIONING

WE SPECIALIZE IN THE CONTRACT CONSTRUCTION FIELD  
Complete Line of Registers and Grilles, Plaster Frames, Angle Frames for  
HEATING • VENTILATING • AIR CONDITIONING

BLADE TYPE

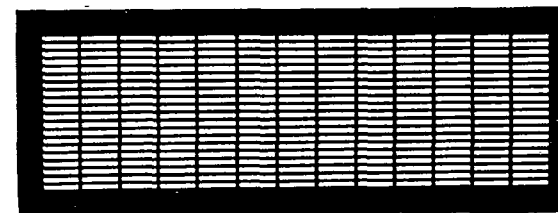
BAR TYPE



Air Conditioning type Registers and Grilles for the maximum in directional and volume control—Noiseless Operation—Strength and Beauty. Registers equipped with tamperproof opposed blade action, key operated shutters.

Solid 14 gauge adjustable bars make this style rugged and long lasting. Interlocking construction makes them tamper-proof, adjustable only with the special tool provided.

Designed for the job where performance and quality are of primary consideration. Architects and Engineers have specified both of these type registers and grilles for America's finest Schools, Hospitals, and Public Buildings. Each of the above types is a complete line in itself and is available in all the standard styles.



81 STYLES OF PERFORATED GRILLES

Available in Bronze, Aluminum, Stainless Steel and Steel.

Trade Names Include Directrol, Quantrol, Aircon Shutter, Arrowtrol Shutter, 13W Frames.

Catalog on Request

1453

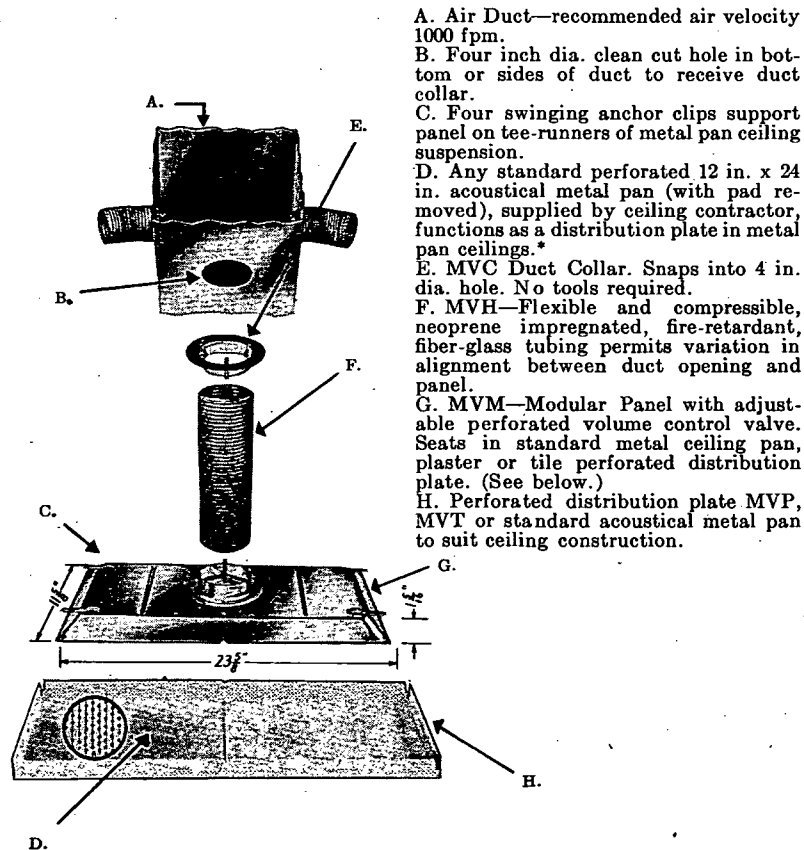


## The Pyle-National Company

Multi-Vent Division  
1363-78 N. Kostner Ave.  
Chicago 51, Illinois



Sales Engineers and Agents  
in Principal Cities of  
U. S. and Canada



### ADVANTAGES OF MULTI-VENT TYPE AIR DIFFUSER

1. Conditioned air is delivered straight down into the room at a comfortable low velocity.
2. Complete concealment when used with standard perforated metal pan ceilings.
3. Complete freedom of partition movement with no mechanical adjustment or relocation required because air gently drops straight down.
4. Eliminates dirt smudge on ceiling, usually found adjacent to conventional diffusers having horizontal high velocity distribution.
5. Exceptional performance with no drafts even when used on applications requiring 60 air changes per hour.

\* Sect. 1-C-Page 37 of the Multi-Vent Engineering Manual for Sound Level Data.

## THE PYLE-NATIONAL COMPANY

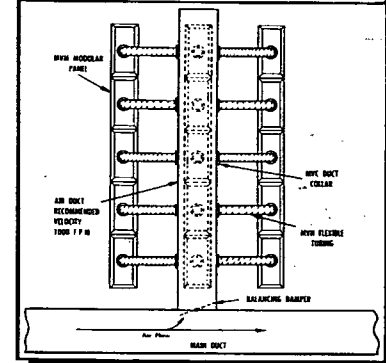
### Multi-Vent Division

#### MVM MODULAR PANEL SELECTION DATA

| T/D | CFM†<br>LIMIT | BTU/<br>HR | VALVE OPENED TO: |      |      |      |
|-----|---------------|------------|------------------|------|------|------|
|     |               |            | ¼"               | ⅜"   | ½"   | ¾"   |
| 15° | 60            | 971        | .138             | .099 | .087 | .077 |
| 20° | 45            | 971        | .076             | .055 | .048 | .043 |
| 25° | 36            | 971        | .048             | .035 | .031 | .027 |

\* For plenum applications consult factory  
† Refer to sound level chart when perforated acoustical ceiling pans are used for distribution

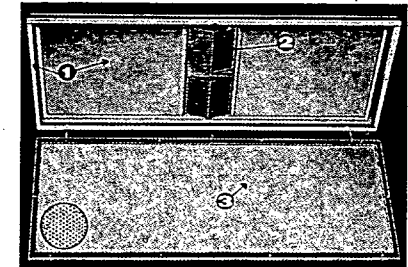
#### RECOMMENDED MODULAR LAYOUT



#### TYPE-MVAR UNITARY MULTI-VENT PANEL

1. The Control Plate and Frame are installed in the bottom of the air supply duct of plenum or in a collar extending down through the ceiling.
2. The Pressure Displacement Air Valve is located in the center of the control plate. Its function is to control the volume of air admitted to the unit and to reduce both velocity and pressure of the incoming air.
3. The Perforated Plate spreads the delivery of the incoming air over a large area and further reduces the velocity which, in a typical installation, is only 30 to 50 ft per minute at 6 in. below the perforated plate.

cleaning equipment, perforations will not clog.



Type MVAR Multi-Vent Panel for duct or plenum applications

Even with relatively inefficient air

#### TYPE MVAR PANEL SELECTION DATA

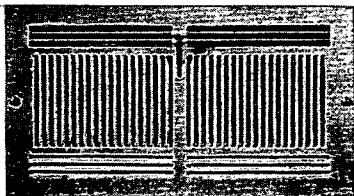
| PANEL<br>CATALOG<br>No. | PANEL<br>DIMENSIONS |              |               | COOLING OR COMBINATION<br>HEATING & COOLING LIMITS PER PANEL |            |            |            |            |                      |            |            |            |            |
|-------------------------|---------------------|--------------|---------------|--------------------------------------------------------------|------------|------------|------------|------------|----------------------|------------|------------|------------|------------|
|                         | Width<br>ft         | Length<br>ft | Area<br>sq ft | CUBIC FEET PER MINUTE                                        |            |            |            |            | BTU/HR SENSIBLE HEAT |            |            |            |            |
|                         |                     |              |               | 5°<br>T/D                                                    | 10°<br>T/D | 15°<br>T/D | 20°<br>T/D | 25°<br>T/D | 5°<br>T/D            | 10°<br>T/D | 15°<br>T/D | 20°<br>T/D | 25°<br>T/D |
| MVAR-122-1              | 1                   | 2            | 2             | 74                                                           | 70         | 60         | 46         | 36         | 405                  | 756        | 972        | 994        | 972        |
| MVAR-123-2              | 1                   | 3            | 3             | 111                                                          | 105        | 90         | 69         | 54         | 600                  | 1134       | 1458       | 1490       | 1458       |
| MVAR-124-2              | 1                   | 4            | 4             | 148                                                          | 140        | 120        | 92         | 72         | 799                  | 1512       | 1944       | 1987       | 1944       |
| MVAR-125-3              | 1                   | 5            | 5             | 185                                                          | 175        | 150        | 115        | 90         | 999                  | 1890       | 2430       | 2484       | 2430       |
| MVAR-126-3              | 1                   | 6            | 6             | 222                                                          | 210        | 180        | 138        | 108        | 1199                 | 2268       | 2916       | 2981       | 2916       |
| MVAR-224-1              | 2                   | 4            | 8             | 280                                                          | 240        | 176        | 144        | 104        | 1512                 | 2592       | 3564       | 3888       | 3510       |
| MVAR-245-1              | 2                   | 5            | 10            | 300                                                          | 300        | 220        | 180        | 130        | 1620                 | 3240       | 4320       | 4666       | 4212       |
| MVAR-246-1              | 2                   | 6            | 12            | 300                                                          | 300        | 220        | 180        | 130        | 1620                 | 3240       | 4320       | 4666       | 4212       |
| MVAR-364-1              | 3                   | 4            | 12            | 300                                                          | 264        | 216        | 156        | 120        | 1620                 | 2851       | 3499       | 3370       | 3240       |
| MVAR-365-1              | 3                   | 5            | 15            | 300                                                          | 300        | 270        | 195        | 150        | 1620                 | 3240       | 4374       | 4212       | 4050       |
| MVAR-365-2              | 3                   | 5            | 15            | 450                                                          | 350        | 270        | 195        | 150        | 2430                 | 3564       | 4374       | 4212       | 4050       |
| MVAR-366-1              | 3                   | 6            | 18            | 300                                                          | 300        | 234        | 180        | 120        | 1620                 | 3240       | 4360       | 5054       | 4860       |
| MVAR-366-2              | 3                   | 6            | 18            | 540                                                          | 396        | 324        | 234        | 180        | 2916                 | 4277       | 5249       | 5054       | 4860       |



## Standard Stamping & Perforating Co.

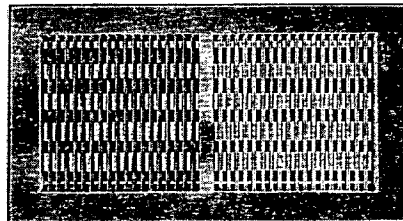
3111 W. 49th Place, Chicago 32, Illinois

Air Conditioning Registers and Grilles—Cold Air Faces  
Perforated Metals for all Purposes



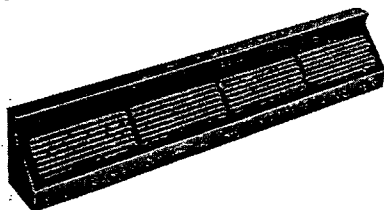
No. 551 Perimeter Wall Register

Gives four way air diffusion. Equipped with Fractionator Volume Control and Damper Tension Screws. Also available with a base extension as Model No. 451 perimeter base board register.



No. 331 Sidewall Register

Horizontal multiple valve louvers attached to vertical "bend-ezy" faces, adjustable for four way deflection.



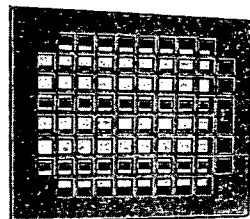
B-24 Perimeter Baseboard Diffuser

Maintains heating and cooling comfort at a high level. New Adjustamatic fingertip control regulates built-in damper. No damper installation required. Provides uniform temperature along outer walls, keeping floors warm and avoiding condensation on windows. Replaces lost heat immediately, where it's lost, without creating blasts, hot spots, or cold corners.

2 ft sections, 4½ in. high.

Open area 28 inches.

Heavy gauge steel construction, baked-on metallic finish.



No. 100-LO Multiple Louvre, Lever operated register.

Also available as: 100-KL, a Key Operated register; 100-RK, a register with a Removable Key; 100-PO, a Pulley Operated register (especially suited for inaccessible installations). Register faces are attached to louver boxes with screws so that the boxes are detachable.

### Single System Ceiling Air Diffusers

For Air Conditioning And Warm Air Heating



Supply full dimension distribution of warm air in the winter and cool air in the summer. FLUSH or EXTENDED models available with dampers and installation rings. Both models are finished in Standard's baked-on metallic finish. Packed one to a box and 10 to a carton.

Complete specifications will be furnished upon request

1456

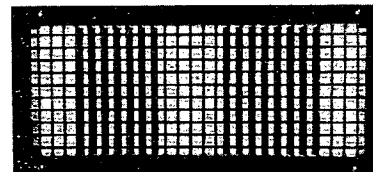
## Stewart Manufacturing Co., Inc.

Cedar Grove, Essex County, New Jersey

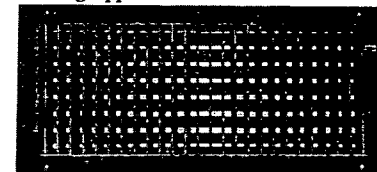


Technical and price information available through representatives in all principal cities, or at factory headquarters.

A complete line of Registers, Grilles and Scoops for all types of Industrial and Residential air conditioning applications.

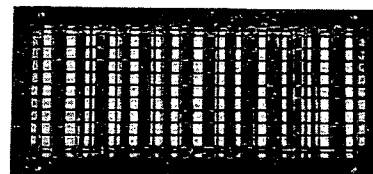


DDV A double deflection grille affording four way diffusion—individually adjustable streamlined fins ¾ in. C.-C. heavy gauge metal and sturdy construction.

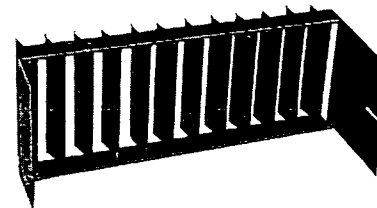


DVL A directional-type register employing 1 in. wide, parallel-acting valves. Face fins are individually adjustable right and left.

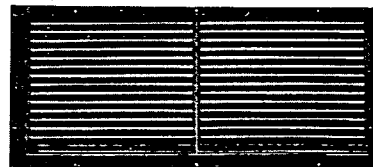
The 1 in. wide, parallel-acting valve mechanism is available with any/all STEWART face patterns.



DDVO A double deflection grille with opposed action valves. The valve consists of a series of hollow, internally reinforced air-foil sections. Through a unique actuating mechanism each air-foil section turns in a 90 deg arc toward a similarly turning section.



SCOOPTROL A device designed to deflect and control the air from a supply duct into a collar, and installed at the junction of the duct and collar. Scooptrol is a double-blade functional product, easily adjusted, positioned and then fastened by sheet metal screws; it cannot move or fall.



DG An exhaust grille with non-adjustable fins. Fins are normally factory set at 45 deg down angle to restrict vision. Also available with fins set at 0 deg vertical or horizontal.



PLASTER FRAME Permits the removal of grille when desired without damage to surrounding painted areas.

FINISH DIRECTIONAL TYPE OUTLETS ARE PROTECTED BY A PRIME COAT FINISH AND A FINISHING COAT OF SILVAIR ENAMEL, BAKED ON. SILVAIR FINISH IS A MODERN, ATTRACTIVE COATING CONTAINING ALUMINUM PIGMENT, AND IS SILVER-BLUE IN TONE. NO ADDITIONAL PAINTING IS REQUIRED.

Send for Illustrated Catalog No. 55

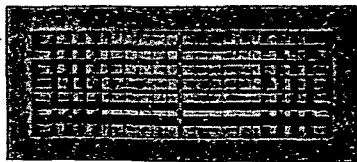
1457

# Airfoil

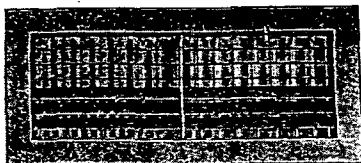
AIR CONDITIONING OUTLETS

Titus Mfg. Corp.  
WATERLOO, IOWA

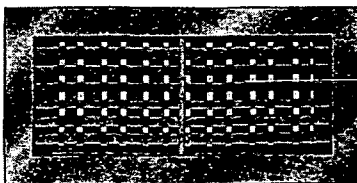
Titus Mfg. Corp. are designers and manufacturers of Airfoil Grilles featuring the Airfoil Louver—patterned after the airfoil section of an airplane. The following distinctive features identify Titus Airfoil Louvers. (1) Smooth as glass streamlined surface (2) Solid construction (3) Noiseless performance (4) Minimum turbulence.



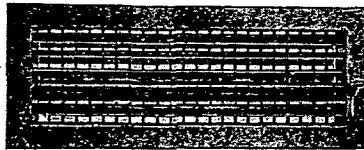
270 Airfoil Grille Gives 4-way directional control. Louvers set on  $\frac{3}{4}$  in. centers. Individually adjustable to create any air pattern desired.



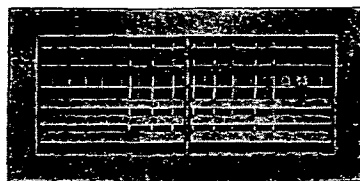
274 Multi-Shutter Register Airfoil Louvers are featured in front. Individually adjustable. Rear multi-shutter damper blades.



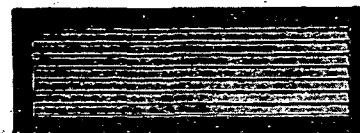
275—Double deflection register with opposed blade damper, key operated.



276 4-Way Multi-Shutter Register Consists of the #270 4-way directional grille combined with a multi-shutter damper. Damper blades inter-locked when closed to provide complete shutoff.



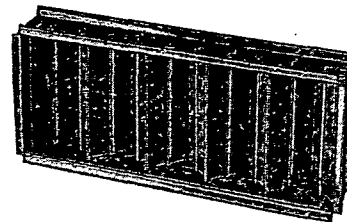
277 4-Way Registers with opposed blade dampers. Two front sets Airfoil louvers individually adjustable,  $\frac{3}{4}$  in. spacing. Opposed blade damper key operated in rear.



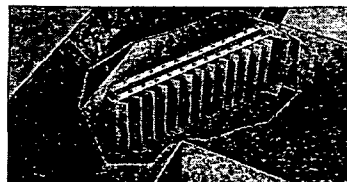
230 Return Air Grille—blades on  $\frac{3}{4}$  in. centers. Parallel to long dimension. Deep fins. Standard  $1\frac{1}{4}$  in. beveled border. Any size grille can be furnished. R-240 (not illustrated) combines #230 return air grille with multishutter damper blades. R-241 (not illustrated) combines #230 with opposed blade damper.



AG-25 Volume Controllers provide positive control of air volume. Blades individually adjustable. Sponge rubber gasket holds unit firmly in duct.



AG-35—Opposed acting volume controller. Provides complete control of air volume to the outlet with minimum disturbances of air pattern. Louvers move simultaneously in opposite directions and can be set at any degree from full open to full closed.

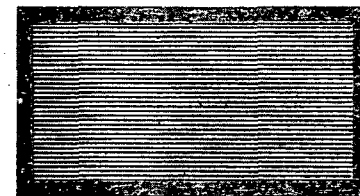


AG-45—Air volume extractor and controller. Will control air volume and also produce balanced air distribution. Replaces extra volume controller. Fifty percent savings on cost and installation.

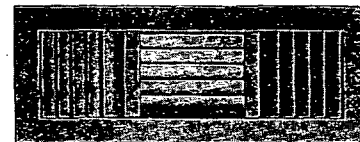


Perimeter Baseboard Diffusers—Made in 17 in., 30 in. or 60 in. lengths complete with built-in damper. Easily installed. Outstanding performance.

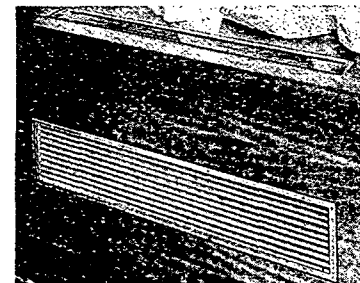
WRITE FOR NEW ILLUSTRATED CATALOG.



Door Grilles—No vision door and partition grilles. Made with flange frame or channel frame. All steel—V shaped louvers. T-700 standard thickness. T-800 thin core.



200 Series—New hi-efficiency sidewall or ceiling diffuser. Adjustable curved design louvers. 1, 2, 3, or 4 way deflection.



CONVECTOR GRILLES—Louvers closely spaced. Heavy-duty support bars on 6 in. centers. Over 70 per cent free area. Can be installed in any special surface, such as marble or tile.

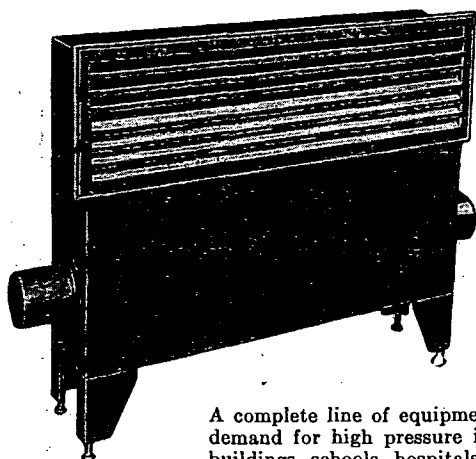
FRAME 115 FOR ALL AIRFOIL GRILLES AND REGISTERS (not illustrated) Allows quick easy removal for cleaning or adjusting. Can be installed either before or after plastering has been completed.



Engineered Products  
for Residential, Com-  
mercial and Institu-  
tional Air Condition-  
ing, Heating, Venti-  
lating

NEW BRITAIN, CONNECTICUT

### HIGH PRESSURE AIR DISTRIBUTION UNITS



Type MPW

A complete line of equipment designed to meet the growing demand for high pressure installations in multi-story office buildings, schools, hospitals, hotels and institutions.

#### TYPE MPW

Medium Pressure Periphery Wall Mixing Plenum Unit for individual room control on heating or cooling cycle, or zone control. Handles static pressure in system up to 3.5 in. w.g.

#### TYPE MP

Medium Pressure Sub-Central Station Unit for distribution of air to one or more diffusers by means of rigid or flexible ductwork. Handles static pressure in system up to 3.5 in. w.g.

#### TYPE MPD

Medium Pressure Ceiling Diffuser Double Duct Mixing Plenum Unit for individual unit or zone control. Single duct units also available. Handles static pressure in system up to 3.5 in. w.g.

#### TYPE HPD

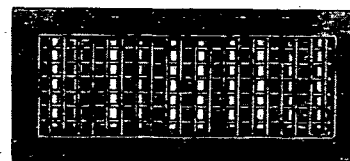
High Pressure Ceiling Diffuser Unit for individual unit or zone control. Handles static pressure in system up to 6.0 in. w.g.

### Aerofuse CEILING DIFFUSERS



A wide selection of diffuser types and sizes, styled and engineered to meet the most rigid requirements of appearance and performance at the point of air delivery.

### TRI-FLEX SUPPLY AIR GRILLES AND REGISTERS



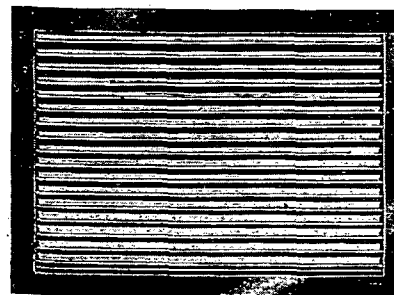
Available as single and double deflection grilles; single and double deflection registers with opposed blade dampers. Blades are regulated by means of a key operator and may be set in any position from fully open to fully closed. Face bars are individually adjustable. Stocked in 26 standard sizes.

#### 26 STANDARD SIZES

|        |        |         |         |
|--------|--------|---------|---------|
| 8 x 4  | 14 x 4 | 20 x 6  | 30 x 6  |
| 10 x 4 | 14 x 5 | 20 x 8  | 30 x 8  |
| 10 x 6 | 14 x 6 | 24 x 5  | 30 x 10 |
| 12 x 4 | 16 x 5 | 24 x 6  | 30 x 12 |
| 12 x 5 | 16 x 6 | 24 x 8  | 36 x 8  |
| 12 x 6 | 20 x 5 | 24 x 10 | 36 x 10 |
|        |        | 24 x 12 | 36 x 12 |

### AEROVANE RETURN AIR GRILLES AND REGISTERS

Aerovane grilles are available with horizontal or vertical bars. Aerovane registers are furnished with the same opposed blade damper units as supplied with Tri-Flex registers. Stocked in 20 standard sizes.



#### 20 STANDARD SIZES

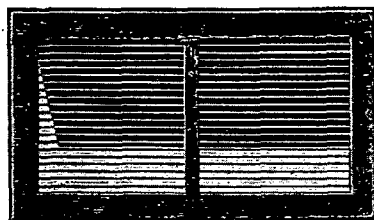
|         |         |
|---------|---------|
| 10 x 6  | 24 x 24 |
| 10 x 8  | 30 x 12 |
| 12 x 6  | 30 x 18 |
| 12 x 8  | 30 x 24 |
| 12 x 12 | 36 x 18 |
| 18 x 6  | 36 x 24 |
| 18 x 12 | 36 x 30 |
| 18 x 18 | 48 x 24 |
| 24 x 12 | 48 x 30 |
| 24 x 18 | 48 x 36 |

## United States Register Company

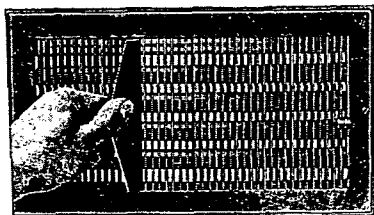
General Offices: Battle Creek, Mich., U.S.A.

Branches: MINNEAPOLIS, MINN., KANSAS CITY, MO., ALBANY, N. Y.

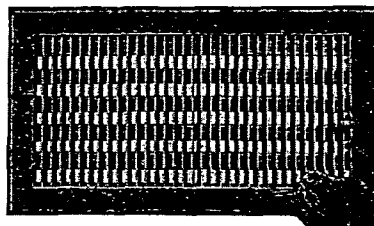
Air Conditioning Registers, Vents and Grilles



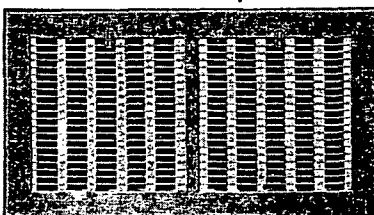
No. 249—Multiple-Valve Air Conditioning Register. Gives complete Air Control. Vertical Front Bars—Key-pin adjusted to provide 45 deg Right and Left or Two-way Side Flow. Lever operated Horizontal Back Valves Give from Full Closed to any degree of Upflow and to 45 deg Downflow. FULL FACE COVERAGE. Can be supplied with any style of Setting Frame. Fits all Stack Heads of Standard Size Dimensions.



No. 153—Single-Valve Air Conditioning Register—Bars  $\frac{1}{4}$  in. deep—Spaced 4 openings to the inch affords Non-Vision. Can be supplied in Directional Flow in either Horizontal or Vertical Bar Styles. Can be furnished with all styles of Setting Frames.



No. 256—Multiple-Valve Flex-bar Air Conditioning Register. Vertical Front Bars set 22 deg Right and Left. Side Flow Deflection attained by setting of Grille Bars with bending wrench to accommodate room condition. Back-valves give same Up and Down control of air flow as No. 249 above. FULL FACE COVERAGE. Can be supplied with any style of Setting Frame. Fits all Stack Heads of Standard Size Dimensions.



No. 153-VVL Horizontal Bar Non-Vision Design Vertical lever operated rear valves. No. 145-VVL—Specially adapted to Combination Heating and Cooling Systems. Horizontal Bar Adjustment to 60 deg Up and Down Flow.

All of above Styles can be supplied with either Lever or Individually adjusted Multiple Valves or Louvers. i.e. 177VVI—Vertical Valves Individually adjusted. 145VVL—Lever operated Vertical Valves. Specially adapted to Combination Heating and Cooling Systems.

Grilles and Vents in Matching designs are available.

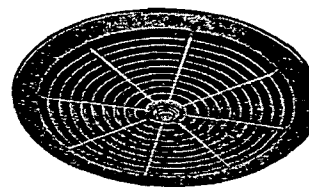
For Complete Information Write for Catalog No. 55-6.

Multiple Valve A. C. Registers available with Key Operation.

1462

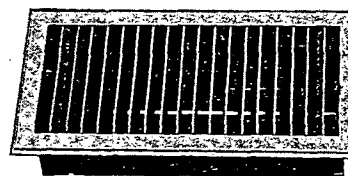
## United States Register Co.

No. 500 U.S. Round Ceiling Diffuser  
Step-Down Style



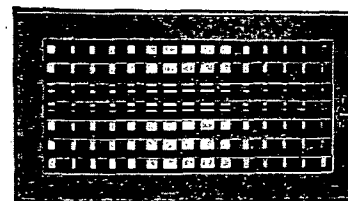
No. 500 U. S. Round Ceiling Diffuser. Made in 6 in., 8 in., 10 in., 12 in. and 14 in. sizes. Furnished with or without No. 900 frames. However, frames are recommended. No. 500 diffusers will be furnished with Dampers when required.

No. 410 U. S. Perimeter Floor Register.



No. 191 U. S. Multi-Flex Register Streamlined Double-Edged Grille bars. Front bank of bars—Horizontal Adjustable. Second bank of bars—Vertical Adjustable. Opposed Rear Valves—Key operated.

No. 191 U. S. Multi-Flex Register



No. 192 U. S. Multi-Flex Register—same as No. 190—but with Vertical Front Bars.

No. 193 U. S. Multi-Flex Grille—same as No. 190—but less Rear Valves.

No. 194 U. S. Multi-Flex Grille—same as No. 191—but less Rear Valves.

No. 195 U. S. Multi-Flex Grille—same as No. 193—but Vertical Bars only.

No. 196 U. S. Multi-Flex Grille—same as No. 194—but Horizontal Bars only.

See our Catalog No. 55-6 for the additional Non-Flex Register and Grille Line.

1463

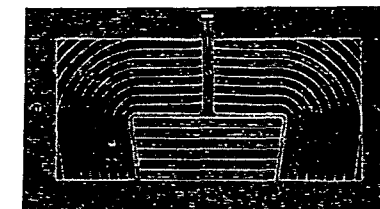
No. 1000 U.S. Super Base Diffuser is equipped with Balancing Set-Lock and Adjustable Slide-Plate bottom opening. Furnished in 2 ft and 4 ft sections with which any continuous lengths may be assembled.

No. 1000 U.S. Super Base Diffuser

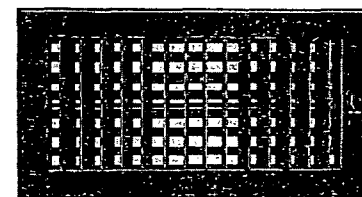


No. 105 U.S. Diffuser Sidewall Register furnishes a complete 180 deg Sunburst Diffusion at an even fpm at every degree of air diffusion.

No. 105 Diffuser Sidewall



No. 190 U.S. Multi-Flex Register

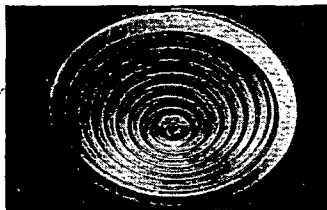


No. 190 U. S. Multi-Flex Register Streamlined, Double-edged Grille bars. Front bank of bars—Vertical, Adjustable. Second bank of bars—Horizontal, Adjustable. Opposed Rear Valves—Key operated.

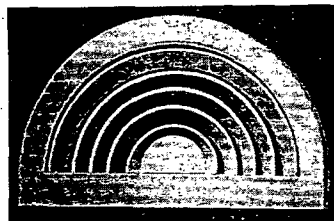
## Universal Diffuser Corp.

1360 Garrison Ave., New York 59, N. Y.

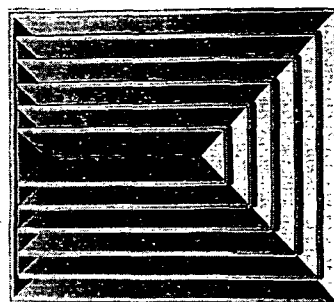
Manufacturers of FLEXIFLO Adjustable Diffusers



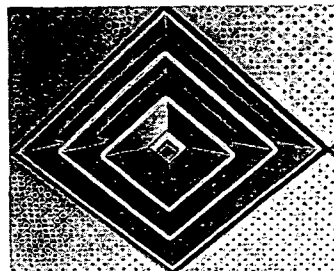
*Flexiflo-Type R and V*



*Flexiflo-Type S*



*Flexiflo-Series MP*



*Flexiflo-Adjustable Series HAR*

### VARIABLE EFFECTIVE AREA

The FLEXIFLO diffuser is unique in that it has an infinitely variable effective area. All blades move simultaneously when the control knob is moved up or down. This provides a simple, effective means of controlling the volume of air. The pattern of diffusion for cooling purposes remains constant on the Type "R" FLEXIFLO. For cooling and heating purposes the Type "V" FLEXIFLO provides a variable pattern of diffusion from horizontal to downflow.

#### Type R—For Cooling

Provides a diffusion pattern and radius of diffusion that are not altered by change in air volume. Air leaving the Type R diffuser always travels parallel to the ceiling, assuring satisfactory performance under all operating conditions.

#### Type V—For Cooling, Ventilating and Heating

Has a special blade configuration that gives a variable air distribution cone from horizontal to downward flow. Air can be delivered at practically any angle.

#### Type S—For Side Wall or Ceiling Installations

Model SC is for ceiling installations in cooling work. Model SW is for wall installations. Every Type S diffuser has one set of equalizing deflectors.

#### Series MP—Multi-Pattern Diffusers

FLEXIFLO Series MP diffusers are made to order in all rectangular shapes for one, two, three and four way blows to accommodate rooms of irregular shape. The diffusion pattern is parallel to the ceiling in all cases. Standard finish is metallic gray baked enamel. Other colors are available at no extra cost.

#### Series HAR

The FLEXIFLO HAR Series of adjustable square diffusers is built for either ceiling or acoustical tile installation. The blades move simultaneously when the control knob is moved up and down. Air volume can thus be controlled with great precision and can be varied between near zero and full output at constant horizontal pattern.

## Waterloo Register Co. Inc.

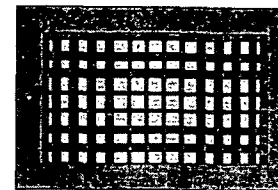
"Since 1902"

P.O. Box 72

Waterloo, Iowa

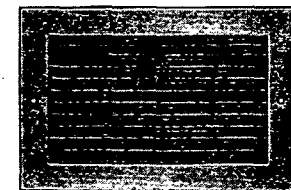


Complete Line of Air Diffusion Equipment for All Air Conditioning and Heating Installations. Offers: Performance. Appearance. Selection. Prompt Delivery. Features Silent Flow "Tear Drop" Louvre Design which provides unobtrusive diffusion with SUFFICIENT SURFACE to turn high velocity air WITHOUT TURBULENCE.



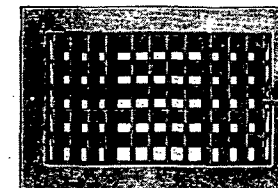
#### 2V SUPPLY GRILLE

Two sets of extruded aluminum louvers, each individually adjustable for four-way deflection at degree desired. Designed for long or short throw.



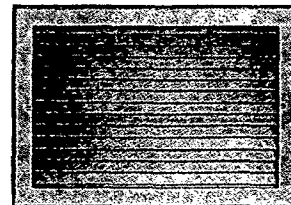
#### 3H RETURN AIR GRILLE

Fixed fins at 45 degree or 0 degree deflection, in heavy gauge frame, strengthened with adequately spaced support bars.



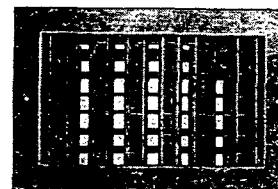
#### IVMH SUPPLY REGISTER

One set of adjustable louvers for easy control of air, right or left, with multi-shutter damper, horizontal blades. Ideally suited for home installations because of narrow stack depth.



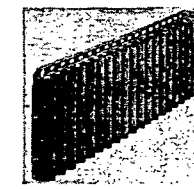
#### DV DOOR VENTILATORS

V-Shaped fixed fins, permanently spot welded in channel frame for rigidity. Offers more than 57 per cent free area, yet completely sight proof. Available flange both sides, one side, or no flange.



#### 2VO SUPPLY REGISTER

Two sets of adjustable louvers, vertical and horizontal, with opposed blade damper, vertical blades, for even volume control. Fins spaced on 3/4 inch centers. Provides positive air control.



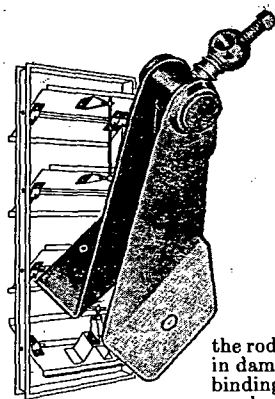
#### DUCTROL Air Volume Extractor

Volume controller and extractor adjusts from full open to full closed, to provide even distribution to entire grille surface. Completely assembled at the factory—ready to install on job.

Waterloo 6-page "Size Selection Table" available in folder form to use in making SIZE SELECTIONS of outlets on commercial jobs.

## Duro-Dyne Corporation

800 Third Avenue, New Hyde Park, N. Y.  
Manufacturers of Accessories for the Sheet Metal,  
Heating, Air-Conditioning and Ventilating Fields



### NEVA BIND DURO-BLADE KIT

#### Multi-blade Louver Damper Hardware

The Neva Bind Duro-Blade Kit—multi-blade louver damper hardware permits smoothly operating, *absolutely non-binding* dampers to be assembled with little care and no alignment afterward. The Kit's unique 4-way adjustability automatically compensates for slight errors in blade dimensions or formation, minor misplacements of bearing holes or other inaccuracies which cause stress or bending of the connecting rod—the main cause of binding. The Neva Bind feature allows the rod to remain absolutely straight regardless of inaccuracies in damper construction. Besides operating smoothly and never binding, dampers made with the Neva Bind Duro-Blade Kit can be fully closed without the bracket hitting the duct. The damper can be fully opened without interference of the connecting rod.

### JIFFY DAMPERS

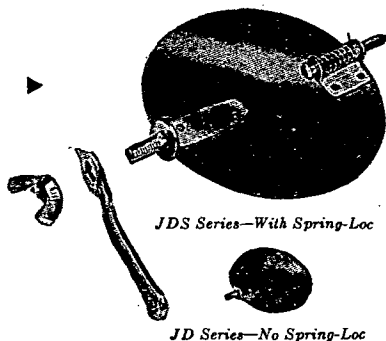
#### Complete, Prefabricated Dampers for Round Pipe

Jiffy Dampers are complete, prefabricated dampers ready for immediate installation in ductwork. A comparable damper fabricated in the shop costs considerably more. The P-K Jiffy Regulator (now manufactured by Duro-Dyne) is pre-attached to a galvanized damper blade. The steel threaded bearing will never break. There are no loose parts to rattle.

JD Series—Consists of damper plate with a 1/4 in. square end bearing, washer, handle and wing nut.

JDS Series—Same as JD Series plus patented P-K Spring-Loc Bearing. For high air velocities or when necessary to keep damper in perfect position.

JD and JDS Series Jiffy Dampers are regularly available in 4 in., 5 in., 6 in., 7 in., 8 in. and 9 in. pipe sizes. Other sizes, and rectangular dampers on quotation.



JDS Series—With Spring-Loc

JD Series—No Spring-Loc

### DAMPER REGULATORS AND CONTROLS

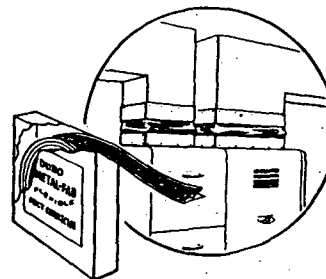
(formerly Manufactured by Parker-Kalon)



UNXLD Damper Quadrant Heavy Duty Quadrant Jiffy Regulator Dial Damper Regulator

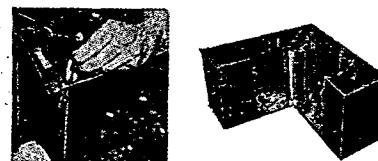
### FLEXIBLE DUCT CONNECTOR PRODUCTS

#### Rolls of Preassembled Metal-to-Fabric-to-Metal



### LAI D OUT AND PUNCHED SIDE RAILS FOR MAKING AIR TURNING VANES

Air turning vanes made with Duro-Vane-Rail side rails save 50 per cent to 70 per cent in installed costs. Vanes are merely sheared from scrap. No tab cutting on vanes is necessary. Insert vanes in notches provided in Duro-Vane-Rail.

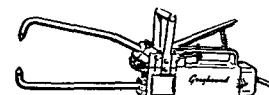


Place chisel (supplied with each bundle of Duro-Vane-Rail) on protruding portion of vane in slot. One blow securely locks vane to rail. Duro-Vane-Rail allows maximum free area; eliminates noise and "whistle." Completed air turning vane assembly meets most engineering specifications.

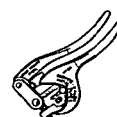
Duro-Metal-Fab and Econ-O-Fab are preassembled metal-to-fabric-to-metal for making flexible duct connectors (for eliminating vibration travel). They eliminate the annoying time-consuming job of attaching metal to fabric in the shop. The exclusive Double-Loc Seam cannot pull apart and prevents the metal from cutting the fabric when the finished connector vibrates. Duro-Metal-Fab for industrial or heavier gauge ductwork consists of 24-gauge galvanized iron attached to U.L.-Approved Canvas, Asbestos or Neoprene Fiberglass. Econ-O-Fab, for residential and lighter gauge ductwork, is identical to Duro-Metal-Fab, except lighter. Both Duro-Metal-Fab and Econ-O-Fab are packed 50 ft or 100 ft to the handy Dispens-O-Flat carton.

DUCT FABRIC is available for special cases where fabrics without metal are desired. Packed in 100 ft rolls, available 6 in. or 10 in. wide canvas and 6 in. wide asbestos or neoprene.

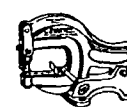
### TOOLS FOR SHEET METAL FABRICATION



Grayhound Portable Spot Welder



X. X. Metal Punch



O. X. Metal Punch



Shur-Grip File and Solder Iron Handles





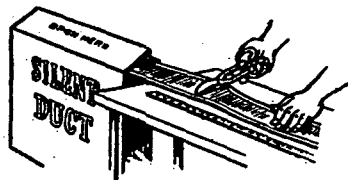
## Elgen Manufacturing Corporation

41-34 39th St., Long Island City 4, N. Y.

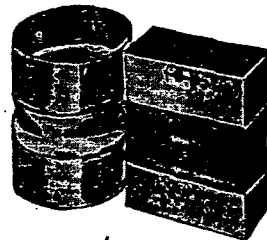
**ELGEN SILENT DUCT**—Pre-assembled metal and material for flexible duct connectors.

**ELGEN ALL-TITE VANE RUNNERS**—for making turning vanes for square elbows.

**ELGEN DAMPERSET**—for damper control in blower and exhaust systems.



### ELGEN SILENT DUCT



Factory-assembled metal and material. Delivered in dispenser carton . . . pulls out flat, ready to use. Union made.

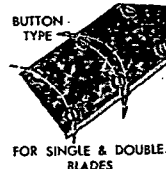
- Available in 24 or 26-gauge galvanized steel . . .
- Fastened to fire, water and mildew-resistant *UL* approved canvas (*Govt. Spec. MIL-D-10860*) or to Johns-Manville asbestos (wire-filled, if

- desired) or to U.S. Rubber Co. Neoprene-coated fiber glass.
- Delivered in 100-ft (approx.) coils; 50-ft coils with asbestos available.

### ELGEN ALL-TITE COILED VANE RUNNER

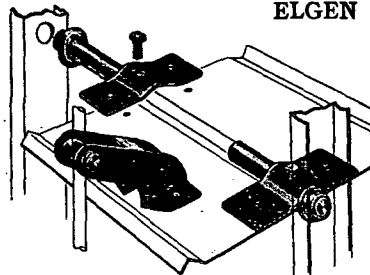
Button Type for single and double blades

- Quick, inexpensive method of making turning vanes.
- 24-gauge galvanized steel.
- Eliminates notching, punching, etc. No special tools needed.
- Is screwed into elbow . . . absolutely rigid and rattleproof.



- Delivered in the 100 ft coils (approx.) Unrolls absolutely flat. Union made.

### ELGEN DAMPERSET



for multi-blade dampers—parallel or opposed

- Licensed by Minneapolis-Honeywell.
- Quick and easy to assemble.
- Precision-machined—cadmium plated.
- Bronze self-oiling bearings.
- Packed in single boxes or bulk 100's.

All Elgen products engineer-approved; available at leading jobbers in U. S., Canada, Hawaiian Islands. Descriptive literature on request.

## The WIREMOLD Company

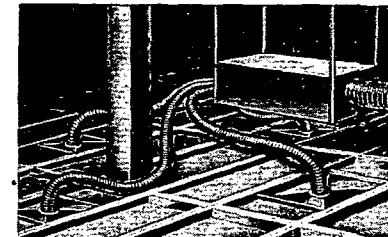
Hartford 10, Connecticut

Manufacturers of Wiremold Air Duct for  
Commercial Air Conditioning Systems.

### Wiremold Air Duct has REMARKABLE FLEXIBILITY

. . . proved on every type of Commercial  
Air Conditioning System!

Designed for connecting air-distribution  
units to branch ducts, strong, durable,  
and extremely flexible Wiremold Air  
Duct conducts air at temperatures of 0  
to 250F at high or low velocities.



Wiremold Flexible Air Duct Type 57-1A connecting  
four diffusers to sound box and sound box to main duct  
in modular ceiling construction.

Takes all bends without kinking. Flexi-  
bility of duct allows for expansion and  
contraction of system and prevents  
transmission of mechanical vibration.

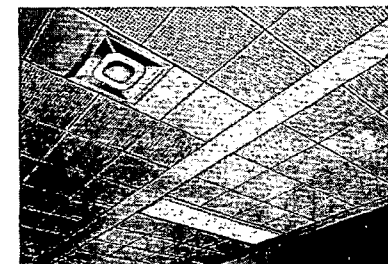
Wiremold Engineering Data Sheets give  
details of Wiremold Air Duct installa-  
tions. Send for your copies.



Type 57-1A, 6-in. and 7-in. I.D. flexible connectors  
high velocity system, City County Building, Detroit.

Unique construction—vinyl coated fiber-  
glass fabric mechanically locked into the  
steel spiral—gives Wiremold Air Duct  
extraordinary longevity and strength.  
No glue or other adhesive to dry out and  
crack.

Saves time, effort, and money in in-  
stallation—easily bends 90 deg to 180  
deg. Can be easily run around structural  
members. Solves misalignment problems.



Finished modular ceiling installation—Wiremold Air  
Duct permits relocating of diffusers.

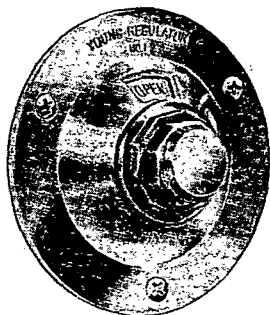
There are WIREMOLD AIR DUCT  
SALES ENGINEERS to give you on-  
the-job service throughout the United  
States and Canada.



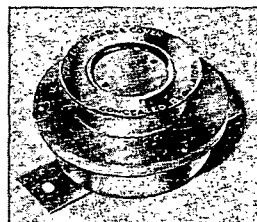
## Young Regulator Company

5209 Euclid Avenue, Cleveland 3, Ohio

### YOUNG SURFACE - CONCEALED - SPLITTER - SQUEEZE - REMOTE CONTROL DAMPER REGULATORS



No. 1



No. 315



No. 700-CP

A complete line of manually controlled damper regulators for every type of heating, ventilating and air conditioning installation in office buildings, factories, hospitals, ships, schools, churches and residences. Young Regulators are used by many leading companies in nearly every industry and are specified by leading architects and engineers.

**Model No. 1, FOR SURFACE MOUNTING.** The original Young Damper Regulator, of which thousands have given satisfactory service for years, has been modernized and streamlined. It is used to regulate a damper, controlling the air flow through a duct. It is readily set and locked into position by a key.

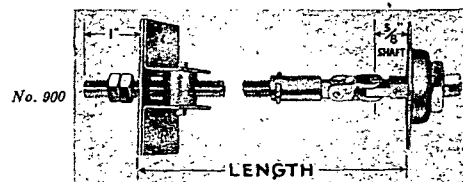
**Model No. 315, ADJUSTABLE COVER CONCEALED REGULATOR.** For use in acoustical ceilings. Similar to No. 301 Concealed Type, except the cover plate is adjustable for height to meet the various thicknesses of acoustical or plastered ceilings by screwing down the cover plate. The adjustment or locking the regulator is by a socket wrench.

**Model No. 700, CP REMOTE CONTROL.** For manual operation of dampers and registers to give individual room temperature by remote control. With No. 704 Corner Pulleys, Remote Control operates Young Dampers at a distance of 250 ft or more. Two registers or dampers can be operated by a single unit.

**Model No. 900, AIR-SPLIT REGULATORS.** For operating a splitter or squeeze damper. Operating head may be placed in any accessible location. Operation is by a crank.

**Model No. 914, CONCEALED AIR-SPLIT REGULATOR,** with beveled gears. It is used when regulator is operating a vertical damper from suspended ceiling. No. 301 Operator is used.

**Model No. 912, CONCEALED AIR-SPLIT REGULATOR.** It is used when regulator is operating a horizontal damper from suspended ceiling. No. 301 Operator is used.



No. 900

1470

### OPPOSED BLADE DAMPERS— REGISTERS—GRILLES—CEILING DIFFUSERS

**Model No. 830, OPPOSED BLADE DAMPER** distributes the air evenly over the entire face of the grille. It is easy to install in the duct behind the grille. It is operated by a Young Remote Control placed in any convenient location. Tubing to Remote Control is attached to duct by Young Compression Fitting. Furnished as part of No. 840 Series Air Conditioning Register, No. 855 Ceiling Diffuser, or separately.

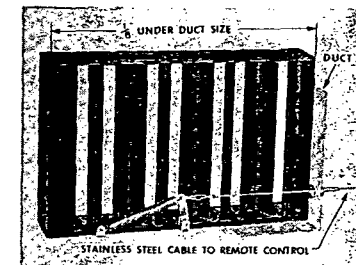
**Model No. 831.** Same as No. 830, but without the Remote Control attachment. It can be locked in any position. A Phillips head screw driver is the tool required to operate it.

**No. 840 SERIES REGISTERS** is a combination of the various No. 800 Grilles and a vertically Opposed Blade Damper. All specifications as to register construction are identical to the No. 800 Series details. These registers give individual room control when operated by Model No. 700 Remote Control.

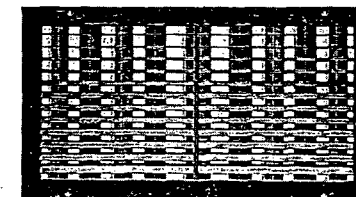
**No. 800 SERIES AIR CONDITIONING GRILLES.** Grille bars are made of extruded aluminum secured in a frame and dividing mullions. They must be adjusted with a hand tool, lessening the possibility of tampering. Gasket is furnished with all supply grilles. No. 800-VH has double banks of blades, one vertical, the other horizontal, both banks adjustable.

**SERIES No. 845 RETURN AIR GRILLES** for intake has been designed to match the No. 800 Series for supply.

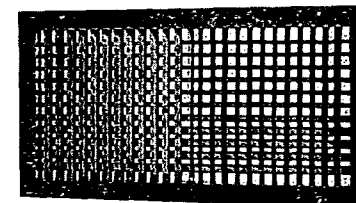
**No. 855, CEILING DIFFUSER** is designed to distribute the air without drafts. The unit has two banks of bars; each bank is 4-way adjustable to 45 deg angle to direct the air flow. The Opposed Blade Damper that is attached to the Diffuser is controlled by Young No. 700 Remote Control.



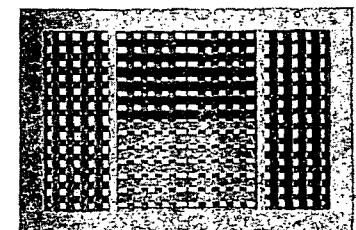
No. 830



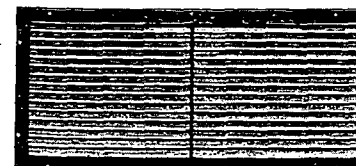
No. 840-H



No. 800-VH



No. 855



No. 845-D

FOR COMPLETE DETAILS SEE OUR CATALOG IN SWEET'S FILE ARCHITECTURAL 29F YQ

1471

## Alco Valve Company

ENGINEERED REFRIGERANT CONTROLS

851 Kingsland Avenue, St. Louis 5, Mo.

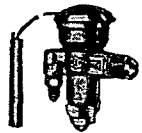
New York Office: 55 West 42nd Street

Chicago Office: 4554 North Broadway

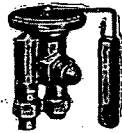
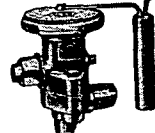
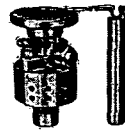


### THE COMPLETE LINE OF REFRIGERANT CONTROLS

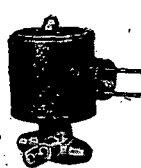
**ALCO THERMO EXPANSION VALVES:** for automatic control of liquid refrigerant on all types of refrigeration and air conditioning systems. Capacities—from fractional tonnage to 220 tons "Freon-12," 350 tons "Freon-22," selective charges. Low temperature valves for  $-40^{\circ}\text{F}$  to  $-100^{\circ}\text{F}$ .



Type 40S with pressure limiting feature

Type TK  
"3 valves in 1"Type TCL  
Angle type or straight-through connectionsType TR—  
Multi-Outlet

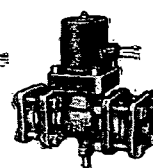
**ALCO SOLENOID VALVES:** for all types of service. For Liquid: "Freon-12" up to 75 tons; 110 tons "Freon-22." For Suction: "Freon-12" up to 10 tons; 15 tons "Freon-22." For brine, water, steam, hot gas discharge, air and oil.



Type S1



Type M3

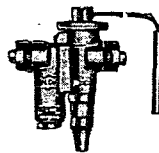


Type R2

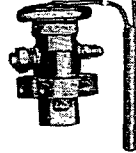
**ALCO AMMONIA CONTROLS:** Solenoid Liquid Valves—up to 172 tons. Solenoid Suction Valves—up to 28 tons. Thermo Expansion Valves—from fractional tonnage to 125 tons. Automatic Expansion Valves—from fractional tonnage to 60 tons.



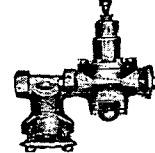
Type M91P



Type UG

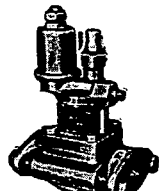


Type TX

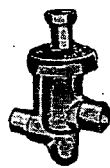


Type E with Strainer

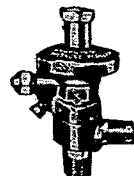
### ALCO SUCTION LINE CONTROLS:



Type EPR EVAPORATOR PRESSURE REGULATORS—for all refrigerants, with connection sizes up to 6 in.



Types 771-772 SUCTION PRESSURE REGULATORS—HOLD-BACK VALVES—prevent motor overload. Freon-12, Freon-22.

Type 760 "EVAPOTROL"—Pressure Regulator— $\frac{1}{2}$  ton, "Freon-12"— $\frac{3}{4}$  ton, Methyl Chloride.

**ALCO ALSO MAKES:** Constant Pressure (Automatic) Expansion Valves—Liquid and Suction Line Strainers—High Pressure Float Valves—Electric Float Switches—Reversing Valves.

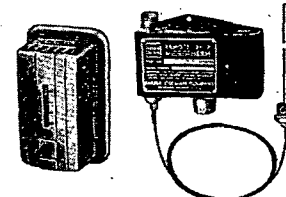
## Barber-Colman Company

Automatic Temperature Controls

Rockford, Illinois

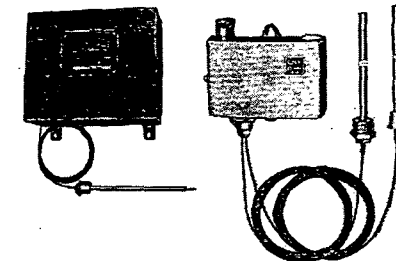


### THERMOSTATS



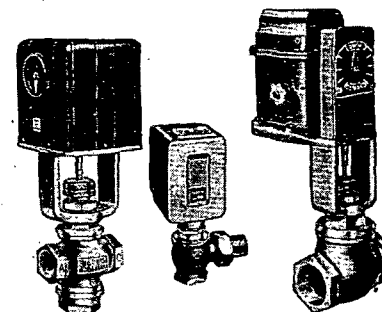
Single and two-stage room and remote bulb thermostats for on-off control; room and remote bulb thermostats for proportioning control.

### OUTDOOR RESET CONTROLS



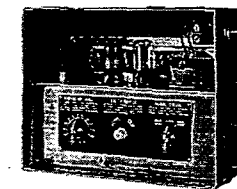
Both fixed and adjustable ratio outdoor reset hot water controls applicable to any size building.

### MOTOR-OPERATED VALVES



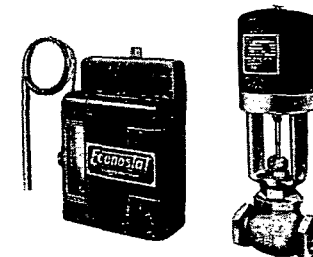
A complete line of factory-assembled motor-operated valves for two-position and proportioning control.

### ELECTRONIC CONTROLS



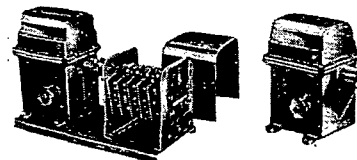
On-off or fully proportioning. Extremely sensitive and flexible control of air or liquid temperature. Large, legible, easily understood dials. Mounted in metal "Control Center."

### ECONOSTAT ZONE CONTROL



Outdoor-indoor zone control for multi-occupancy buildings. Night depression with automatic morning warm-up. Optional week end cutout.

### CONTROL MOTORS—PROGRAM SWITCHES



Spring return, unidirectional, reversible, multi-position, and proportioning types. Adjustable speed optional. Program switches for multiple step control of compressors, pumps, etc.

## Cam-Stat, Incorporated

Division of The Paul Henry Company

11831 W. Olympic Blvd.

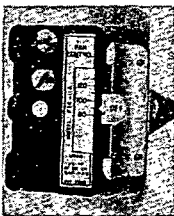
Los Angeles 64, California

District Offices in All Principal Cities

### AUTOMATIC TEMPERATURE CONTROLS

These compact warm air furnace controls are available, as shown below, for integral mounting on the furnace, and also in conduit housings to meet U.L. requirements for plenum or duct mounting. Any one of the controls below is available in combination with any one of the other controls, complete in a conduit housing. Extreme sensitivity is obtained through the use of a low mass bimetal actuator. This insures uniformly accurate control results even with high rates of temperature change.

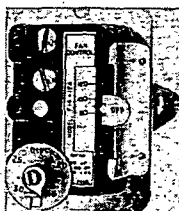
#### FAN CONTROL



Model No. F14-11A

Specification: Range—80 to 120 F. Differential—25 F. (Fixed). Rating— $\frac{1}{2}$  hp at 120 or 240 volts A.C. Other differentials available on request.

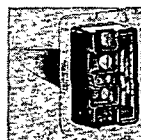
#### FAN CONTROL



Model No. F14-12A

Specification: Range—80 to 120 F. Differential—20 to 35 F. (Adjustable). Rating— $\frac{1}{2}$  hp at 120 or 240 volts A.C.

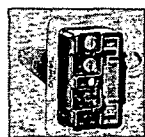
#### FIXED LIMIT CONTROL



Model L22-7A

Specifications: Fixed cut-out and differential to manufacturer's requirements. Rating—90 volt-amperes at 30 volts A.C.

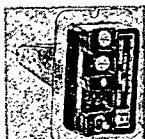
#### ADJUSTABLE LIMIT CONTROL



Model L22-8A

Specifications: Range—170 to 200 F. or to manufacturer's requirements. Differential—Fixed anywhere between 15 and 50 F. Rating—90 volt-amperes at 30 volts A.C.

#### RESET LIMIT CONTROL



Model No. L22-9A

Specifications: Fixed cut-out to manufacturer's requirements. Equipped with push button to reset after cut-out. Rating—90 volt-amperes at 30 volts A.C.



## COMBUSTION CONTROL DIVISION ELECTRONICS CORPORATION OF AMERICA

718 Beacon Street, Boston 15, Mass.

### FIREYE PANEL CONTROL SYSTEMS FOR AUTOMATIC OIL, GAS BURNERS.

Fireye flame failure protection plus complete automatic programming in a single integrated unit, assembled and tested by factory experts. Includes System FP-2 primary controls, short circuit protection, motor starters, fuel selector switches, signal lights, any needed optional equipment such as sequence draft controls, draft and temperature indicators.

### FIREYE SAFETY INTERLOCK SYSTEMS FOR SEMIAUTOMATICALLY AND MANUALLY-LIGHTED BURNERS.

Complete safeguard systems for up to four burners per boiler—oil, gas, or combination oil-gas. Assures safe light-off and firing. Includes System FP-4 primary control in pre-wired cabinet assembly, plus all external valves, switches, and alarms.

### FIREYE ELECTRONIC SAFEGUARDS AND PRIMARY CONTROLS.

System FP-2. Flame failure protection and programming for automatic industrial oil, gas, and combination oil-gas burners.

System FJ-2. Flame failure protection and programming for automatic commercial light oil, gas, and combination light oil-gas burners.

System FP-4. Flame failure protection for semiautomatically and manually-lighted oil, gas, and combination oil-gas burners.

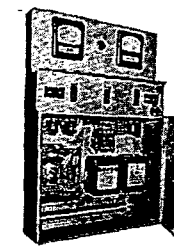
### FIREYE FLAME FAILURE INDICATION AND ALARM SYSTEMS.

System FP-3. Electronically senses presence or absence of oil, gas or pulverized coal flames, and actuates a visible or audible signal.

Type F18T-3. A sensitive photoelectric switch in a rugged industrial housing. Used with industrial oil burners to shut off fuel on loss of flame.

### FIREYE PHOTOELECTRIC SMOKE DENSITY INDICATOR.

System FE-3. Provides low cost, easy-to-install smoke density indication with assured accurate readings. Helps keep smoke within legal limits. Saves fuel dollars. Chart recorders also available.



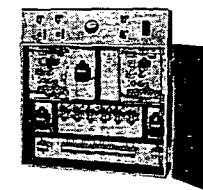
Panel Control System for Automatic Burners



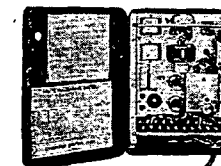
Solenoid Fuel Valve



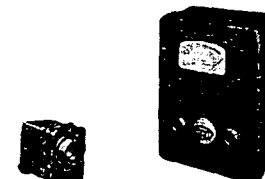
Manual Reset Valve



Safety Interlock for Semi-Automatically and Manually-Lighted Burners



System FP-2



Scanner

System FE-3

Light Source

# The Electric Auto-Lite Company

INSTRUMENT AND GAUGE DIVISION

Department HV

TOLEDO 1, OHIO

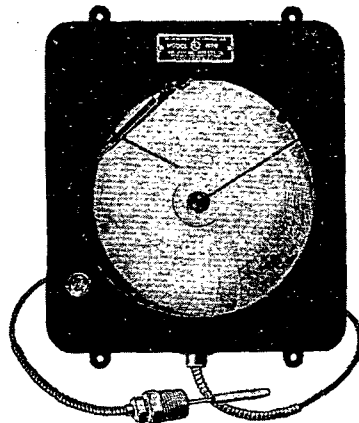
NEW YORK • CHICAGO • SARNIA, ONTARIO



## TEMPERATURE INDICATING AND RECORDING THERMOMETERS

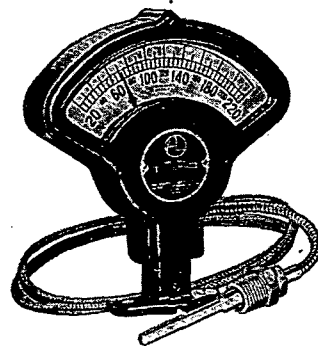
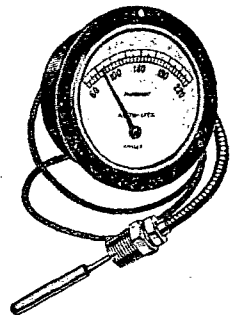
### MODEL 1000 RECORDING ← THERMOMETER

Temperature cycles are permanently charted by this latest addition to the Auto-Lite line of temperature recorders. Has evenly calibrated, 6-in. chart; attractive die-cast case. Various standard chart ranges from minus 40°F to plus 550°F. The style shown is wall mounting type, with capillary tubing for remote, eye-level reading. Also available with portable case with capillary and portable self-contained. Obtainable with cycle indicator for refrigeration. Choice of 24-hour or 7-day mechanical chart rotation.



### MODEL F-1 INDICATING THERMOMETER →

Designed to facilitate systematic temperature observation for air conditioning, refrigeration or heating applications. Large, easily read dial, evenly calibrated and fully compensated for temperature changes at the indicating head. Adjustable to 3 positions. Choice of temperature ranges from minus 40°F to plus 750°F. Available with electric alarm contact at small added cost.



### MODEL "G" INDICATING ← THERMOMETER

These thermometers have the same efficient one-to-one ratio, solid liquid-filled movement as Model "F" with evenly calibrated scales. Capillary tubing for remote reading or rigid stem.

Send for Catalog describing styles and types of Auto-Lite Thermometers.

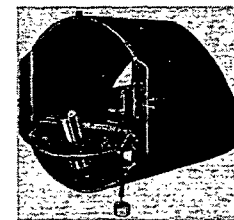
# Field Control Division

of H. D. Conkey & Company, Mendota, Ill.

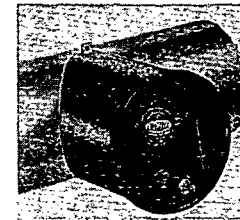
Manufacturers of FIELD DRAFT CONTROLS



## FIELD BAROMETRIC DRAFT CONTROLS



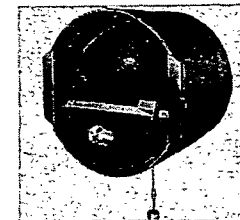
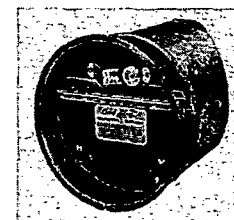
**FIELD "MG" DOUBLE ACTING:** For commercial gas fired heating plants. Double acting gate opens inward to regulate up-drafts, and outward to relieve down drafts. Highly sensitive. Optional safety switch closes main gas valve in case of prolonged down draft, thus providing full protection. Available in 10 in., 12 in., 16 in., 20 in., 24 in., 28 in. and 32 in. sizes. Illustration shows up-draft view.



**FIELD TYPE M:** For automatic heating equipment, designed to assure finer performance, greater fuel economy, through highly accurate control of drafts. Available in sizes from 6 in. through 24 in. for pipe diameters of 6 in. through 25 in. Features "Rocking Chair" gate action, off-center gate mounting, sidewings, extended housing. Widely used in the heating industry.

**FIELD TYPE RC:** Calibrated draft control in sizes 7 in. and 9 in. for 6 in. through 10 in. flues. Features extreme capacity, and reversible wing flap on gate for more precise adaption to either vertical, horizontal or sloping flues. Friction-free gate mounting, single strap attaching, easily leveled on a sloping flue.

**FIELD TYPE M Heavy duty commercial** model for oil and coal fired equipment, in sizes 28 in. and 32 in. Features stainless steel knife edge bearing, and very heavy construction to eliminate vibration (14 gauge steel throughout, weights up to 140 lbs net). Includes all the outstanding patented type "M" features for accuracy and dependability.



## Fulton Syphon Division

ROBERTSHAW-FULTON  
CONTROLS CO.

Knoxville 1, Tenn.

Sales Representatives  
in  
Principal Cities

Manufacturers of

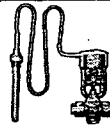
Sylphon Automatic Temperature  
Controlling Instruments and  
Packless Expansion JointsSeries 800  
ROOM  
THERMOSTATS

Heavy duty, super sensitive wall thermostats for accurate, direct control of electric heating units, air conditioning units, etc. Sensitive thermostat responds to both radiant heat and air temperature changes to  $\pm 1/2^\circ$  differential under actual load conditions. Other features include: positive snap-action switch; mounts on standard outlet box with only two screws and without removing cover; electrically rated for both non-inductive load ratings and motor ratings; instrument type construction; accurately calibrated dial; calibrated thermometer eliminates guesswork as to room temperatures; shock-proof plastic cover; compact, attractive design; UL approved, and guaranteed for 18 months against defective workmanship or materials.

801 Series: Temperature Range: 64°-80°F. Operating Differential:  $\pm 1/2^\circ$  20 amps (non-inductive load) at 125-250 volts ac, 3/4 hp at 115 volts ac, 1 1/2 hp at 230 volts ac.

802 Series: Temperature Range: 55°-85°F. Operating Differential:  $\pm 1^\circ$  20 amps (non-inductive load) at 125-250 volts ac, 3/4 hp at 115 volts ac, 1 1/2 hp at 230 volts ac.

Type 801-A3: Combination thermostat for heating-cooling use. Temperature Range: 64°-80°F. Operating Differential:  $\pm 1/2^\circ$ . Requires only a simple connection with a manually operated summer-winter switch to provide change from heating to cooling.

HOT WATER SUPPLY  
No. 999

Temperature Regulator controls temperature of liquids. Particularly suited for storage water heaters and for all industrial processes requiring accurate temperature control. Stainless steel frame for minimum heat conduction. Large size Sylphon Bellows provides added power. Self-operating. Valve sizes from 1/2 in. to 4 in. Temperature ranges start at 40° F, up to 420°F. *Bulletin HVG-E.*

## SPACE HEATING CONTROL

No. 885

## Automatic Radiator Valve—

For exposed radiation. Small, neat, attractively finished, adjustable to room temperature desired. Simply replace ordinary radiator valves with these Sylphon Automatic Valves—no wiring, piping or auxiliary equipment is required. These valves answer the demand for an inexpensive means of providing accurate, dependable space temperature control in rooms, sections or throughout large buildings, new or old. Similar type valves for concealed radiation—get *Bulletin HVG-E.*

Sylphon No. 890  
Radiator Control Valve

For either exposed or concealed radiation. Similar in appearance and action to other Sylphon Automatic Valves, but operated by an electric wall thermostat. The closing of the thermostat circuit energizes a low voltage electric heater coil surrounding a bulb containing a volatile liquid. This liquid expansion causes pressure on a bellows in the valve head operating the valve. This provides radiator valve control from a remote location, permits regulation of several radiators from a single thermostat, enables a time switch to be installed, if desired, offers effective zone control of large areas at a fraction of the cost of conventional motor-operated valve systems. *Bulletin HVG-E.*

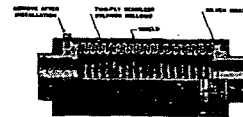
REFRIGERATION  
CONTROLS  
No. 945-Z Regulator

Adaptable wherever brine is used as the refrigerant. Latest development is a "freeze-proof" valve (illustrated) on the popular Sylphon No. 945-Z Regulator. *Bulletin HVG-D.*

PACKLESS  
EXPANSION JOINTS

## No. 110-M Sylphon Expansion Joint

The Sylphon Packless Expansion Joint eliminates expensive construction, non-revenue producing space. No leaks or repairs, no repacking. Use No. 110-M for steam lines; No. 111-M for water lines. Sizes 3/4 in. to 3 in., inclusive. *Bulletin HVG-65.*

NO. 96066 SYLPHON EXPANSION  
JOINT

Used on hot water lines, a simple, compact means for absorbing expansion of "baseboard" radiation, finned convectors, horizontal supply lines, etc. A two-ply Sylphon bellows absorbs expansion, prevents noise, pipe strains, leakage. Complete factory assembled unit. Easily installed or removed. Sizes 3/4 in. to 2 in., inclusive. *Bulletin HVG-E.*

HEATING AND AIR  
CONDITIONING CONTROL

Almost any type of heating, ventilating or air conditioning system can be advantageously controlled wholly or in part by Sylphon Regulators. Basic advantages of Sylphon Controls are:

**Modulating**—Maintain ideal conditions—not continually correcting too hot, too cold, too humid or too dry conditions.

**Compensating**—Many Sylphon Regulators offer compensating control, automatically raising their low limit setting at a predetermined rate as outside temperatures fall.

**Sensitive**—Close operating temperature differentials. Quick response.

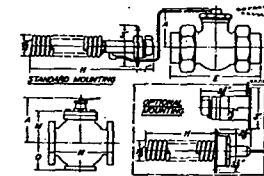
**Simple**—in design.

**Rugged Construction**—Give years of satisfactory service.

**Adaptable**—Any one of many combinations of Sylphon Instruments can be ar-

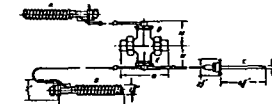
anged to control any air conditioning system and to provide exactly the conditions desired. Write for *Bulletin SAC-850.*

## The No. 928-H Regulator



Simple, compact yet highly sensitive. Suitable for modulating control of air temperatures in ducts. Bulb is constructed of numerous coils of copper tubing giving sensitivity to the slightest temperature variation. Packless valve eliminates service problem and makes this regulator ideal for installation in inaccessible locations. Suitable for steam pressures up to 15 lbs; other types available for pressures up to 75 lbs.

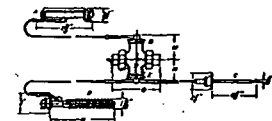
## The Sylphon No. 889-C Regulator



A modulating, dual-function regulator for control of duct heating and ventilating systems—two independent valves in a single body.

Adjustable Thermostat "A" governing Valve "D" functions to maintain room temperature from temperature of recirculated air. Adjustable Thermostat "B" acts as a low-limit ductstat controlling Valve "E" to maintain minimum discharge air temperature. Bulb "C" compensates Bulb "B" to maintain even discharge air temperature irrespective of demand. Compensated Thermostat "B" can also be furnished to raise its setting at a predetermined rate with falling fresh air temperatures if desired. Suitable for steam pressures up to 15 lbs.

## The Sylphon No. 889-C7 Regulator



The No. 889-C7 regulator has a wall type adjustable thermostat that is placed in the room or space to be controlled. This thermostat "A" operates upper half of the regulating valve. Otherwise, same as No. 889-C regulator described above.



## GENERAL CONTROLS

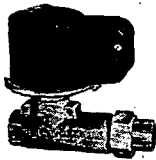
MANUFACTURERS OF AUTOMATIC CONTROLS FOR HOME, INDUSTRY AND THE MILITARY

**GENERAL CONTROLS • PERFEX CONTROLS**  
40 FACTORY BRANCH OFFICES SERVING THE UNITED STATES AND CANADA

FIVE PLANTS: IRON MOUNTAIN, MICHIGAN •  
GLENDALE, CALIFORNIA • BURBANK, CALIFORNIA •  
SKOKIE, ILLINOIS • GUELPH, CANADA



(A) Type T-70



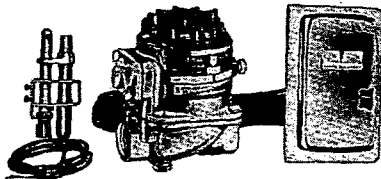
(B) Type K-10

### (A) THERMOSTATS

Compact, snap action, Line or Voltage Thermostats. Functional beauty for accurate, remote control of desired temperature. Extends only  $\frac{3}{8}$  in. from wall. Streamlined stainless cover, sensitive to slightest temperature change, ivory plastic base.

### (B) K-10 MAGNETIC LEVER VALVES

Provides six times more power than ordinary solenoid valves. Controls air, gas, water, light, heavy oils, steam. Positive opening, complete shutoff, packless, hum-free. Available for any voltage, a.c. or d.c., in sizes up to  $1\frac{1}{4}$  in. I.P.S., port sizes up to  $\frac{3}{8}$  in.



### (C) BX-69 GAS ACTUATED PACKAGE SETS

No outside current required. Operates on all types of gases. Safe, quiet, dependable. For all gas-heating appliances. Set consists of a PG-9 700 millivolt pilot generator, a B-60 gas control valve, a T-70 snap action thermostat, thermostatic cable and vent tubing. Everything needed in convenient package for remote gas control.



(D) Type B-55G

### (D) SLOW OPENING GAS VALVES

New combustion control afforded by these diaphragm-controlled gas valves. Governor model regulates fuel supply to burner in direct ratio to steam pressure, eliminating hunting aspect. Available 1 in. to 6 in. I.P.S.

### (E) MAGNETIC GAS VALVES

Versatile, two-wire, straight magnetic current-failure valve. Packless. Insures tight shutoff indefinitely. Humless. Size range  $\frac{3}{8}$  in. to 6 in. I.P.S. Operating pressures up to 10 lb. Voltages and frequencies a.c. or d.c. Quiet, positive, trouble-free. Available in explosion-proof housing.



(F) Type V-110

### (F) MANUAL RESET VALVES

Equipped with manually-reset electromagnetically-held valve operator. Current flowing to operator permits manual opening by turning valve wheel at side. Current failure releases operator allowing valve to close. Trip-free mechanism won't open under unsafe conditions. Closed, valve must be reopened manually.

(E) Type K-3A



(G) Type G-2-1



(H) Type K-16



(I) Type PV



(L) Type V-200



(M) Type MR-5 PG/SC

### (G) HYDROMOTOR VALVES

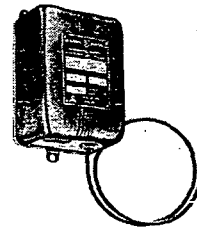
Simplify valve control installations. Two-wire, current failure, electric-hydraulic operation. Ample motor-driven power, slow opening and closing movement. G-1 Series, designed for low pressure steam, hot and chilled water circulating systems. G-2 and G-3 Series for high pressure applications.

### (H) REFRIGERANT CONTROLS

Magnetic Stop Valves. Piloted, two-wire current failure, high pressure, packless. Handle large capacities with minimum pressure drop and loss. Tight shutoff. Operates on air, steam, water, and refrigerants.

### (I) "hi-g" MAGNETIC VALVES

Designed for positive operation on aircraft, trucks, tractors, tanks, graders, ships, and other moving equipment. Handle all fluids, vapors and gases on anything that rolls, floats or flies at pressures up to 3000 lbs or more. Packless, two-wire, current-failure type, available normally open, normally closed for intermittent or continuous duty.



(K) Type A-100



(J) Type RS-100 Relay

### (J) RELAYS AND TRANSFORMERS

Type RS-100 handles single phase motor loads up to 1 hp or heating loads up to 1.1 kw. Combines double break relay and integral transformer. Normally open; large double-break contacts. Two-wire control circuit; maximum holding current 0.4 amps. Furnished with  $\frac{1}{2}$  in. conduit connections and low voltage outlet. a.c. only.

\* Trade mark—"hi-g" indicates positive ability to function in any position, regardless of vibration, change of motion or acceleration.

### (K) A-100 THERMOPILLOT RELAY

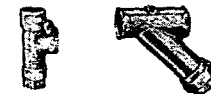
Gas safety control—thermocouple in pilot flame closes control circuit automatically through relay to hold gas valve open. Gas valve shuts off when pilot is extinguished, prevents gas escape. Thermocouple adapts to pilot burners. Pilot generator models for long couple lengths or operating multiple controls.

### (L) THERMAL EXPANSION VALVES

Type V-200 with new selective capacity cartridge provides instant sizing adjustment. Only one valve required for full capacity range in each body size at all back pressure or suction temperature ranges. For Freon, Methyl Chloride or Sulphur Dioxide.

### (M) THERMOPILLOT VALVE AND GAS COCK SAFETY VALVE

Manually reset, electromagnetically holds valve open with current generated by thermocouple, subject to heat of pilot flame. Automatically shuts off gas if pilot goes out. Type MR-5 combines manual gas cock with thermopilot safety valve. Available in  $\frac{3}{8}$  in. to  $1\frac{1}{2}$  in. I.P.S.



(N) SA & SY Strainers

### (N) STRAINERS

Protects automatic regulators or valves from pipe scale, other foreign matter. Assures proper seating, closing of valve. Prevents leakage. Convenient cleaning or blowoff without breaking line. Monel screen.

### OTHER GENERAL CONTROLS ITEMS

- IMMERSION THERMOSTATS
- COMBINATION FAN AND LIMIT CONTROLS
- STEAM PRESSURE, VAPOR AND VACUUM CONTROLS
- TEMPERATURE CONTROLS
- LOW WATER CUTOFFS

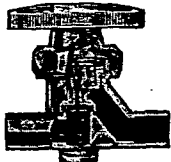




## Henry Valve Company

MELROSE PARK, ILLINOIS  
(A Chicago Suburb)

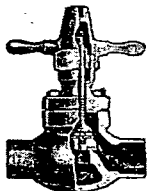
HENRY PRODUCTS FOR REFRIGERATION, AIR CONDITIONING, AND INDUSTRIAL APPLICATIONS: CONTROL DEVICES, VALVES, STRAINERS DRIERS, FITTINGS, AND ACCESSORIES.



Balanced-Action Diaphragm Packless Valves

**STANDARD TYPE**—Valves cannot stick shut regardless of pressure above or below Valve seat. Forged brass body and bonnet, ports-in-line and non-directional. Back seat and ball check permit diaphragm inspection and replacement under pressure. Sizes:  $\frac{1}{4}$ " thru  $\frac{3}{8}$ " Flare;  $\frac{1}{4}$ " thru  $1\frac{1}{2}$ " O.D.S.;  $\frac{1}{4}$ " thru  $\frac{1}{2}$ " F.P.T. Line, angle and branch types.

**BLUE BANTAM TYPE**—Two-way line shut off valves, flare or solder connections. Contain same field proven features as STANDARD line except that diaphragms cannot be inspected or replaced while valves are under pressure. Stock sizes  $\frac{1}{4}$ " thru  $\frac{3}{8}$ " flare and solder.



**WING CAP PACKED VALVES**—Bronze with solder connections, sizes  $\frac{1}{8}$ " thru  $4\frac{1}{2}$ " O.D. Semi-steel with F.P.T. connections in valve body, sizes  $\frac{1}{2}$ " thru  $2\frac{1}{2}$ ". Semi-steel flanged type, with separate brass O.D.S. adapters, sizes  $1\frac{3}{8}$ " thru  $5\frac{1}{8}$ "; with separate steel butt weld adapters, sizes  $1\frac{1}{4}$ " thru  $5$ "; with one piece F.P.T. flanges, or with one piece slip-on weld flanges, sizes  $1\frac{1}{4}$ " thru  $6$ ".

### RELIEF VALVES

Straight-Through Type and Ferrous Type

Most sizes meet ASME Standards—National Board Certification.



**STRAIGHT-THRU TYPE**—Large capacity—Brass Construction.  $\frac{1}{4}$ " thru  $1$ ".

**ANGLE TYPE**—for ammonia,  $\frac{3}{8}$ " thru  $2$ ".

### DRIERS

Filled with PA400 silica gel.



**TYPE 705**—Brass shell, forged brass end caps with integral fittings—silver brazed joints. Dehydrant capacity 10 to 32 cu in. Sizes,  $\frac{1}{4}$ " thru  $\frac{1}{2}$ " flare.

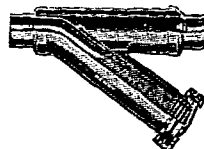


**TYPES 77, 78 and 79** cartridge driers with side outlet, safety disc, cartridge retaining spring and distortion-proof access flange. Dehydrant capacity 12 to 500 cu in. Sizes  $\frac{3}{8}$ " thru  $2\frac{3}{8}$ " O.D. solder. Can be converted to strainer by use of strainer screen cartridges.

### STRAINERS



**TYPES 891 and 892**. Brass shell, forged brass end caps. Screen area 11 and 25.5 sq in. respectively. Sizes  $\frac{1}{4}$ " thru  $\frac{3}{8}$ " flare and  $\frac{3}{8}$ " and  $\frac{1}{2}$ " O.D. solder.



**TYPE 895**—Brass plated steel "Y" strainer, welded construction, forged brass end caps. Distortion-proof access flange. Screen area 12 to 150 sq in. Sizes  $\frac{3}{8}$ " thru  $4\frac{1}{8}$ " O.D.S.; and  $2\frac{1}{2}$ " thru  $4$ " butt weld.

Stocked by Wholesalers. Ask for Catalogs

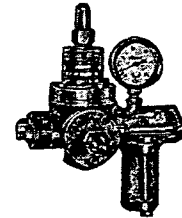
## Hubbell Corporation

Mundelein, Illinois

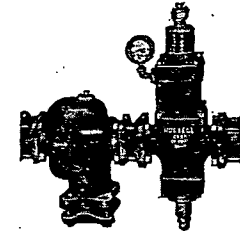
C. & S. EQUIPMENT CO., INC.  
2103 San Pedro St., Los Angeles 11, Calif.

MASON EMMANUELS CO.  
91 Dearborn St., Seattle 4, Wash.

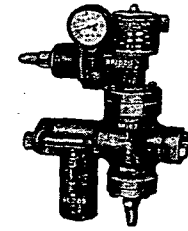
Designers and Manufacturers of Automatic Control Valves for All Refrigerants



Type SA-5, SF-5



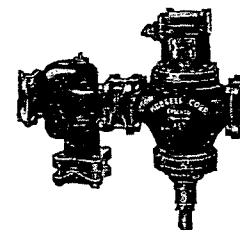
Type SA-6, SF-6



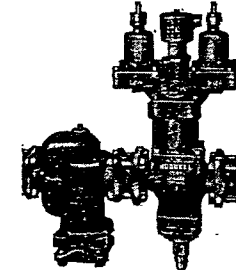
Type SA-7, SF-7

Back Pressure Regulating Valves are of the conventional type used to maintain a constant evaporator pressure.

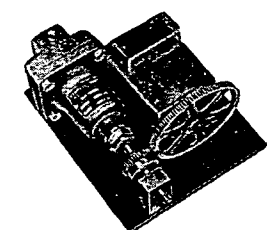
Combination Back Pressure Regulator and Stop Valves. This regulator is of the conventional type used to maintain a constant evaporator pressure and the addition of a small solenoid pilot valve built into the head, makes it a suction stop valve.



Type "T"



Type DSA-9, DSF-9



Type SAC-6, SFC-6

1. The Type "T" suction stop valve is used where automatic suction line control is required. It is operated by high pressure gas and its construction makes a tight closing valve and its dependability surpasses the conventional magnetic stop valve.

2. The DSA-9-DSF-9 is a dual regulator which will control evaporators with two load conditions requiring different refrigerant temperatures. The diaphragms in the dual head may be set for

any two evaporator pressures and will automatically change from one to the other by the opening or closing of the solenoid pilot valve.

3. The SAC-6 and SFC-6 valves are of the compensating type and are used where a constant temperature is desired in the medium being cooled. These valves will increase or decrease the evaporator pressure to compensate for the increase or decrease of the cooling load. Operated with air, electricity, or thermal type.

Solenoid Valves from  $\frac{3}{8}$  in. to 2 in. inclusive for liquids and gases with composition seat discs readily renewable, coils for any electrical characteristics, built-in lifting stem standard, with either screwed, welding flanges or copper tube connections.

Strainers in all sizes for liquids and gas with very large screen areas and arranged to bolt directly to valve or with screwed, welding flange or copper tube connections for installation wherever strainer is necessary.

HUBBELL-ize your plant with "Service Free" controls.



## Johnson Service Company

**AUTOMATIC TEMPERATURE AND AIR CONDITIONING CONTROL**  
General Office and Factory 507 E. Michigan St. Milwaukee 1, Wis.

Direct Branch Offices in Principal Cities

JOHNSON TEMPERATURE REGULATING COMPANY OF CANADA, LTD., 120 BERMONDSEY RD., TORONTO 16, ONT.

**MANUFACTURERS, ENGINEERS and CONTRACTORS.** A complete line of automatic temperature and humidity controls for heating, cooling, ventilating, air conditioning, industrial processing, military installations and special temperature and humidity control applications.

**SPACE CONTROL**—Automatic room temperature and humidity control for convectors, radiators, radiant heating, unit ventilators, unit heaters, and heating and cooling air delivery equipment.

**INDUSTRIAL PROCESSING**—Automatic temperature and humidity control for every requirement in manufacturing and industrial processing.

Thermostats, valves, dampers for tanks, dryers, vats, kettles, curing rooms, coolers, kilns, and other special equipment in textile, rubber, paper, petroleum, meat, dairy, baking, sugar, brewing, distilling, tanning, candy, foods, pharmaceutical, and other industries.

**SERVICE ORGANIZATION**—Johnson sales engineers, and trained installation experts at all branches in United States and Canada. No agents, jobbers, or part-time representative! All Johnson salaried personnel for exclusive service of Johnson Service Company customers.

**JOHNSON LITERATURE:** Available at your nearest JOHNSON branch office or write to address above.

### JOHNSON THERMOSTATS

**Room Thermostats**—single and dual temperature (Day-Night, Heating and Cooling). Proportional or two-position action. Maintain temperatures within one degree above or below setting. Wide selection of adjusting features, guards, and mounting. Furnished with or without thermometers.

**Insertion and Immersion Thermostats**—Liquid-filled temperature measuring elements. Stem type for direct measurement. Remote bulb types for applications requiring location of thermostat at a distance from the point of temperature measurement. Various bulb styles available. Standard capillary length is 8 ft. Lengths of 15, 25, 35 and 50 ft available on special order.

**Submaster Thermostats**—The set point of these Johnson controllers is changed from a remote location by the action of another (master) controller. Available with liquid-filled stem and remote bulb measuring elements.

Johnson "Duo-Stats," weather compensated primary controllers, control heating system temperatures in accordance with the outdoor temperature. Duo-Stats are available for any heating system, all types of buildings, and furnished in pneumatic, electric or electronic models.

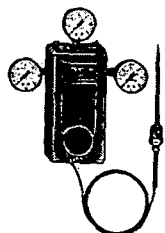
### PRESSURE CONTROLLERS

**Pressure Regulators** with ranges of 30 inches of water to 300 psi. Static pressure regulators measure variations in pressure from .009 inches to 3 inches of water. Used also as differential regulators measuring difference in pressure between two chambers. Pressure switches and governors also available.

### JOHNSON HUMIDITY CONTROL

**Humidistats**—Room and insertion types with humidity measuring elements of wood or animal membrane, the most sensitive of which controls within 1 per cent at relative humidities as high as 95 per cent, at temperatures of 200 F. Submaster models also available which are adjustable from a remote point by another controller (master) or may be manually readjusted from a remote point by means of a Johnson Gradual Switch.

**Humidifiers**—Steam grid (perforated pipe supplied with low pressure steam) or pan type with copper evaporating pan, brass or copper heating coils and float control.



T-901 Liquid-filled Remote Bulb Submaster Thermostat



Series T-400 Room Thermostat



T-804 Liquid-filled Immersion Thermostat

## Johnson Service Company

## Controls and Instruments

### SPECIAL CONTROLLERS

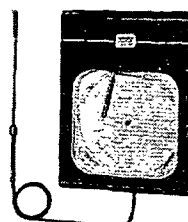
**Aspirating Cabinets**—Several models with many combinations of controlling and auxiliary devices required to provide control of temperature and humidity. Cabinets equipped with blowers for positive air circulation and air gages for checking function of controllers at all times.

**Pneumatic Step Controllers**—for capacity control of reciprocating refrigeration equipment or any application where sequence of pressure switches is used.

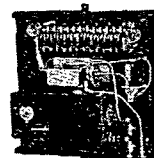
**Record-O-Stat**—Combination capillary temperature controller and recorder. Available in single pen, two-pen, and submaster models. Indicating controllers and recorder-controllers also available.

**Liquid Level Regulators**—(Float Type) control within extremely close limits. Mounted through wall of containing vessel by stem with 1 inch pipe thread. Floats of copper, stainless steel or special alloys.

**Thermometers**—Insertion and immersion types for air and liquids. Stem and remote bulb temperature measuring models with vapor tension or liquid filled elements. Variety of styles, mountings and finishes.



T-1000 Single Pen Record-O-Stat



18 Point Model Pneumatic Step Controller

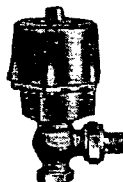
### JOHNSON VALVES

**Johnson Diaphragm Valves**—Simple, rugged. Diaphragms of special molded rubber, resistant to age and oxidation, operate valve stems against spring pressure. Available also with "Sylphon" seamless metal bellows. In standard sizes and patterns including compact valves for convectors and unit conditioners. Normally open or normally closed. Three-way mixing and bypass valves, for water, brine and other liquids.

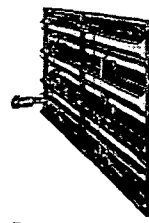
**Johnson "Streamline" Diaphragm Valves**—With modulating discs and special internal construction. Smooth proportional control. Where maximum power is required for repositioning at slightest demand of controlling instruments, the larger molded rubber diaphragm valves are fitted with pilot positioners.



V-108 3-way Mixing Valve—Rubber Diaphragm



V-165 "Sylphon" Convector Valve



D-225 Proportioning Lower Damper

### JOHNSON DAMPERS AND SWITCHES

**Standard Johnson Dampers**—Galvanized 16-gauge steel blades in flat steel frames with adequate bracing to form rigid assembly. Black lacquer or special corrosion-resisting finishes. Angle iron frames optional.

**Special Dampers**—Galvanized iron frames and monel metal, aluminum, copper or rust-resisting steel blades on special order. Frames of same material as blades, if desired. Brass pins in steel bearings or ball bearings.

**Johnson Damper Operators**—Similar in operating principle to valves. Specially molded rubber diaphragm or seamless metal bellows operates damper through suitable linkage. Johnson "piston" damper operators afford long travel at full power. With or without pilot mechanism, as described for "Valves."

**Johnson Pneumatic Switches**—For direct operation of dampers and to switch controllers in and out of service from remote locations. Standard switchboard panels are Masonite. Ebony, asbestos, steel, polished oak and genuine or imitation marble panels on special order. Special switchboards including all types of control equipment available on special order.

D-251 Piston Damper Operator

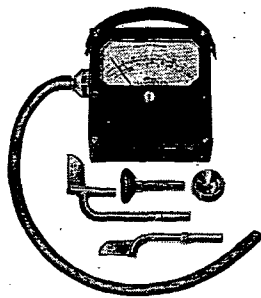


## Illinois Testing Laboratories, Inc.

Room 516, 420 N. La Salle St., Chicago 10, Ill.

*Alnor*

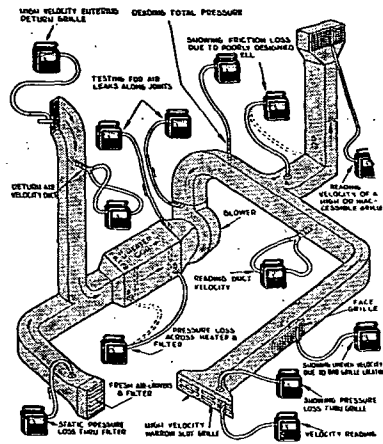
Precision Instruments for Every Industry

The direct-reading ALNOR  
VELOMETER

TYPE 4-F Standard minimum set for heating and air conditioning air velocity measurements.

The Alnor Velometer is an instantaneous, direct-reading air velocity meter designed for convenient, rapid determination of air velocities in air conditioning, heating and ventilating, and exhaust systems. It gives instantaneous direct readings in feet per minute, without timing, calculations, or reference to tables or charts. Accurate information on performance of equipment, duct systems, etc., can be obtained with a few moments inspection with the VELOMETER. It can be effectively used to locate drafts and leaks around windows and doors, or in duct systems.

The Alnor Velometer is built in several standard ranges from 20 fpm to 6000 fpm, and up to 3 in. static or total pressure. Special ranges available as low as 10 fpm and up to 25,000 fpm velocity and 20 in. pressure.



Alnor Velometer, Jr. A miniature, direct reading Velometer—4 in. high, 3 in. wide, 1-1/4 in. deep. Weight, 8 oz. Accurate, strong. Available in single and double scale ranges: 0-200 to 0-2500 fpm. Bulletin 725.



Alnor Thermo-Anemometer. For accurate measurement of low air velocity. Compact, direct-reading, battery operated, self-contained, portable. Scale 6 in. Meter ranges: 0-600 fpm and double range 0-300/100-2000 fpm. Accurate readings as low as 5 fpm. Temporary Bulletin 913-A.

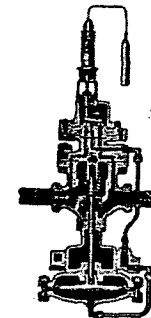
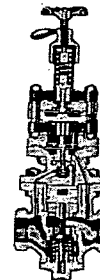
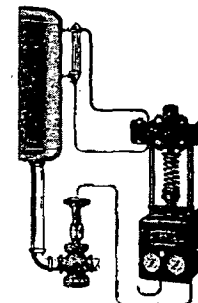
## Leslie Co.

266 Grant Avenue

Lyndhurst, New Jersey

REGULATORS and CONTROLLERS for  
the Regulation and Control of Pressure,  
Temperature, Flow and Liquid Level.

TRADE  
**LESLIE**  
MARK

Temperature Regulator  
Class TPump Pressure Regulator  
Class PRFloatless Level Control for  
Boilers, Tanks, Evaporators,  
Heaters, Standpipes, etc.

**LESLIE COAST-TO-COAST SERVICE**  
In all principal industrial centers LESLIE factory-trained engineers are available to help with any control problem involving steam, liquid, air or gas. Look for LESLIE REGULATORS under "Valves" or "Regulators" in your classified telephone directory.

**INTERCHANGEABILITY** — Internal parts of LESLIE Regulators are dimensionally interchangeable. Maximum interchangeability in all sizes and classes.

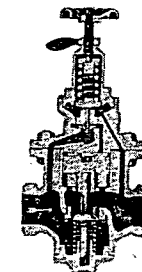
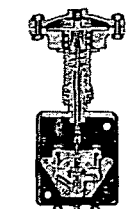
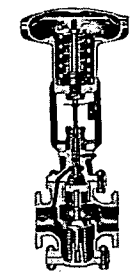
**LESLIE EXCLUSIVE FEATURES**—at no extra cost!

- Stellite Seat Rings
  - Hardened Stainless Steel Main Valves, 500 Brinell
  - Corrosion Resistant Springs
  - Hardened Stainless Steel Cylinder Liners, 500 Brinell.
- Supplied as standard equipment.

**LESLIE PRESSURE REDUCING VALVES, PUMP PRESSURE REGULATORS and TEMPERATURE REGULATORS**

Self-contained, spring loaded, internal pilot piston or diaphragm operated with stellite seat rings, hardened stainless steel trim, bronze, iron, or steel construction. All LESLIE Regulators feature:

- Accuracy of regulation comparable to instrument control
- Single-seated construction for positive dead-end shutoff
- Valve acts fast for sudden load changes
- Maximum resistance to corrosion and wear
- Maximum spring range—from minimum to maximum controlled pressure range without change of spring or diaphragm

Reducing Valve  
Class L-3Self-Cleaning  
StrainerControl Pilot  
Type PDDiaphragm Control  
Valve  
Class D-8

SEND FOR BULLETIN 552 DESCRIBING THE LINE

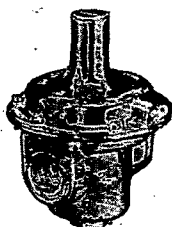
## Maxitrol Company

12200 Beech Road

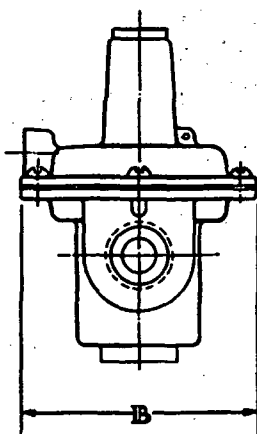
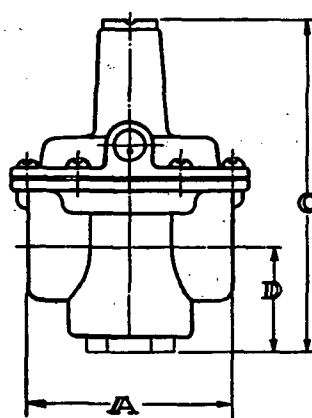
Detroit 39, Michigan

*Maxitrol*

LOW PRESSURE GAS REGULATORS

Pacific Coast Distributor; PACIFIC SCIENTIFIC CO.  
San Francisco, Los Angeles, Seattle, Portland

Maxitrol gas regulators feature the patented "Straight-Thru-Flow" design principle. This construction sharply reduces pressure loss commonly encountered in conventional type gas pressure regulators. The new feature permits greater flexibility in design of manifolds for domestic equipment, and frequently allows a reduction in pipe size of gas manifolds. Capacity charts at greater differential pressures for industrial use at inlet pressures up to 5 psi available on request.



CAPACITY RATING (A. G. A. Listed)

| Model No. | Pipe Size | Cu Ft./Hr at 0.3 Pressure Drop 0.6 Sp. Gr. Gas | Btu/Hr Gases 800 Btu/Cu Ft. or More (Natural Gas) | Btu/Hr Gases Less Than 800 Btu/Cu Ft. (Mfd. Gas) |
|-----------|-----------|------------------------------------------------|---------------------------------------------------|--------------------------------------------------|
| RV10      | 1/4       | 15                                             | 11,000                                            | 7,450                                            |
| RV40      | 1/2       | 150                                            | 111,000                                           | 75,000                                           |
| RV41      | 1/2       | 118                                            | 87,300                                            | 59,000                                           |
| RV41      | 3/4       | 130                                            | 98,000                                            | 65,000                                           |
| RV42      | 1/2       | 176                                            | 130,000                                           | 88,000                                           |
| RV50      | 1/2       | 270                                            | 200,000                                           | 135,000                                          |
| RV50      | 3/4       | 270                                            | 200,000                                           | 135,000                                          |
| RV51      | 1         | 450                                            | 333,000                                           | 228,000                                          |
| RV51      | 1         | 460                                            | 340,400                                           | 230,000                                          |
| RV60      | 1 1/4     | 676                                            | 500,200                                           | 338,000                                          |
| RV60      | 1 1/4     | 705                                            | 521,700                                           | 352,500                                          |
| RV80      | 1 1/2     | 1,250                                          | 925,000                                           | 625,000                                          |
| RV82      | 1 1/2     | 1,260                                          | 932,400                                           | 630,000                                          |
| RV90      | 2         | 2,030                                          | 1,502,000                                         | 1,015,000                                        |
| RV90      | 2 1/2     | 2,030                                          | 1,502,000                                         | 1,015,000                                        |
| RV110     | 2 1/2     | 4,200                                          | 3,108,000                                         | 2,100,000                                        |
| RV110     | 3         | 4,900                                          | 3,628,000                                         | 2,450,000                                        |

DIMENSIONS

| Model No. | A     | B      | C      | D     | Shipping Weight Each |
|-----------|-------|--------|--------|-------|----------------------|
| RV10      | 1 1/4 | 1 1/4  | 2 1/2  | 3 1/2 | 3 oz                 |
| RV40      | 2 1/2 | 2 1/2  | 4 1/4  | 1 3/4 | 9 1/2 #              |
| RV41      | 2 1/4 | 2 1/4  | 3 1/2  | 2 3/4 | 1 1/2 #              |
| RV41      | 2 1/4 | 2 1/4  | 3 1/2  | 2 3/4 | 1 1/2 #              |
| RV42      | 2 1/2 | 3 1/2  | 4 1/4  | 1 3/4 | 9 1/2 #              |
| RV50      | 3     | 3 1/4  | 5 1/4  | 1 3/4 | 1 1/2 #              |
| RV50      | 3     | 3 1/4  | 5 1/4  | 1 3/4 | 1 1/2 #              |
| RV51      | 3 3/4 | 4 1/4  | 6 1/4  | 2 1/4 | 1 3/4 #              |
| RV51      | 3 3/4 | 4 1/4  | 6 1/4  | 2 1/4 | 1 3/4 #              |
| RV60      | 4 3/4 | 5 1/4  | 7 1/4  | 2 1/4 | 2 1/4 #              |
| RV60      | 4 3/4 | 5 1/4  | 7 1/4  | 2 1/4 | 2 1/4 #              |
| RV80      | 6     | 7      | 8 1/4  | 2 1/4 | 5 #                  |
| RV80      | 6     | 7      | 8 1/4  | 2 1/4 | 5 #                  |
| RV90      | 7 1/4 | 9 1/4  | 9 1/4  | 2 1/4 | 8 3/4 #              |
| RV90      | 7 1/4 | 9 1/4  | 9 1/4  | 2 1/4 | 9 #                  |
| RV110     | 9     | 12 3/4 | 14 1/4 | 3 3/8 | 20 #                 |
| RV110     | 9     | 12 3/4 | 14 1/4 | 3 3/8 | 20 #                 |

## The Mercoid Corporation

Main Office and Factory, 4201 BELMONT AVENUE, Chicago 41, Illinois  
 New York Office, 205 EAST 42ND ST. PHILADELPHIA OFFICE, 3137 N. BROAD ST.  
 AUTOMATIC CONTROLS FOR HEATING, AIR CONDITIONING,  
 REFRIGERATION AND VARIOUS INDUSTRIAL APPLICATIONS

## 100% MERCURY SWITCH EQUIPPED CONTROLS

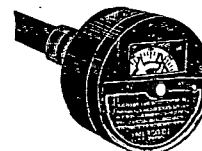
## STEAM PRESSURE CONTROLS



Type DA-31 Circuit opens on pressure rise. For application where pressures change slowly. Equipped with outside double adjustments for setting cut-in or cut-out points. Elec. Cap.—A-C or D-C 10 Amp. 115V; 5 Amp. 230V. 1/4 in. I.P.S. connection. Ranges 0-14 lbs, 0-30 in. vac., 10 in. vac.—12 lbs, 0-20 lbs, 0-35 lbs, 0-60 lbs, 0-100 lbs, higher ranges available.

Type DA-21 Circuit opens on pressure rise. For applications where pressures fluctuate rapidly. Similar to Type DA-31. Electrical Capacity same as DA-31 above. Ranges available to 2,500 lbs.

## HOT WATER TEMPERATURE CONTROLS



Type 437 Circuit opens on temperature rise. Bimetal-operated (back angle immersion well type) used as a high limit for hot water boilers. Equipped with outside double adjustment for setting cut-in or cut-out operating points. Electrical Capacity—A-C or D-C 10 Amp. 115V; 5 Amp. 230V. Connection 1/4 in. I.P.S. Ranges 80-240 F and 40-200 F.

Type DA-36 (straight stem) Circuit opens on temperature rise. For immersion applications where bulb is directly installed into boiler water. Equipped with outside double adjustments. Electrical Capacity same as 437 above. Connection 1/2 in. I.P.S. Immersion bulb 3 in. long. Ranges 100-200 F and 135-235 F.

## WARM AIR TEMPERATURE CONTROLS



Type M-41 Limit Control. Equipped with outside adjustments for setting cut-in and cut-out operating points. Range 70-310 F.

Type M-43 Fan or Blower Control has outside adjustments together with summer switch used for ventilating purposes during summer. Range 50-300 F. Electrical Capacity all types A-C or D-C 115V, 10 Amp; 230V, 5 Amp.

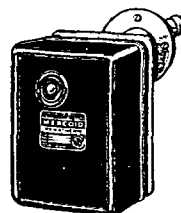
## ROOM THERMOSTATS



Type H, opens circuit on temperature rise (low voltage). Regulates heating equipment from True Room Temperature without the aid of artificial stimulation. The Mercoid switch is unaffected by dust, dirt or lint. The cover has a jewel hard alumilite finish that will last a lifetime. Electrical Capacity 3/40 Amp, at 24V, or less. Ranges 55-85 F and 65-95 F.

Type R same as above except circuit closes on temperature rise.

## OIL BURNER PRIMARY CONTROLS



Type JMI (intermittent ignition) stack mounted safety ignition control provides complete protection against flame or ignition failure—low line or power failure protection.

Type JM (constant ignition) same as above except that no ignition switch is employed. Electrical Capacity A-C 10 Amp. 115V; 5 Amp, 230V.

Write for Catalog No. 800ASHV.

## MINNEAPOLIS-HONEYWELL REGULATOR CO.

# Honeywell

2644 Fourth Ave. S. Minneapolis 8, Minn. Cable Address: Minnreg, Minneapolis

HONEYWELL CONTROLS for Heating, Ventilating, and Air Conditioning

BROWN INSTRUMENTS for Indicating, Recording, and Controlling

APPLIANCE CONTROLS for Gas, Water, and Space Heaters

MICRO SWITCHES for all applications

VALVES for Industrial applications

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## A COMPLETE LINE OF MATCHED CONTROLS

## TO FACILITATE THE EARLY DESIGN OF EVERY CONTROL SYSTEM

Minneapolis-Honeywell manufactures a complete line of automatic controls for heating, ventilating and air conditioning. They are used singly or in combination in any type of control system. Therefore, at the time the building is designed you can specify Honeywell for all controls. You can be sure all the controls you need will be available from one manufacturer.

## FOR ALL TYPES OF BUILDINGS

Honeywell control systems may be adapted to your own individual plans to give custom-tailored performance in such various structures, as apartments, hospitals, hotels, schools, motels and commercial, industrial and residential buildings. And, there are Honeywell controls for all three principal types of control systems—electric, electronic and pneumatic.

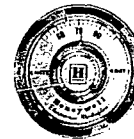
## FOR ELECTRIC CONTROL SYSTEMS

Honeywell offers a complete line of such precision-tested equipment as thermostats, humidity controls, temperature controls, pressure controls, valves, relays, motors and accessories, all of which may be interlocked and co-ordinated to obtain a high degree of operating economy and efficiency in every heating, ventilating or air conditioning system.



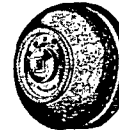
Motorized Valve Assembly

## FOR ELECTRONIC CONTROL SYSTEMS



Electronic Thermostat

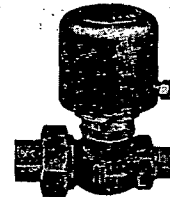
The flexibility of electronic controls makes them adaptable to control applications from the simplest to the most complex. From small buildings where completely automatic control of heating, ventilating and air conditioning requires only one thermostat, to large buildings where the entire control system can be supervised at one control-supervision center. All electronic thermostats, from the round room model to the 27 foot duct model, are co-ordinated at a convenient central panel where complex sequences can be set up; adjusted, and inspected in minimum time.



Pneumatic Round Thermostat

## FOR PNEUMATIC CONTROL SYSTEMS

Honeywell offers a complete line of pneumatic controls for applications from simple domestic temperature regulation to precision control of industrial processes. New Pneumatic Round thermostats provide faster response and more accurate control plus a "decorator" cover which can be painted to match surroundings. Honeywell pneumatic operators have a positive positioning feature which provides full power for even a relatively small adjustment.



Pneumatic Radiator Valve

## FOR COMBINATION SYSTEMS

Honeywell combination systems make it possible for you to take advantage of the most salient features of electric, electronic and pneumatic controls. These systems also allow you maximum flexibility, low-cost installation and permanent dependable control results.

## INSTRUMENTATION



Recording Thermometer

Honeywell indicating and recording instruments provide quality control of air conditioning systems. Used to measure temperature, humidity, pressure, or flow, they offer many advantages. These remote reading instruments also facilitate central panel supervision of control systems.

## AT YOUR SERVICE

There is a Honeywell sales and service office near you. This office maintains a staff of experienced control engineers who are highly qualified to give you advice on a broad range of applications and to install and service all types of control equipment. Honeywell engineers are equally well prepared to assist you in the writing of specifications and to furnish control layouts and cost estimates without charge.

## WRITE FOR FREE HONEYWELL LITERATURE

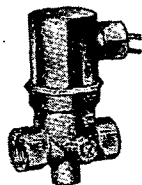
Listed below are but a few of the many pieces of literature Honeywell has prepared to help you select controls and control systems for your own specific requirements. In addition, instruction sheets on design systems and reference manuals for both electric and pneumatic controls are available to you. You may obtain literature and answers to your problems by contacting your nearest Honeywell office or writing to the Merchandising Division, Minneapolis-Honeywell Regulator Co., Minneapolis 8, Minnesota.

Handbook of Individual Apartment Temperature Control  
Heating and Air Conditioning Controls for the Modern Hospital  
Honeywell Control Systems for the Modern School  
Controlling the Thermal Environment of the Co-ordinated Classroom

Honeywell Dampers and Shutters  
Instruments Applied to Commercial Air Handling Systems  
Automatic Controls for the Marine Industry  
Electronic Control of Heating and Air Conditioning  
Honeywell Pneumatic Round

## Milwaukee Gas Specialty Company

730 North Jackson St., Milwaukee 2, Wisconsin

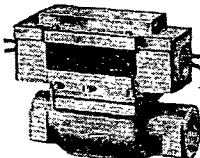


### SERIES EA SOLENOID VALVE

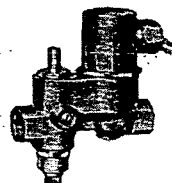
Internal parts in contact with gas are aluminum or stainless steel to prevent corrosion; aluminum bodies. Straight through models in  $\frac{1}{2}$  in. and  $\frac{3}{4}$  in. pipe sizes with or without pilot tapings and pressure tapping. Voltage types: 20v, 60 c, a-c; 115 v, 60 c, a-c; 230 v, 60 c, a-c; and 440 v, 60 c, a-c. Low voltage transformers in three-terminal and two-terminal types, DA1 and DA2, respectively.

### ACTROL® VALVE

Automatic main gas control valve. Maximum force exerted at beginning of stroke. Valve has built-in, current limiting transformer for 24-volt control circuits. Straight through body tapped with  $\frac{3}{4}$  in., 1 in., or  $1\frac{1}{4}$  in. F.P.T. inlet and outlet. Valve can be mounted in a 360 deg circle around horizontal centerline of body. Other models with manual set, safety switch, or Baso® valve.



MA8G1



Type AK Basoid Valve

### BASOID® VALVES

Basoid valves Series AE, AH, and AK are 1 in.,  $\frac{3}{4}$  in., and  $\frac{1}{2}$  in. sizes, respectively. They combine solenoid valve for automatic main gas control and Baso automatic safety pilot in one aluminum body. One or two pilot tapings optional. Current types: 20 v, 60 c, a-c; 115 v, 60 c, a-c; 230 v, 60 c, a-c; and 440 v, 60 c, a-c. Low voltage transformers in three-terminal and two terminal types, DA1 and DA2, respectively.

Switches No. 860 and 861 are wired in series with other controls. Opens circuit to main valve in case of pilot failure. Circuit closes automatically when pilot is relighted. MODEL No. 860 is a two-wire switch and No. 861 is a three-wire switch.

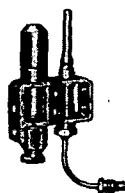
Electrical Rating:  
8 Amp at 115 v, a-c.  
4 Amp at 230 v, a-c.  
 $\frac{3}{4}$  hp 115/230 v, a-c.



860 Switch

ANNULAIR® PILOT BURNERS are available in a variety of tips and dual orifice inlet fittings for all kinds of fuel gas and pilot line connections. They are made in four types, "B" for low consumption appliances, "C" for medium consumption, and "D" and "F" for larger capacity appliances.

Thermocouple leads of the 88D and 58D types are available in standard lengths from 12 in. to 72 in. and in special lengths to 240 in.



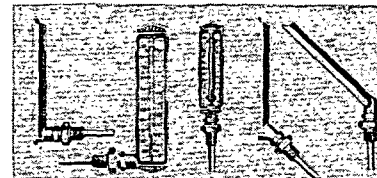
Write for complete catalog SV-300-3.

## Moeller Instrument Company

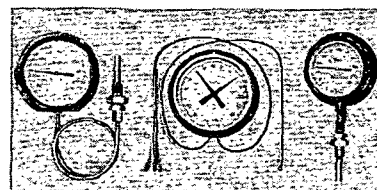
132nd St. and 89th Ave., Richmond Hill 18, New York

Representatives in Principal Cities

### INSTRUMENTS FOR HEATING AND VENTILATING



MOELLER INDUSTRIAL THERMOMETERS made in all forms, in scale ranges from minus 120 to plus 1125 F or its equivalent in centigrade. Available in 5 in., 7 in., 9 in. and 12 in. scale sizes.



DIAL INDICATING THERMOMETERS, Mercury Actuated, made in 4 $\frac{1}{2}$  in., 6 in. and 8 $\frac{1}{2}$  in. sizes with flexible extension tubing. Scale ranges from minus 40 to plus 1000 F or its equivalent in centigrade.



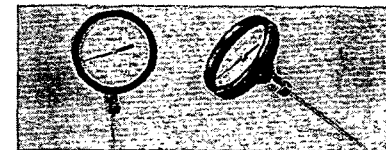
THERMOMETER TEST WELLS, THERMOCOUPLE PROTECTING TUBES and WELLS, made up in all sizes and alloys.



ENGRAVED STEM and PORCELAIN and PAPER SCALE THERMOMETERS made in ranges from minus 150 to plus 1125 F or its equivalent in centigrade.



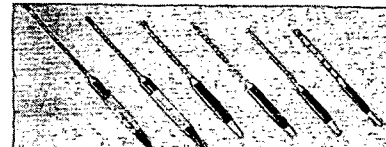
RECORDING THERMOMETERS, Mercury Actuated, made in the round or rectangular cases. Charts 10 in. or 12 in., 1 hr, 12 hr, 24 hr or 7 day. Ranges from minus 40 to plus 1000 F or its equivalent in centigrade.



MOELLER BI-METAL THERMOMETERS are actuated by a powerful, specially processed bi-metal helix. Made in 3 in. and 5 in. diameter cases. Scale ranges from minus 150 to 1000 F. or its equivalent in Centigrade.



RECORDING PSYCHROMETERS, Mercury Actuated. Round and Rectangular Case, 12 hr, 24 hr or 7 day charts, self contained or remote reading, with or without motor driven fan.



HYDROMETERS PLAIN FORM or COMBINED with THERMOMETER. Made in all scales. Standard and commercial grades.

Send for catalogs and literature on

INDUSTRIAL•LABORATORY and RECORDING THERMOMETERS•THERMOSTATS•HYGROMETERS•HYDROMETERS•PSYCHROMETERS and MARINE SPECIALTIES

## Penn Controls, Inc.

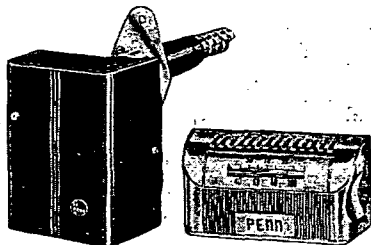
Main Office—Goshen, Indiana; In Canada—Penn Controls, Limited

Offices and Representatives

ALBUQUERQUE; ATLANTA; BERKELEY; CHICAGO; CLEVELAND; COLUMBUS; DALLAS; DAYTON; DENVER; LOS ANGELES; MINNEAPOLIS; MILWAUKEE; MOLINE; NEWTON, MASS.; NEW YORK (North Bergen, N. J.); PHILADELPHIA; PITTSBURGH; ROCHESTER; SALT LAKE CITY; ST. LOUIS; SEATTLE; EXPORT—13 E. 40th St., New York 10, N. Y.

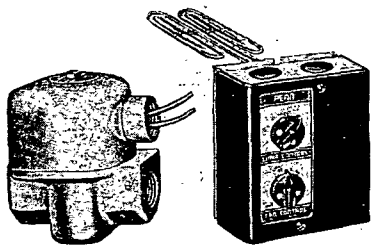
Wholesalers in All Principal Cities

Automatic Controls for Heating, Refrigeration, Air Conditioning, Engines, Pumps, Air Compressors and Gas Appliances



Oil Burner Stack Switches

Heating Thermostats

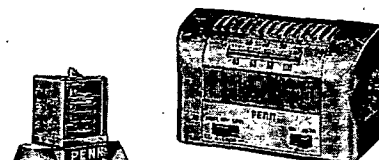


Series 926 Gas Valves

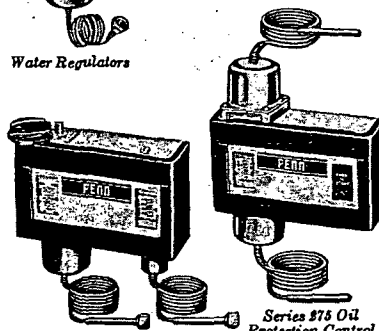
Warm Air Fan and Limit Controls

### HEATING CONTROLS

A wide selection of controls is available for automatic heating service on steam, vapor, hot water, or warm air systems . . . gas, oil or coal-fired. Typical controls in Penn's complete line are: Low and Line Voltage Room Thermostats—Stoker Timers—Oil Burner Stack Switches—Magnetic and Motorized Gas Valves—Hot Water and Warm Air Temperature Controls (including a complete line of Liquid Expansion Fan and Limit Controls)—Vapor and Steam Pressure Controls—Relays and Relay-Transformers—Humidistats—Day-Nite Temperature Controls—Pilot Burners and Pilot Generators—Thermopilot Relays—Low Pressure Gas Regulators—Damper Motor Controls—and Solenoid Valves.



Heating-Cooling Thermostats



Series 271 Dual Pressure Control

Series 275 Oil Protection Control

### COOLING CONTROLS

A complete line of automatic commercial refrigeration controls . . . in a wide choice of pressure and temperature models to fit every need. Series 270 single pole, standard duty or two pole, heavy duty controls feature direct reading, calibrated scales. Other controls in the refrigeration line include: Cooling Room Thermostats—Humidistats—Relays—Solenoid Valves—Line Starters and Motor Contactors in Size 0, 1, and 1½—Water Regulating Valves in sizes up to 2½ in. N.P.T.—and Oil Protection Controls for pressure lubricated refrigeration compressors.

WRITE FOR FREE CATALOGS WHICH GIVE DESCRIPTIONS AND SPECIFICATIONS



# Potter & Brumfield

Princeton, Indiana

Relays: All types—All sizes—For all applications

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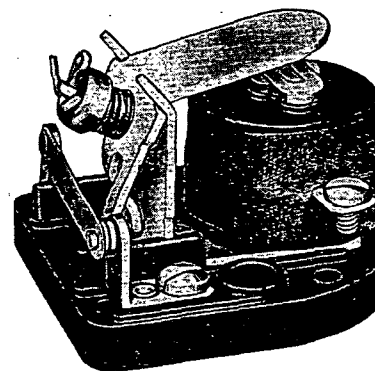
CANAAN, CONN.  
CEDAR RAPIDS, IA.  
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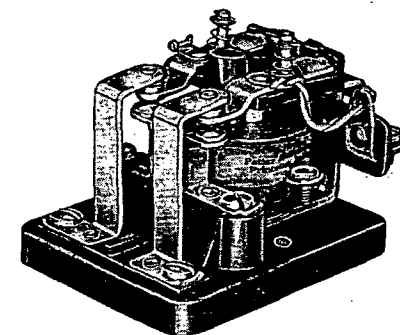
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### SERIES MS RELAYS

MS series motor starting relays are voltage controlled to insure cut of starting windings when the motor reaches running speed, regardless of the load on the motor. This design permits an exceptionally wide differential between pull-in and dropout voltages. Relays can be either factory or field adjusted to meet exact requirements. MS2A for use with ¾ hp motor 115 or 230 volt 60 cycle, MS4A motors up to 3 hp either 115, 230 or 440 volt, 60 cycles. All relays are mounted on molded phenolic bases. Contact arrangement MS2A, SPST-NC, MS4A, SPST-NC double break.



### SERIES PR RELAYS

SERIES PR are heavy duty, fast acting relays designed for high current or high voltage switching requirements. The full floating movable contact carrier assures ample wipe and contact pressure.

Standard contacts are 5/16 in. diameter, fine silver, rated 15 amperes, 115 volt, 60 cycle non-inductive or 20 amperes double break contacts. By the use of equivalent size cadmium oxide contacts higher ratings are possible. A wide variety of standard and auxiliary contact arms are available for multiple current handling requirements.

Terminals for printed circuits, plug or screw type, are available.

The PR series are Underwriter Laboratory approved.



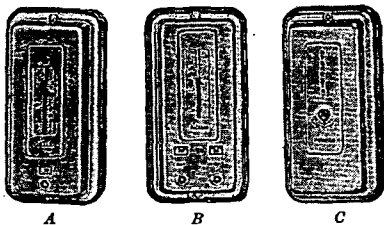
# THE POWERS REGULATOR CO.

Over 60 Years of Automatic Temperature and Humidity Control.



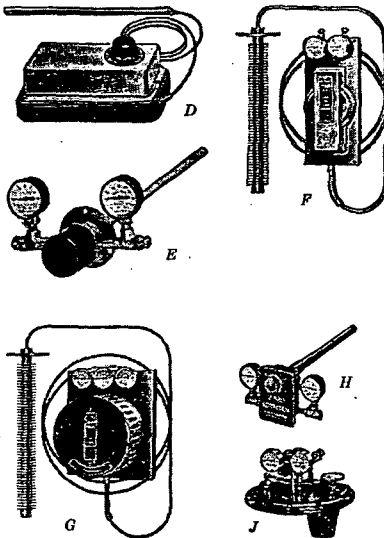
Factory and General Offices: Skokie, Ill.  
Offices in Over 60 Cities, U.S.A., Canada and Mexico, see your phone book.

New York 17, N. Y. Chicago 13, Ill. Toronto Downsview, Ont.  
231 E. 46th St. 3819 N. Ashland Ave. 15 Torbarrie Road  
Los Angeles 26, Cal. Mexico, D. F.  
3200 W. Temple St. Apartado 63 Bis.



Some of the many controls employed in a Powers pneumatic control system for heating, ventilating, air conditioning and industrial processes are shown here. Controls for water heaters, fuel oil pre-heaters and heat exchangers appear on third page.

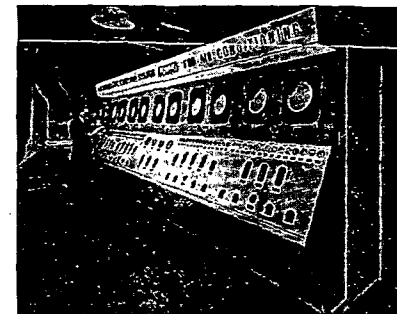
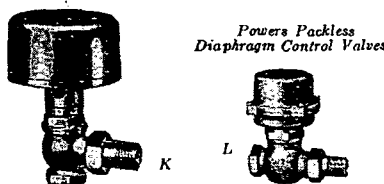
Powers Thermostats have true gradual action with no constant bleed of compressed air. They give many years of dependable control with practically no maintenance. Various types for specific applications are available. Some are shown at left.



A) Type D Single temperature range room thermostat has durable stamped brass cover and plastic insulating base. Because of its small size  $5\frac{5}{8}$  H x  $2\frac{1}{4}$  W x  $2\frac{1}{4}$  in. deep, it fits into narrow vertical spaces. B) Type D Two-temperature range Day-Night thermostat. C) Type 190 Room Hygrostat for humidity control, duct type also available. D) Type D Summer-Winter remote bulb thermostat for air conditioning units. E) Limitem thermostat for unit ventilators and ducts. F) Type K remote bulb thermostat. G) Type K remote bulb Submaster thermostat. H) Accritem Temperature Regulator has adjustable sensitivity and calibrated dial adjustment with ranges 50-250F and 150-350F. J) Static Pressure Regulator for air ducts.

Powers Series 100 Recording and Indicating Controllers also control switches, gages, etc., are available in a variety of models; some are shown on control panels on next page.

Powers Packless Control Valves (K and L) are made in various types and sizes for convectors, unit ventilators, unit air conditioners or coils in ducts. With their durable construction, ample power and Duo-Seal packless feature they eliminate normal packing gland friction and give better control. They eliminate steam or water leakage, loss of vacuum and packing maintenance.



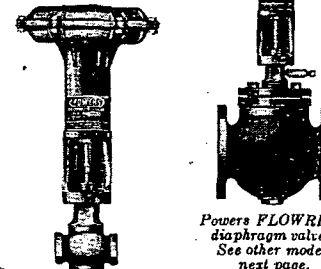
Modern Control Panel employing various types of Powers pneumatic controlling, indicating and recording instruments which regulate four complete year round air conditioning systems.

**UNIT VENTILATOR CONTROL** Powers latest advancement the **LIMITEM Thermostat** (E on previous page) is a precision instrument engineered to provide accurate low limit control of unit ventilator discharge temperatures... a critical requirement for classroom comfort. It has sturdy construction, accurate response, Powers famous **NON-WASTE** double air-valve with adjustable sensitivity and graduated temperature dial for changing the control point. It is fully described in *Bulletin 308*.

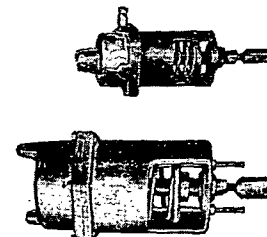
Powers **MASTROL** Systems for controlling forced hot water heating, radiant panel heating, etc., are available in various combinations of Master and Sub-Master controls. Control panel below shows **MASTROL** system using Powers Series 100 Recording Master Controller readjusting Sub-Master Indicating Controllers.



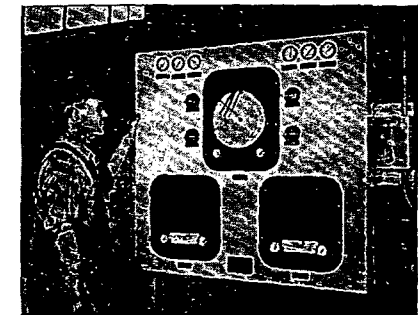
Left: Powers Wet and Dry Bulb Recording Controller with motor driven fan.



Powers FLOWRITE diaphragm valves. See other models next page.



POWERSTROKE Piston Operators for Dampers, etc. Available in 3 in., 4 in. and 6 in. size.

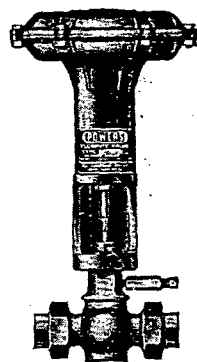
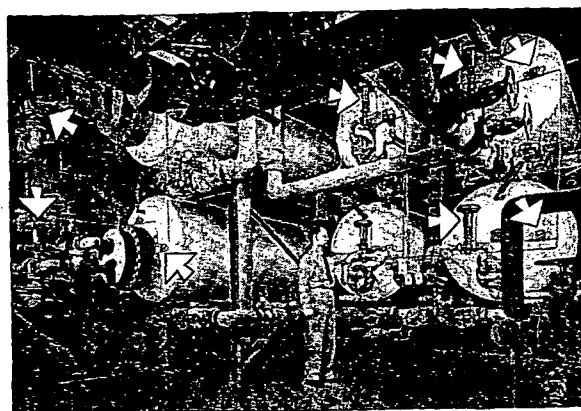


Powers modern line of diaphragm control valves, and damper operators meet all heating and air conditioning requirements.

Simplicity and good design features in Powers **FLOWRITE** Valves give close control and they last longer. They are available with single seat, double seat, 3 way mixing and V-Port characterized valve which gives straight line control. Accurate control results from smooth rolling diaphragm and minimum of valve stem friction. Diaphragm has formed bead which provides increased sealing action with increasing control pressure. It has no bolt holes. Diaphragm lasts longer without replacement.

Piston plate assembly has a free floating thrust plate which absorbs side thrust. Closely guided piston plate maintains valve stem in accurate alignment. Series 344 Bulletins give more facts about these valves.





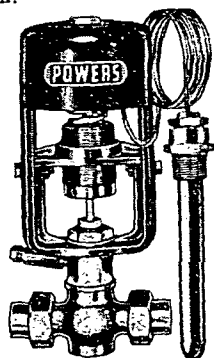
Above: Powers FLOWRITE  
Diaphragm Control Valve.

## POWERS

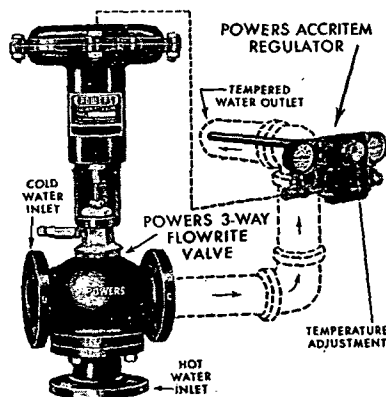
Temperature Control for Water Heaters, Heat Exchangers, Fuel Oil Preheaters, and many other uses.

No. 11 Regulator below, is self-operating, especially adapted for hot water storage heaters. Available with 60F, ranges, various types of valve bodies and trim, also 3 way valves for water mixing.

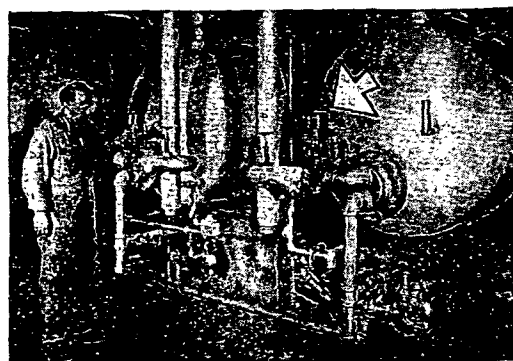
Accritem Regulator at right, is compressed air or water operated, used to control Powers Three-way Flowrite valves. Is especially adapted for control of instantaneous water heaters, submerged and indirect heaters, 2-Temp. domestic water heating systems—applications requiring accurate control and having frequent load changes and for large size valves. Has adjustable sensitivity, calibrated dial temp. adjustment, ranges 50-250F and 150-350F. Sensitive bulb 12 in. long, 1/2 in. IPS connection.



No. 11 Regulator



Thermostatic Water Mixing Valves—complete line for individual shower baths, gang showers, hydrotherapy, hot water line control, and processes. Contact nearest Powers office for bulletins.



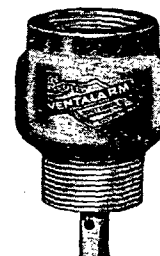
## Scully Signal Company

Main Offices and Factory: 174 Green Street, Melrose 76, Mass.

Representatives in Principal Cities  
Canadian Branch: Scully Signal Ltd., 286 King St., W., Toronto, Ontario

SCULLY PRODUCTS include VENTALARM Whistling Tank Fill Signal, VENTALARM GAUGE, combination audible fill signal and tank gauge, and the separate SCULLY GAUGE.

**VENTALARM Signal**—An audible whistling tank fill signal installed directly on the fuel oil tank as an integral part of the vent pipe. Displaced air forced from the tank by intruding oil motivates a sensitive but sturdy whistle within the body of VENTALARM Signal. The sound travels up and out the vent pipe where it is audible to the man filling. He simply fills until the whistle stops which is when the oil reaches the bottom of the whistle stem (at a predetermined safe level within the tank allowing for expansion zone). Permits householder to come and go regardless of oil delivery time. Eliminates need for delivery man to enter home. Stops damaging spills and while the whistle sounds there is positive proof that all parts of the tank fill system are in good working order.



Models LA and L for New Tanks

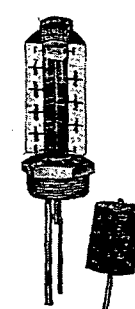
These models thread into tank vent flange opening. The lower end of vent pipe threads into top of VENTALARM Signal.

Model LA (Listed as Standard by Underwriters Laboratory)

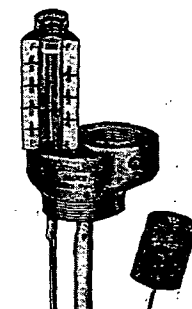
|                                      |               |          |
|--------------------------------------|---------------|----------|
| Bottom                               | Top           | Part No. |
| 1 1/4" male                          | 1 1/4" female | 201      |
| Model L (same as LA except for size) |               |          |
| Bottom                               | Top           | Part No. |
| 2" male                              | 1 1/4" female | 521      |
| 1 1/4" male                          | 1 1/4" female | 240      |

Special models for special situations including Model LC for Old Tanks—furnished complete with quick-fit compression lock device eliminating need for threading or special fittings.

**SCULLY TANK GAUGE**—Easily read even 10 feet away. Gauge face adjustable for convenient reading. Pure white button indicator within oil and odor-proof plastic housing in a gasketed seat. Jam-proof lever arm. Oil resistant cork float. Button-Lift allows installation with or without oil in tank. Model GA for 2 in. tank opening. Model GB for 1 1/2 in. tank opening. Model GC for 1 1/4 in. tank opening. Specify tank depth—24 in., 26 in., 27 in., 28 in., 37 in., 42 in., 44 in., 47 in. Underwriters' approved.



Scully Tank Gauge



Combination Ventalarm Gauge

**Combination VENTALARM-GAUGE**—Both an audible fill signal and gauge in one unit. No reducing bushing needed. Only one item to install instead of three. Sizes VG-A, 2 in. x 1 1/4 in.; VG-B, 1 1/2 in. x 1 1/4 in. For 275 gal cellar tanks with depth of 24 in., 26 in., 27 in., 28 in., 37 in., 42 in., 44 in., 47 in. Scully products are manufactured under U.S. and Foreign Patents or Patents Pending.

Prices subject to change.  
Over 4,000,000 Scully VENTALARM Signals in use—UL approved.

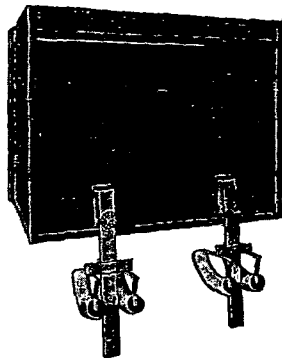
SEE YOUR SUPPLY HOUSE

## Simplex Manufacturing Company

198-206 North Main Street

Fond du Lac, Wis.

SIM-TROL Barometric Draft Controls—SIMPLEX Roof Vent Flashings



Type "A"

Breechings and stacks must provide sufficient draft under adverse atmospheric conditions. During normal and high barometric periods, cold months and windy days they generate excessive intensities with resulting inefficiency and fuel waste.

### ADVANTAGES

SIM-TROLS automatically maintain a minimum draft required for good combustion, fuel economy, increased heat transfer by reduction of gas velocity through the boiler, and minimize cold air infiltration and inrush causing sudden shrinkage of boiler parts. They eliminate local hot spots, floating and pulsating flame and sucking out of pilots. They improve feed water regulation, super-heater results, boiler life and boiler room ventilation.

SIM-TROLS aid materially in smoke abatement and boiler cleanliness by reduction of unburned combustibles and air dilution of stack gases. Lowered stack temperatures prolong liner life and reduce fire hazards.

### CONSTRUCTION

Properly sized SIM-TROLS adjust easily to any desired draft intensity. The races adjust laterally, the race assembly vertically, and the arm angle may be varied in relation to the plane of the gate.

Gates of Type A and Type C SIM-TROLS rotate on cold rolled arbors and dust proof ball bearings. Curved tubular counterbalances contain metal balls which constantly change position to compensate for varying rotation angles of the gate, maintaining over-fire draft within 0.01 in. water, plus or minus.

SIM-TROLS are protected by hard, heat resisting boiler room enamels. All counterbalance members are outside, free from encrustment and corrosion by products of combustion.

### DESIGN FACTORS

Sizing is important. The input opening should equal the stack area, plus 10 per cent for each 35 ft of stack height over 65 ft thereof. Preference should be given to control width, rather than height for ease of adjustment and smooth operation.

Horizontal clearance from installation point approximates gate height plus 30 in. Over-all height approximates gate height plus 37 in. Over-all width approximates gate width plus 8 in. Designs for limited space may be made if plans are submitted.

Types A, C and F are individually designed to plant specifications presented, including breeching and stack dimensions, clearances, fuel, method of firing and number of boilers. Detailed sketches are submitted for approval without obligation.

### GAS MODEL SIM-TROLS

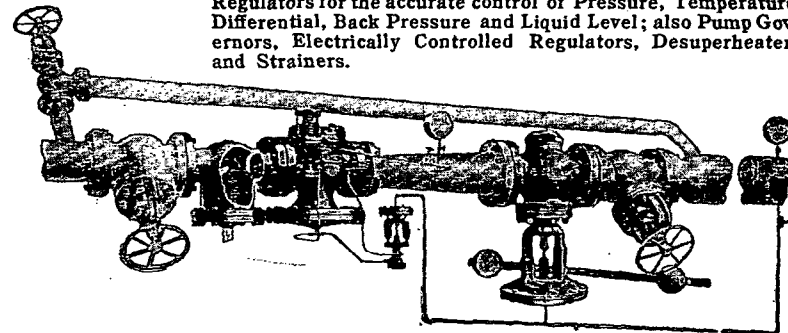
Types A, F and H are available to provide full back pressure relief and draft control. If specified, Types A and F are designed for use with coal, gas or oil by minor adjustment by the operator.



## Spence Engineering Company, Inc.

28 Grant Street, Walden, N. Y.

Regulators for the accurate control of Pressure, Temperature, Differential, Back Pressure and Liquid Level; also Pump Governors, Electrically Controlled Regulators, Desuperheaters and Strainers.

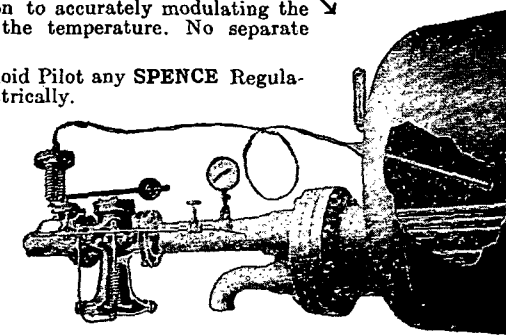
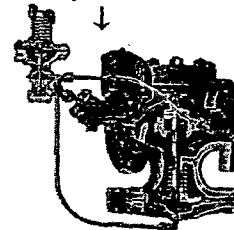


The SPENCE Type ED-W27 Two-Stage Pressure Reducing Station is designed to serve a heating system dependably, at low cost and with utmost safety. The primary is a pilot operated, Type ED Pressure Regulator. SECO Metal trim affords guaranteed resistance to wire-drawing. The secondary is a direct operated, Type W27 Valve, simply constructed, yet engineered for long trouble-free, heating duty.

Note that the Diaphragm of the SPENCE Safety Pilot is connected to the low side. Should the secondary valve fail, this Pilot will assume control of the primary; thereby effecting a one-stage reduction from primary to final delivery pressure.

A Spence Type E2T100 Temperature Regulator reduces the steam pressure in addition to accurately modulating the flow as required to control the temperature. No separate reducing valve is necessary.

By adding a SPENCE Solenoid Pilot any SPENCE Regulator may be cut on and off electrically.



The Spence design provides a self-operated, pilot controlled regulator entirely packless in construction and guaranteed to shut tight. SECO Metal seats and discs will not be cut by the wire-drawing action of steam. Spence thermal elements are not injured by overheating.

Pilot Type T100 is weight-loaded for heaters requiring not more than 10 psi pressure. Pilot Type T150 is spring-set for pressures up to 50 psi. Either may be used on a storage or instantaneous heater in combination with a main valve selected to suit the initial steam conditions.



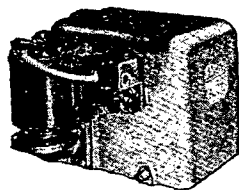
## Sterling, Inc.

3738 North Holton Street, Milwaukee 12, Wisconsin

Heating and Temperature Control Products

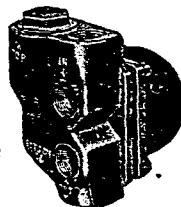
Distributed through leading Heating and Plumbing Wholesalers

Sales Representatives in Principal Cities



## CONDENSATION and VACUUM PUMPS

4100 and 4200 Series (illustrated): neat, convenient unit with either steel or cast iron tank. Dual voltage capacitor type motor and carbon type rotary seal—for all jobs up to 15,000 sq ft EDR, 20 psi. 3500 Series: heavy duty units with pedestal mounted steel tank for a wide range of jobs—2000 to 65,000 sq ft, up to 150 psi. 3700 Series: with heavy cast iron tank for installation underground or in wet locations. 2000 to 20,000 sq ft, 20 or 30 psi. Vacuum Pumps: Type V, 2500 and 5000 sq ft, 20 psi. Type S, 10,000 to 40,000 sq ft, 20 to 40 psi.

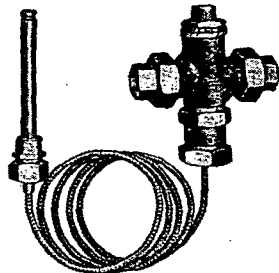


Popular 69B illustrated

## FLOAT and THERMOSTATIC TRAPS

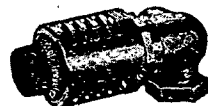
Used wherever it is desired to prevent flow of steam, but to permit passage of air and water... on unit heaters, large radiators and convectors, water heaters, steam main drips and other types of equipment where steam is used. Compact, rugged, easy to service. Bellows thermostat vents air, float valve has plenty of capacity for large amounts of condensate. Sizes:  $\frac{3}{4}$  in., 1 in.,  $1\frac{1}{4}$  in.,  $1\frac{1}{2}$  in., 2 in. Max. pressures: 15, 100 psi.

Also Strainers, Radiator Valves, Boiler Return Traps.



## Series 150-E TEMPERATURE CONTROL VALVES

Self-powered, modulating control valves—applicable to any process involving heating and cooling by means of water, oil, steam or other fluids. Sturdy bellows—sealed valve with stainless steel trim and monel bellows. Armored capillary tube. Extremely compact—MOUNTS and OPERATES in ANY POSITION. Sizes:  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in., 1 in. Max. pressure: 125 psi. Direct or reverse acting. Series 117-A: Dependable action for larger capacities. Sensitive thermostat bellows operates a pilot valve—steam supply pressure is used for smooth positive operation. Sizes:  $1\frac{1}{4}$  in.,  $1\frac{1}{2}$  in., 2 in. Max. pressure: 125 psi. Direct acting only.



## SERIES 120-A THERMOTROLS

Self-contained individual radiator temperature controls for steam or hot water. Simple to install! Eliminate overheating, save fuel. Maintain even temperature for comfort and health. Sizes:  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in., 1 in. Body styles: Angle, Straightway, Corner.

**THERMOSTATIC TRAPS:** Keep radiators clear of condensate without wasting steam. Dependable bellows thermostat, sturdy bronze bodies and covers, replaceable seats. Sizes:  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in., 1 in. Max. pressures: 15, 65, 100, 125 psi. Body styles: Angle, Straightway, Corner, Vertical.

## Taylor Instrument Companies

Rochester 1, N. Y., U. S. A.

Mfg. Subsidiaries: Taylor Instrument Companies of Canada Limited, Toronto, Canada  
Taylor Instrument Companies of Australia Pty. Ltd., Melbourne, Australia  
Short & Mason Ltd., London, England

NEW YORK  
CHICAGO  
BOSTON  
PHILADELPHIA

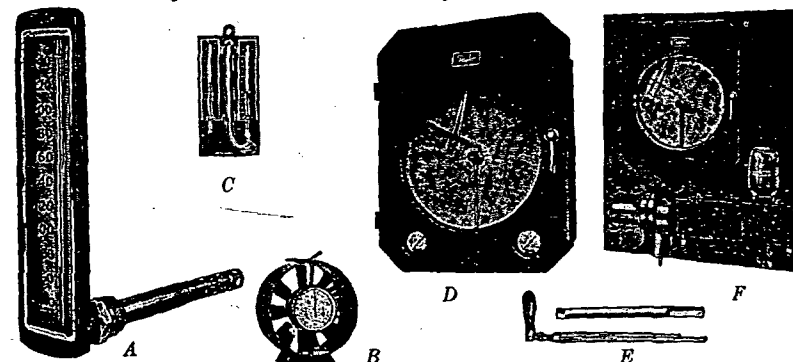
BUFFALO  
LOS ANGELES  
PITTSBURGH  
CLEVELAND

ST. LOUIS  
SAN FRANCISCO  
HOUSTON

CINCINNATI  
TULSA  
BALTIMORE  
ATLANTA

MINNEAPOLIS  
WILMINGTON  
SCHENECTADY  
SCOTIA

Taylor Instruments for Indicating, Recording and Controlling Temperature, Pressure, Humidity, Flow and Liquid Level



(A) Taylor Industrial Thermometers—with BINOC\* Tubing. Includes many styles and scale ranges with bulbs for every application. These thermometers use the well known Taylor BINOC Tubing—a designed and optically correct glass tubing which assures ease of reading generally lacking in industrial thermometers. BINOC tubing more than doubles the angle of vision within which readings can be made. Because of the patented triple-lens construction, its broad mercury column can be read easily and accurately with both eyes. Bore reflection is absent.

(B) Taylor Biram's Anemometer. For measuring air velocities with fan revolutions indicated on dial. Various models for a wide range of air speeds and registration limits.

(C) Mason's Form Hygrometer. Provides temperature and humidity measurements. Magnifying thermometer tubes are mercury-filled, approximate range 30 to 120 F. Thermometer scales and siphon reservoir are mounted on a mahogany finished wood panel,  $8\frac{1}{2}$  in x  $4\frac{1}{2}$  in.

(D) FULSCOPE\* Recording Controller. An air-operated controller that gives practically any character of process control.

\*Trade Mark

trol regardless of time lag in apparatus. Available for controlling temperature, pressure, humidity, rate of flow, liquid level. Where extreme load changes or badly balanced operating conditions exist, precision control can be maintained by the automatic reset feature. For applications where a record is not essential, Taylor supplies an Indicating FULSCOPE Controller.

(E) Sling Psychrometer. Two accurate etched-stem thermometers mounted on die-cast frame, with the bulb of one covered with a wick to be moistened. Whirling bulbs subject this hygrometer to complete air contact to produce extreme accuracy of temperature and humidity measurement.

(F) Recording Hygrometer. Records both wet and dry bulb temperatures on the same chart in different colored inks, making comparison very easy. Type shown has motor-driven fan for conditioned rooms or passages where circulation is poor. Furnished without fan for installations where circulation across bulb is good.

Taylor also offers a complete line of the famous Taylor Recording and Dial Thermometers; Ratio, Pneumatic Set, Self-Acting and Type "P" Controllers; Indicating Hygrometers and many types of Humidifiers.

## White-Rodgers Electric Company



1209 Cass Ave., St. Louis 6, Mo.

In Canada, White-Rodgers Limited, Toronto

NEW YORK, N. Y.  
(LONG ISLAND CITY)  
BUFFALO, N. Y.

CHICAGO, ILL.  
DETROIT, MICH.

CLEVELAND, OHIO  
PHILADELPHIA, PA.  
(HARTTOWN)

Distributors in Principal Cities

### HYDRAULIC-ACTION CONTROLS

The complete line of White-Rodgers controls includes:

|                              |                                             |
|------------------------------|---------------------------------------------|
| Warm Air Controls            | Relays                                      |
| Low Voltage Thermostats      | Gas Valves                                  |
| Line Voltage Thermostats     | Oil Burner Controls                         |
| Hot Water and Steam Controls | Refrigeration and Air-Conditioning Controls |

Hydraulic-Action temperature controls operate on the principle of expansion and contraction of a solid liquid charge against a diaphragm.

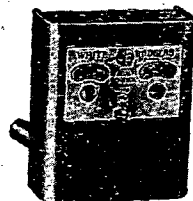
This system, developed and perfected by White-Rodgers provides accuracy comparable to that of a fine thermometer... and other outstanding features guaranteeing excellent performance.

### ADVANTAGES OF HYDRAULIC-ACTION

Hydraulic-Action controls provide maximum sensitivity—positive dial settings—full range accuracy—consistent differential—eliminates temperature drift—simplified installation—extra sturdy switch mechanism—and other qualities that assure long satisfactory operation.

### PRIMARY CONTROLS

In addition to Hydraulic-Action Controls, White-Rodgers manufactures Oil Burner primary controls, Gas Valves (both diaphragm and solenoid types) and automatic safety pilots for gas installations.



Dual Hot Water Controls. Limit and Circulator, High and Low Limit combinations. Also made in single controls.



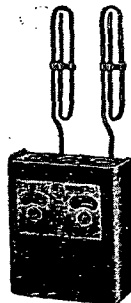
Low voltage room thermostat. Ivory and chrome finish.



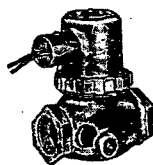
Line voltage thermostat for unit heaters or air conditioning installations.



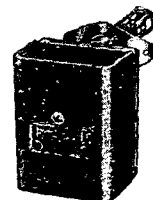
Remote bulb heavy-duty thermostat, also available with self-contained bulbs.



Fan & Limit controls in single case. Note the flexible elements. Also in single units.



"Cushioned Power" Solenoid Gas Valves. Quiet, soft seat, spring loaded. For ALL gases.



Oil Burner primary control (stack switch). Intermittent or Constant Ignition types.

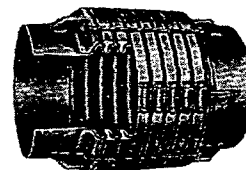
Contact your nearest White-Rodgers office for complete information. Catalog and engineering data furnished quickly.



## AMERICAN DISTRICT STEAM DIVISION

AdSCO INDUSTRIES, INC.

20 MILBURN ST. BUFFALO 12, N. Y.  
PLANTS, BUFFALO, N. Y.—RICHMOND, CALIF.

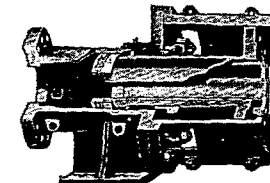


### PACKLESS EXPANSION JOINTS

AdSCO's Corruflex packless expansion joints absorb pipe expansion and are adaptable to any piping condition. They are made in two basic types. The self-equalizing joint is used for various types of motion and is suitable for pressures to 300 psi and higher. The non-equalizing type is generally used to absorb vibration and a small amount of expansion under vacuum or pressures to 30 psi.

Depending on the type of metal used in the expansion element, these joints are suitable for temperatures from sub-zero to 1600 F. With variations in design, these joints will absorb axial, lateral, or angular motion, or any combinations of these motions. Some types handling these conditions are the universal, hinge, swing, gimbal, tie-rod, balanced, and anti-compression joints.

They are made in nominal pipe sizes ranging from 3 in. to 54 in., with single or multiple corrugations. Most types can be supplied with covers to permit joints to be fully insulated and to prevent foreign matter from being lodged between the corrugations. When used for axial movement, joints can be equipped with internal guide sleeves to provide a guiding feature and rigidity. For other purposes they can be equipped with telescoping inner sleeves to reduce turbulence in the fluid being handled.



### SLIP-TYPE JOINTS

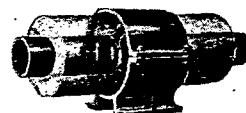
Slip-type expansion joints, designed for axial motion, offer long traverse, low initial cost, and produce minimum stresses and strains on pipe anchors. With proper maintenance, they will last as long as the pipeline.

The piston-ring joint, illustrated above, with external-internal guiding, can be unpacked and repacked under full line pressure because of its piston-ring feature. The polished, chrome-plated slip is in contact with packing only. Hence, it cannot be scored by metal-to-metal contact. Packing can be quickly lubricated to prolong its life. The slip in the externally-internally guided joint is fully supported at both ends throughout its entire length of travel. The gland is not used as a guiding feature.

The internally-guided joint (not illustrated), being more compact, is especially recommended for use where space is limited.

AdSCO slip joints are furnished in both single and double units, with flanged ends or welding ends. Sizes range from 1 1/4 in. to 48 in. and traverse per slip is 4 in., 8 in., and 12 in. Semi-steel joints can be used for working pressures to 250 lbs and temperatures to 450 F. Steel joints can be used for working pressures to 400 lbs and temperatures to 800 F.

### PIPE ALIGNMENT GUIDES



AdSCO pipe alignment guides insure straight movement of pipe line for efficient operation of expansion joints, permit line to be completely insulated. In all nominal pipe sizes for various thicknesses of insulation; 12 in. of pipe movement permitted.

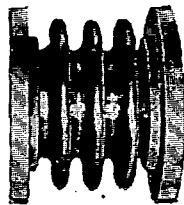
## Badger Manufacturing Company

230 Bent St., Cambridge 41, Mass. • 60 East 42nd St., New York 17, N. Y.

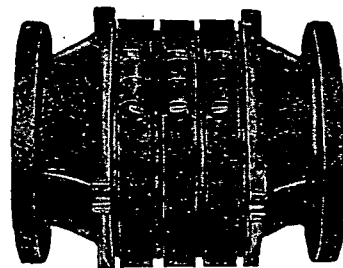
Representatives in principal cities  
Also in Canada and Mexico

### "BADGER PACKLESS CORRUGATED EXPANSION JOINTS"

To compensate for thermal expansion and contraction in pipe lines carrying hot gases or fluids; also used to absorb vibrations. Hinged, Tandem, and Balanced Expansion Joints are available for complex piping problems where forces are critical.



Badger Non-Equalizing Expansion Joint, Multiple Corrugation. Single corrugation type available. Wide range of sizes.



Badger Self-Equalizing Expansion Joint, Directed Flexing Type. Wide range of sizes and traverses available.

### INSTALLATION, OPERATING, MAINTENANCE FEATURES

**Packless**—Each Badger Packless Expansion Joint is formed from a single tube hence, no packing is needed etc.

**Engineered Relationship**—Between diameter of joint, depth of corrugation and allowable traverse.

**Heat Treatment**—Successive heat treating operations during manufacture removes forming stresses and increases life.

**Wide Pressure Range**—Standard joints for pressures up to 300 psig.

**Wide Temperature Range**—Standard joints for temperatures up to 900 F.

**Wide Traverse Range**—In standard in-

crements up to 7½ in. for single joints; up to 15¼ in. for double joints.

**Connections**—Flanged or welding ends available.

**Materials**—Standard joints fabricated from stainless steel or copper.

**Compact, Easy to Install**—Outside diameters of all Badger Expansion Joints are approximately the same as standard pipe flanges; joints are as easily installed in the line as any fitting.

**Special Designs**—Our Engineering Department will be pleased to consult with you regarding applications involving large sizes, special alloys, or abnormal operating conditions.

## Flexonics Corporation

### EXPANSION JOINT DIVISION

1329 S. Third Ave.

Maywood, Illinois

#### DISTRICT OFFICES

ATLANTA BOSTON BUFFALO CINCINNATI CLEVELAND DETROIT FT. WORTH KANSAS CITY  
LOS ANGELES MEMPHIS MILWAUKEE NEW YORK PHILADELPHIA SAN FRANCISCO  
IN CANADA: FLEXONICS CORPORATION OF CANADA, LTD., BRAMPTON, ONTARIO

### FLEXON EXPANSION COMPENSATORS FOR STEAM AND HOT WATER HEATING SYSTEMS

#### Model L for pressures to 40 psig

The Flexon Model L Expansion Compensator consists of a two ply phosphor bronze bellows with copper tube end connections enclosed in a floating protective shroud of brass. It is especially designed for control of expansion in finned type convectors, baseboard, radiator or heating supply and return lines.

Sizes from ¾ in. through 1½ in. Suitable for temperatures from -60 F to 250 F and for pressures up to 40 psig. A single unit will handle motion up to ½ in. (¾ in. compression, ½ in. extension). Available with all commonly used fittings.



#### Sizes and Dimensions

| Pipe Size (in.) | Overall Length, in. |                      | Max. O.D., in. |                      |
|-----------------|---------------------|----------------------|----------------|----------------------|
|                 | Sweat Ends          | Female Threaded Ends | Sweat Ends     | Female Threaded Ends |
| ¾               | 5⅞                  | 7⅞                   | 1½             | 1½                   |
| 1               | 6¼                  | 8¾                   | 1⅞             | 1⅞                   |
| 1¼              | 7¾                  | 9⅞                   | 2¼             | 2¼                   |
| 2               |                     | 10⅞                  |                | 3⅞                   |

#### Model H for pressures to 150 psig

The Flexon Model H Expansion Compensator is used primarily on vertical risers for high pressure steam and hot water lines. However it may also be used on horizontal runs. The Model H consists of a corrosion resistant Flexon bellows enclosed in an all-welded steel housing. The unit is provided with a positive anti-torque device to prevent possible bellows damage during installation.

Sizes from ¾ in. through 3 in. Suitable for temperatures from -60 F to 750 F. A single unit will handle motion up to 1¼ in. (1½ in. compression, ¼ in. extension). Mild steel male NPT pipe nipples on both ends are standard. Ground joint unions or weld ends are optional.



#### Sizes and Dimensions

| Pipe Size (in.) | O/A Length (in.) | Max. O.D. (in.) | Working Press (psi) | Unit Wt. (lb.) |
|-----------------|------------------|-----------------|---------------------|----------------|
| ¾               | 9⅞               | 2⅞              | 150                 | 2.6            |
| 1               | 9⅞               | 2⅞              | 150                 | 2.8            |
| 1¼              | 13½              | 3¼              | 100                 | 7.7            |
| 1½              | 13½              | 3¼              | 100                 | 8.0            |
| 2               | 12¾              | 4¼              | 100                 | 10.3           |
| 2½              | 13⅞              | 5               | 100                 | 13.7           |
| 3               | 14⅞              | 5½              | 100                 | 17.4           |

### FLEXION EXPANSION JOINTS FOR POWER AND PROCESS PIPING

For medium and high pressure piping, Flexonics offers a complete line of corrugated expansion joints in free-flexing and controlled flexing types. Free-flexing units are available in standard sizes from 3 in. to 48 in., I.D. for pressures to 30 psi, temperatures to 850 F. Designed for expansion travel up to 3¼ in. per unit.

Controlled-flexing units are available in standard sizes from 3 in. to 48 in., I.D. for pressures to 300 psi, temperatures to 850 F. Designed for expansion travel up to 7½ in. per unit. Both free-flexing and controlled flexing types are available with flanged or welding ends.



TO MARK PROGRESS

## LADISH CO.

Cudahy,  
Wisconsin

Complete service in Controlled Quality pipe fittings regardless of size, type, wall thickness, pressure rating or material specifications.

DISTRICT OFFICES: Atlanta, Buffalo, Chicago, Cleveland, Havana, Houston, Los Angeles, Mexico City, New York, Odessa, Philadelphia, Pittsburgh, St. Louis, St. Paul, San Francisco, Seattle, Tulsa.

BRANCH PLANTS: Los Angeles, California—Brantford, Ontario, Canada—Kenosha, Wisconsin

Standardizing on Ladish assures unrestricted selection in meeting your entire fittings requirements . . . for the Ladish fittings line is complete in types, sizes, pressure ratings and materials, including carbon, alloy and stainless steels, aluminum, brass and other non-ferrous alloys. All Ladish fittings are produced under rigid metallurgical and manufacturing controls.

### BUTT WELDING FITTINGS

½ in. through 42 in. Schedule 5 through Double Extra Strong and special heavy wall thickness up to 4 inches. All fittings carry permanent heat code identification.

### ASA AND MSS FLANGES

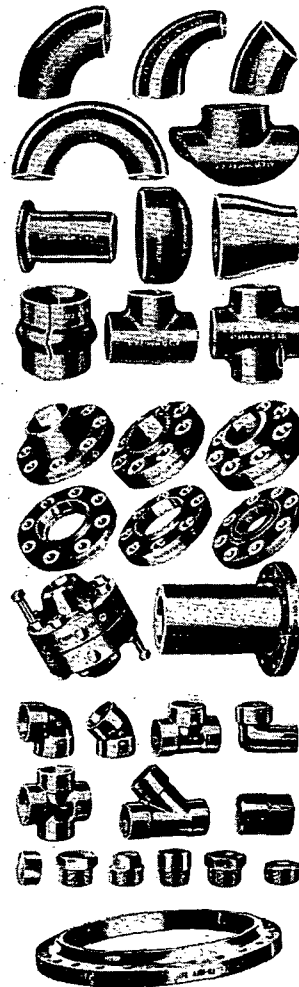
ASA Flanges ½ in. through 24 in. 150 lb through 2500 lb ratings. MSS 150 lb Flanges ½ in. through 12 in. Large O.D. Flanges in sizes up to 20' ft diameter. Forged under exacting metallurgical controls, accurately machined to full dimensions.

### SCREWED AND SOCKET WELDING FITTINGS

Forged Steel Fittings ½ in. through 4 in. 2000 lbs through 6000 lbs. Wide reinforcing bands provide ample wrench grip surface and extra strength at stress points. Sharp, clean threads of Ladish Screwed Fittings assure tight, leak-proof joints. Socket Welding Fittings have deep, true welding sockets to assure proper alignment and slip fit. 150 LB STANDARD SCREWED FITTINGS are also available in a complete range of sizes.

### PRODUCED IN ANY FORGEABLE MATERIAL

|                  |                            |
|------------------|----------------------------|
| Carbon Steels    | Carbon-Molybdenum Steels   |
| Stainless Steels | Chromium-Nickel Steels     |
| Alloy Steels     | Chromium-Molybdenum Steels |
| Inconel          | Aluminum                   |
| Monel            | Forging Brass              |
| Titanium         | Nickel-Copper Alloys       |
| Nickel Steels    | Aluminum-Manganese Alloys  |



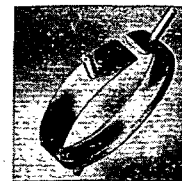
LADISH 304 PAGE CATALOG NO. 55  
SENT ON REQUEST

## The Robvon Backing Ring Co.

675 Garden Street

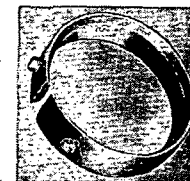
Elizabeth 2, New Jersey

Robvon Backing Rings for Welding Pipe, Valve and Fitting Joints



ROBVON Type "CCC"

**ROBVON BACKING RING TYPE "CCC."** This RING is designed for application where variation inside diameters is relatively great. Extra-long chamfered NUBS maintain the established root opening under the most adverse fit-up. The easy "STRIKE OFF" feature of the "CCC NUBS" permits each to be removed with a light tap of a hammer. Normal welding currents may be used when the NUBS have been removed.



ROBVON Type "CC"

**ROBVON TYPE "CC"** is inserted into beveled end of pipe with the split end of the ring placed at the bottom of the pipe and the spacer NUBS flush against the land of the pipe.

The beveled end of adjoining pipe is slipped onto the backing ring until the edge of pipe bevel is firmly abutted against the spacer NUB. Diameter of NUB automatically sets the root opening for the electrode.

The welder has the choice of "STRIKING OFF" the NUBS or leaving them intact. If the NUBS are not chipped off, a higher welding current will insure full penetration and fusion of the spacer NUB.



ROBVON Type "C"

**ROBVON TYPE "C."** The fit-up procedure is the same as outlined above. The non-removable NUB is readily and completely fused during welding by using a slightly higher than normal welding current.

**MACHINED** rings are manufactured to specification in either the solid or split type design.

All ROBVON Rings are available in carbon steel, wrought iron, alloys, stainless steel, aluminum, etc.



Machined Ring

### SPECIFICATIONS

| Nom. Pipe Size | I.D. of Pipe |               | No. of Root Opening Spacers |               | Dia. of Spcr. | Ring Thickness | Ring Width | Width of Land |
|----------------|--------------|---------------|-----------------------------|---------------|---------------|----------------|------------|---------------|
|                | Std. Inches  | X Hvy. Inches | Type C                      | Type CC & CCC |               |                |            |               |
| ¾"             | .824         | .742          | 3                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 1"             | 1.049        | .957          | 3                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 1¼"            | 1.380        | 1.278         | 3                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 1½"            | 1.610        | 1.500         | 3                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 1¾"            | 2.067        | 1.939         | 3                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 2"             | 2.469        | 2.323         | 3                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 2½"            | 3.088        | 2.900         | 3                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 3"             | 3.548        | 3.364         | 3                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 3½"            | 4.026        | 3.826         | 4                           | 3             | ¾"            | ¾"             | ¾"         | ¾"            |
| 4"             | 5.047        | 4.813         | 5                           | 4             | ¾"            | ¾"             | 1"         | ¾"            |
| 5"             | 6.065        | 5.761         | 5                           | 4             | ¾"            | ¾"             | 1"         | ¾"            |
| 6"             | 7.981        | 7.625         | 6                           | 4             | ¾"            | ¾"             | 1"         | ¾"            |
| 8"             | 10.020       | 9.750         | 9                           | 4             | ¾"            | ¾"             | 1"         | ¾"            |
| 10"            | 12.000       | 11.750        | 9                           | 5             | ¾"            | ¾"             | 1"         | ¾"            |
| 12"            | 13.250       | 13.000        | 9                           | 5             | ¾"            | ¾"             | 1"         | ¾"            |
| 14"            | 15.250       | 15.000        | 12                          | 5             | ¾"            | ¾"             | 1"         | ¾"            |
| 16"            | 17.250       | 17.000        | 12                          | 6             | ¾"            | ¾"             | 1"         | ¾"            |
| 18"            | 19.250       | 19.000        | 12                          | 6             | ¾"            | ¾"             | 1"         | ¾"            |
| 20"            | 23.250       | 23.000        | 15                          | 6             | ¾"            | ¾"             | 1"         | ¾"            |
| 24"            | 29.250       | 29.000        | 18                          | 6             | ¾"            | ¾"             | 1"         | ¾"            |
| 30"            | 35.250       | 35.000        | 21                          | 6             | ¾"            | ¾"             | 1"         | ¾"            |
| 36"            | 39.250       | 39.000        | 21                          | 6             | ¾"            | ¾"             | 1"         | ¾"            |



## Taylor Forge & Pipe Works

General Offices & Works: Chicago 90, Ill. (P. O. Box 485)

Plants: Carnegie Pa.; Fontana Calif.; Gary, Ind.; Houston, Tex.; Hamilton Ont., Can.

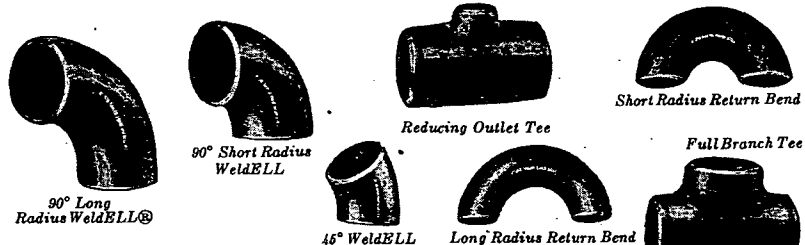
## TAYLOR FORGE

### WeldELLS®

District Offices

New York: 50 Church Street  
Philadelphia: Suburban Station Bldg.  
Pittsburgh: P. O. Box 122, Carnegie, Pa.  
San Francisco: Adam-Grant Bldg.  
Toronto, Ont., The Dominion Bank Bldg.

Chicago District Sales: 208 S. LaSalle St.  
Houston: 707 N. Drennan St.  
Los Angeles: General Petroleum Bldg.  
Atlanta: 705 Mortgage Guarantee Bldg.  
Tulsa: Constantine Bldg.



Whatever your piping requirements the Taylor Forge line—WeldELLS® and Forged Steel Flanges—will meet them. The WeldELLS line offers a wider range of type sizes and weights in a complete range of materials. Popular ranges are listed below; more complete ranges in the big Taylor Forge catalog.

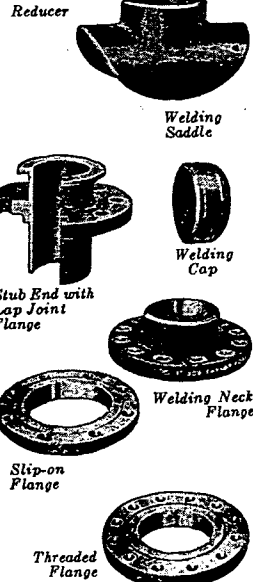
Write for the name of your nearby Taylor Forge distributor, who carries stocks of WeldELLS and Flanges.

#### Welding Fittings—Range of Sizes

| Type of Fitting | Description            | Standard Weight | Extra Strong | Schedule 160 | Double Extra Strong |
|-----------------|------------------------|-----------------|--------------|--------------|---------------------|
| WeldELLS        | 90° Long Radius        | 1"-30"          | 1"-30"       | 1"-24"       | 1"-8"               |
| WeldELLS        | 90° Short Radius       | 1"-24"          | 1"-24"       | 1"-8"        | 1"-8"               |
| WeldELLS        | 45° Long Radius        | 1"-30"          | 1"-30"       | 1"-12"       | 1"-8"               |
| Return Bends    | 180° Long Radius       | 1"-30"          | 1"-30"       | 1"-12"       | —                   |
| Return Bends    | 180° Short Radius      | 1"-24"          | 1"-24"       | 1"-8"        | 1"-8"               |
| Tees            | Full                   | 1"-24"          | 1"-24"       | 1"-12"       | 1"-8"               |
| Tees            | Branch Reducing outlet | 1"×1"×1"        | 1"×1"×1"     | —            | —                   |
| Reducers        | Concentric & Eccentric | 1"×1"           | 1"×1"        | —            | 1"×1"               |
| Caps            | Lap Joints             | 1"-24"          | 1"-24"       | —            | 1"-8"               |
| Stub Ends       | Welding                | 2" 24"          | 2" 24"       | —            | 1"-8"               |
| Saddles         | Welding                | 2" 24"          | 2" 24"       | —            | —                   |
| Sleeves         | Welding                | 2" 24"          | 2" 24"       | —            | —                   |

#### Forged Steel Flanges—Range of Sizes

|                        | 150 lb. | 300 lb. | 400 lb. | 600 lb. | 900 lb. | 1500 lb. | 2500 lb. |
|------------------------|---------|---------|---------|---------|---------|----------|----------|
| Welding Neck           | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"   | 1"-12"   |
| Slip-On                | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"   | 1"-12"   |
| Lap Joint              | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"   | 1"-12"   |
| Threaded               | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"   | 1"-12"   |
| Blind                  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"   | 1"-12"   |
| Socket Type            | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"   | 1"-12"   |
| Reducing               | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"   | 1"-12"   |
| (Threaded and Slip-On) | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"  | 1"-24"   | 1"-24"   |
| Orifices               | 1"-24"  | 1"-24"  | 1"-12"  | 1"-12"  | 1"-12"  | 1"-12"   | —        |



## Tube Turns

A Division of National Cylinder Gas Company  
General Offices and Factory: Louisville 1, Ky.

DISTRICT OFFICES:

NEW YORK, 150 Broadway—Rector 2-8230  
PHILADELPHIA, Sub. Sta. Bldg.—Rittenhouse 6-0722  
PITTSBURGH, 3001 Grant Bldg.—Atlantic 1-8848  
CLEVELAND, 52 Manning Dr., Berea, Ohio—Berea 4-1554  
CHICAGO, 600 S. Michigan Ave.—Harrison 7-8526  
DETROIT, 6432 Cass Ave.—Trinity 3-7938  
ATLANTA, 22 Marietta St.—Walnut 7310  
HOUSTON, 7120 Katy Road—Underwood 2-6631

MIDLAND, Tex., 209 Ridglea Dr.—2-5743  
DALLAS, 155 Leda Drive—Fairdale 0860  
TULSA, 305 Wright Bldg.—Cherry 2-9193  
KANSAS City—Westport 8111  
DENVER, Rm 370, Silver State Bldg.—Main 3261  
LOS ANGELES, 2417 E. 24th St.—Ludlow 7-8287  
SAN FRANCISCO, 2611 Russ Bldg.—Garfield 1-2594  
SEATTLE, 101 Jones Bldg.—Seneca 8118

In Canada: Tube Turns of Canada Limited, Chatham, Toronto, Edmonton

DISTRIBUTORS IN PRINCIPAL CITIES

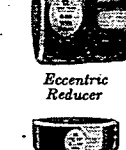
In addition to carbon steel welding fittings listed here, the complete TUBE-TURN line embraces many alloys—types 304, 347 and 316 stainless, carbon moly and chrome moly steels, copper, aluminum, brass, Monel, Inconel, nickel and wrought iron. Dimensions and engineering data are included in TUBE-TURNS catalog sent on request.



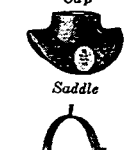
45° Long Radius Elbow



Concentric Reducer



Eccentric Reducer



Cap



Saddle



Welding Ring



Lapped Flange

| TUBE-TURN SEAMLESS WELDING FITTINGS • RANGE OF TYPES AND SIZES |                   |                       |                         |                      |                                   |                           |               |                      |
|----------------------------------------------------------------|-------------------|-----------------------|-------------------------|----------------------|-----------------------------------|---------------------------|---------------|----------------------|
| Type of Fitting<br>(All dimensions in inches)                  |                   | Carbon Steel          |                         |                      |                                   |                           | Light gage    |                      |
|                                                                |                   | Stand-<br>ard<br>wall | Extra<br>strong<br>wall | Sched-<br>ule<br>160 | Double<br>extra<br>strong<br>wall | Special<br>sched-<br>ules | Nom. O.<br>D. | I. P.<br>S. O.<br>D. |
| ELBOWS                                                         | 90 Long Radius    | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | 90 with Tangent   | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | 90 Reducing       | 2 1/2-12              | 2 1/2-12                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
| RETURNS                                                        | 90 Short Radius   | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | 45 Long Radius    | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | 180 Long Radius   | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
| TEES                                                           | 180 Ex. Long Rad. | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | 120 Short Radius  | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Straight Outlet   | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
| REDUCERS                                                       | Reducing Outlet   | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Concentric        | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Eccentric         | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
| CAPS                                                           | Stub Ends         | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Laterals          | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Crosses           | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
| RINGS                                                          | Crane Type        | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Ridge Type        | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Saddles           | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
| SLEEVES                                                        | Crane Type        | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Ridge Type        | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |
|                                                                | Crane Type        | 1 1/2-42              | 1 1/2-42                | 1-12                 | 3/4-8                             | 3/4-8                     | 4-24          | 3-12                 |

\* Since SADDLES and SLEEVES are used for external reinforcement only, they do not conform to Iron Pipe Size thickness.

#### TUBE-TURN FORGED STEEL FLANGES • RANGE OF TYPES AND SIZES

| Type of Flange<br>(All dimensions in inches)              |                                                            | Carbon Steel                                 |                                              |                                              |                                              |                                              |                                              |                                              |
|-----------------------------------------------------------|------------------------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|
|                                                           |                                                            | 150 Lb                                       | 300 Lb                                       | 400 Lb                                       | 600 Lb                                       | 900 Lb <sup>a</sup>                          | 1500 Lb                                      | 2500                                         |
| WELDING NECK<br>SLIP-ON<br>LAP JOINT<br>THREADED<br>BLIND |                                                            | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     |
|                                                           |                                                            | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     |
|                                                           |                                                            | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     |
|                                                           |                                                            | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     | 1 1/2-42                                     |
| BLIND<br>SOCKET TYPE<br>REDUCING<br>ORIFICE               | Threaded or Slip-On<br>Threaded<br>Slip-On<br>Welding Neck | 1 1/2-42<br>1 1/2-42<br>1 1/2-42<br>1 1/2-42 | 1 1/2-42<br>1 1/2-42<br>1 1/2-42<br>1 1/2-42 | 1 1/2-42<br>1 1/2-42<br>1 1/2-42<br>1 1/2-42 | 1 1/2-42<br>1 1/2-42<br>1 1/2-42<br>1 1/2-42 | 1 1/2-42<br>1 1/2-42<br>1 1/2-42<br>1 1/2-42 | 1 1/2-42<br>1 1/2-42<br>1 1/2-42<br>1 1/2-42 | 1 1/2-42<br>1 1/2-42<br>1 1/2-42<br>1 1/2-42 |

\* Dimensions on sizes thru 2 1/2 inch (except Orifice Flanges) same as for 600 lb. range.

\* Dimensions on sizes thru 2 1/2 inch (except Orifice Flanges) same as for 1500 lb. range.

"TUBE-TURN" and "tt" Reg. U. S. Pat. Off.



## Floats

### Arthur Harris & Co.

210-218 N. Aberdeen Street

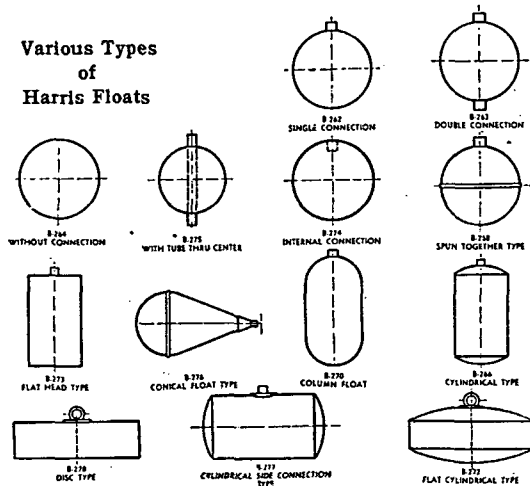
Chicago 7, Ill.

Engineers—Metal Float Manufacturers

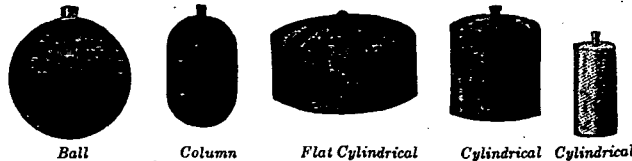
Floats Fabricated of Aluminum, Brass, Copper, Admiralty, Everdur, Monel, Nickel, Inconel, Stainless Steel, Type 304, Type 316, etc., Steel and other Workable Metals

Floats can be plated with copper, nickel, chrome, zinc, tinned, or lead coated. Special connections can be furnished where required. B-262 ball floats are provided with standard female pipe spuds—unless special connections are ordered. Stainless steel, steel, nickel and monel floats, are suitable for high pressure and high temperature. Where corrosion is a factor, our catalog should be consulted so that floats of suitable material can be furnished. Open tank floats can be loaded with sand, lead or steel to bring them to a desired weight. Aluminum floats are vulnerable to corrosion by many solutions, but also give satisfactory results when properly used.

#### Various Types of Harris Floats



#### Metal Floats



Seamless copper ball floats carried in stock in diameters of 3 in., 4 in., 5 in., 6 in., 7 in., 8 in., 10 in., and 12 in. for open tank. . . . 25 lb, 50 lb, 100 lb, and 150 lb working pressure. Copper floats of special sizes and for special pressures made to order.

Stainless steel ball floats 2½ in. to 12 in. diameter for high pressure and corrosion carried in stock. Special stainless steel floats made to order.—Copper Ball floats of 12 in. and to 18 in. diameter, and stainless steel floats over 12 in. to 14 in. diameter made to order. Consult our Engineering Department when you have float problems. Catalog on request.

Copper plated—brazed joint—steel ball and special floats for high and low pressure. Ask for Special Bulletin on these steel base floats.

## Heating Systems • Baseboard Radiation Boiler Burner Units

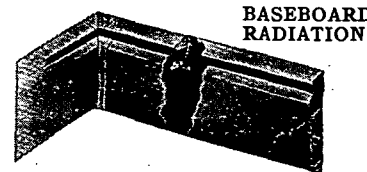
### General Automatic Products Corporation

2300 Sinclair Lane Baltimore 13, Md.

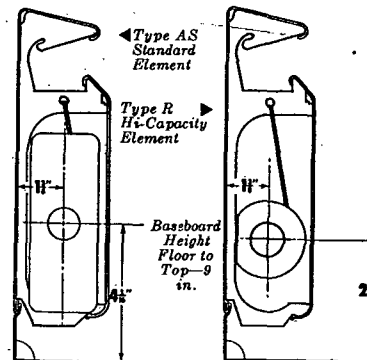


Manufacturers of a Complete Line of Gas and Oil Heating Equipment and Summer Air Conditioning FLOORLEVEL BASEBOARD RADIATION

#### "FLOORLEVEL®" Hot Water



#### TWO TYPES FOR EASY INSTALLATION



| Specifications I-B-R Ratings Water Temp. | Capacity (per lin. ft) STANDARD | HI-CAP  |
|------------------------------------------|---------------------------------|---------|
| 200°                                     | 610 Btu                         | 750 Btu |
| 190°                                     | 550 Btu                         | 680 Btu |
| 180°                                     | 490 Btu                         | 600 Btu |

Each package consists of enough material to do the average installation for the amount of square footage required. The packages are sized to fit any installation. Carton No. 1 contains the fin type heating element, assembled with front panel, back panel, etc., in 10-ft lengths, Carton No. 2 contains the front paneling, top moulding and fittings, and Carton No. 3 contains the panel and moulding. Elements are interchangeable, without adjustment to enclosure or other parts.

Note: Rating at water flow rate of 3,000 lb/hr. The above hot water ratings were based on an active length of 8 ft 9 in. with total length of 10 ft.

#### DUAL DE-AIRATOR TANK



A complete unit with feed and relief valve, for positive elimination of air in hot water heating systems; also acts as an expansion tank. Three sizes to 1500 sq ft.

#### SERIES "L" GAS FIRED BOILER BURNER UNITS



Available for natural, manufactured, mixed or LP gas. All units only 30" high, completely assembled. Controls available to meet all local code requirements. SPECIFICATIONS:

| Model       | Btu Input         | Btu Output        | A.G.A. Ratings Sq Ft Output |
|-------------|-------------------|-------------------|-----------------------------|
| L-4 to L-10 | 72,000 to 180,000 | 57,600 to 144,000 | 384 to 960                  |



#### OIL FIRED BOILER BURNER UNITS



"WA" is pre-wired and pre-assembled, complete with Burner, 3 controls and circulator. Available in 2 sizes:

| Model No. | Boiler Ratings Capacity EDR Hot Water Sq Ft |
|-----------|---------------------------------------------|
| WA-85     | 500                                         |
| WA-100    | 650                                         |

Series "T" Steel water-tube Boiler-Burner unit, constructed to ASME Code. Available in following sizes and ratings:

| Model No.    | Boiler Ratings EDR Hot Water Sq Ft | Steam Sq Ft |
|--------------|------------------------------------|-------------|
| T-16 to T-30 | 580 to 1980                        | 326 to 1100 |

Also manufacturers of a complete line of summer and winter air conditioning equipment.

# KRITZER RADIANT COILS, INC.

**"IF IT'S KRITZER, IT'S RIGHT SIR"**

**2909A LAWRENCE AVENUE**

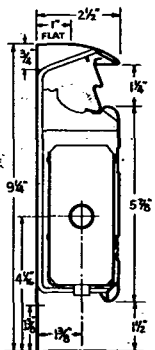
**CHICAGO 25, ILLINOIS**

**"K" LINE Radiant Baseboard for  
RESIDENTIAL, COMMERCIAL,  
INDUSTRIAL and INSTITU-  
TIONAL HEATING**

Quick and easy to install with such KRITZER features (at no extra cost) as Coil Support Bracket, Coil Shoe, Manual Damper, and Optional Knob Control. Capacities shown below are representative of the wide selection available with KRITZER Radiant Baseboard.

Capacities per linear foot. Air at 65F

| Element | Cover  | 1 psi STEAM       |                 | 200F          |
|---------|--------|-------------------|-----------------|---------------|
| Symbol  | Symbol | Sq Ft per Lin. Ft | Btu per Lin. Ft | Water (1 gpm) |
| 275-40A | K-1    | 3.50              | 840             | 645           |
| 21-40A  | KU-1   | 4.40              | 1055            | 820           |
| 21-40   | KU-1   | 3.90              | 935             | 720           |
| SBC-40  | KS-1   | —                 | —               | 780           |



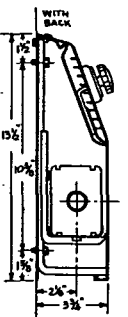
Get BULLETIN 800  
for complete  
information

**STB Radiant Baseboard for  
SCHOOLS, HOSPITALS, OFFICE  
BUILDINGS, INSTITUTIONS,  
and FACTORIES**

**Sturdy. Lifetime of efficient service. Has such KRITZER features (at no extra cost) as Adjustable Coil Support Bracket, Coil Shoe, and Patented Damper and Control. Capacities shown below are but a few of the wide selection available with KRITZER Radiant Baseboard.**

Capacities per linear foot. Air at 65F

| Element  | Cover  | 1 psi STEAM       |                 | 200F          |
|----------|--------|-------------------|-----------------|---------------|
| Symbol   | Symbol | Sq Ft per Lin. Ft | Btu per Lin. Ft | Water (2 gpm) |
| 31-40    | STB3-1 | 5.1               | 1225            | 970           |
| 4125-40  | STB4-1 | 6.7               | 1610            | 1220          |
| 42-40    | STB4-1 | 6.3               | 1510            | 1090          |
| 4125-40A | STB4-1 | 7.9               | 1895            | 1445          |



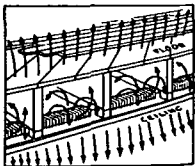
4" minimum height  
from floor.

Write for complete  
information.

## KRITZER Radiant Panel Heating

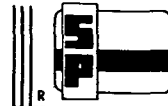
**SEE YOUR  
JOBBER FOR  
KRITZER  
PRODUCTS**

Simple, efficient, and economical method of Radiant Panel Heating. KRITZER coils are positioned between joists slightly back of plaster line. They touch no part of the building, are not imbedded in any building material. Heating Contractor can install complete job without special cooperation from other contractors. Air between joists is heated which in turn heats floor and/or ceiling surfaces. For complete information on installation and advantages, send for *Bulletin 155*.



## Shaw-Perkins Manufacturing Company

manufacturers of convector radiators  
 delivering

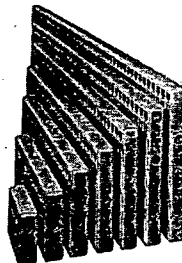


201 East Carson St.

## AIR-e-ATED RADIANT HEAT

Pittsburgh 19, Pa.

## Shaw Panel Radiators



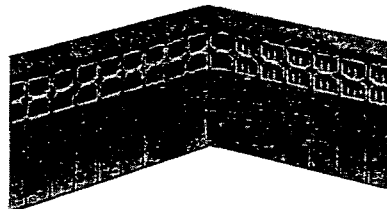
### Shaw Panel Radiators

**WIDTH:** 3 in. thin. **6 HEIGHTS:** 11 in., 14 in., 17 in., 20 in., 23 in., 26 in. **51 LENGTHS:** 11 in. to 111 in. incl. in 2 in. increments. **TAPPING:**  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in., or 1 in.—same end or opposite end. **RATING:** 3.9 to 480.7 sq ft EDR. **GRILLE:** front or top air outlet. **INSTALLATION:** wall hung, free standing, open or closed recess. **APPLICATION:** hot water, steam to 150 psi or mixed systems. End panels, air chambers, wall brackets available for any application.

All Shaw Radiators convert the heat furnished by the steam or hot-water into an exact engineered ratio of warm circulating air and mild radiant heat rays which creates an "ideal heat environment" in each room. It is known as **AIR-e-ATED RADIANT HEAT.**

## Shaw Panel Baseboard Radiators

**WIDTH:** 3 in. thin. **HEIGHT:** 8 in. **LENGTHS:** 2 ft 5 in. to 72 ft 7 in. with opposite end tapping; 2 ft 3 in. to 36 ft 7 in. with same end tapping. **TAPPING:** Supply and return on same end or opposite end. **RATING:** 6.0 sq ft EDR per lineal foot. **GRILLE:** Front air outlet. **INSTALLATIONS:** Wall hung and corner radiators; end panels available. **AIR CHAMBERS:** Factory installed for hot water systems. **APPLICATION:** Hot water or steam systems, up to 15 psi.



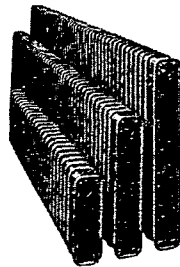
### Shaw Baseboard Radiators

Shaw Panel Baseboard Radiators are factory assembled one-piece-bonded units, each unit individually packaged complete with fittings to assure simplified, quick installation.

## PERKINS AIRadiators

**WIDTH:** 5 in. thin. **3 HEIGHTS:** 14½ in., 23½ in., 45 in. **LENGTHS:** 15 in. to 125 in. inclusive in 2½ in. increments. **PIPING:** 1 in. tapping, can be bushed to ½ in. or ¾ in. as specified. **RATINGS:** 14 to 474 sq ft EDR. **TAPPINGS:** supply and return on opposite ends—radiator reversible. **AIR CHAMBERS:** factory installed for hot water systems. **INSTALLATION:** wall hung, free standing, ceiling mounted. **APPLICATION:** hot water, low or high pressure steam systems to 150 psi.

Factory assembled, sturdy, heavy duty, industrial heating unit ready to connect to new or existing piping. Used on low or high pressure steam or forced circulation hot water systems. Constructed of 1 in. copper tubing and full-height steel plates.



Perkins AIRadiators

**Represented in principal cities. Send for catalog.**

## National Clay Pipe Manufacturers, Inc.

1820 "N" St., N. W., Washington 6, D. C.

311 HIGH LONG BLDG., 5 E. LONG ST., COLUMBUS 15, OHIO  
703 NINTH & HILL BLDG., LOS ANGELES 15, CALIF.  
100 N. LA SALLE ST., RM. 2100, CHICAGO 12, ILL.  
206 CONNALLY BLDG., ATLANTA, GA.



### CLAY PIPE HEATING, VENTILATING, AND AIR CONDITIONING DUCTS

Information contained here includes the basic data needed by engineers, architects, builders, and heating contractors to evaluate and install low-cost Vitrified Clay Heating Ducts in basementless slab-floor homes and other structures. This new development has become so popular that many requests for authoritative information have followed the publication of articles about the new system in the trade press. There are three major reasons for its popularity:

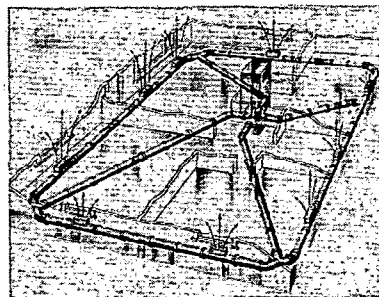
**ECONOMY**—The complete Clay Pipe installation is economical and efficient. It combines the advantages of radiant heat and controlled warm-air circulation at greatly reduced costs.

**SERVICE**—Clay Pipe actually outlasts the foundation slab. It is chemically inert and cannot be eaten away by lime in the concrete. It does not rust, corrode, or disintegrate from moisture and furnace gases. It will not crush or deform as concrete is poured over it.

**INSTALLATION**—Clay Pipe's handy lengths and easy-to-make joints permit fast installation and lower labor costs. A wide variety of fittings is available to solve construction problems with no on-the-job delay, and Clay Pipe cannot "float" as the concrete is poured.

**PERIMETER LOOP SYSTEM**—The data and instructions contained here apply to the Perimeter Loop System, since it is more highly recommended by heating authorities. Its pattern eliminates the "waterfall" of cold air at the outer walls and effectively combats "radiant cold" at the outside edges of the slab. It combines the advantages of forced warm-air heating with heat by radiation through the concrete slab. Heat is concentrated where people are sitting—not at the ceiling. In test installations, the new heating method has cut operating costs from 20 to 30 per cent

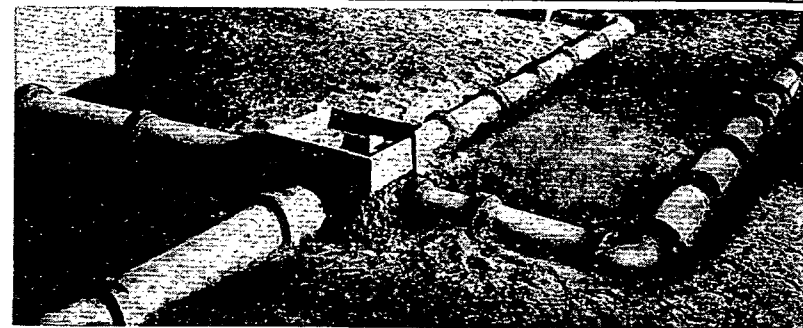
by eliminating high heat-loss at ceilings or attics. Successful research conducted by the *National Warm Air Heating and Air Conditioning Association* has been followed with great interest by the building and heating industries. According to the *Association*, "Warm Air Perimeter Heating is a highly successful method of heating a basementless building. . . . It produces the ultimate of occupancy comfort. It is economical to install; can be designed to use a minimum amount of scarce materials; and requires no unusual skill in its design and installation that the heating contractor cannot supply."



**THIS PERIMETER LOOP DESIGN** is used in structures built upon a concrete slab directly on the ground. Its air distribution system includes a warm air duct that extends completely around the perimeter of the building in a continuous loop. The ducts are buried in the slab 2 to 18 inches from its outside edge, and the tops of the bells will be 1½ inches below the slab surface. Heat is delivered into the rooms by warm air discharged from registers placed in the floor beneath the windows, and by radiant heat from the warm floor surfaces over the embedded ducts. The loop is supplied by feeders extending from a plenum chamber in the slab.

## National Clay Pipe Manufacturers, Inc.

Washington 6, D. C.



Typical Installation of Clay Pipe Heating Ducts

### Heating Ducts

**Advantages**  
It is well known that the greatest heat loss in a well constructed and insulated building—commercial or residential—will be found at the outside walls and glass areas. This loss will usually average 65 per cent of the total structural heat loss. Concrete slab floors will account for approximately 18 per cent of the total heat loss. The rest of the heat will be lost through the ceiling or attic. Perimeter heating introduces the heat along the outside walls and along the glass area. The heat rises and the resulting blanket effect reduces the radiant heat loss from all outer walls and windows. Furthermore, this blanket effect also eliminates air drafts which are caused by the cooling influence of the walls. The heating ducts, embedded in the concrete slab floors, help to maintain the floor surface temperature at desired comfortable levels. It can be seen that perimeter heating accomplishes three important basic functions: first, it replaces the heat that is lost; second, it replaces the heat at the same point where it is lost; and third, it replaces the heat as fast as it is lost.

**Test Results**  
Tests conducted by the *National Warm Air Heating and Air Conditioning Association* at its *University of Illinois Research Center* and in actual installations throughout the country indicate that temperatures in residential structures can be maintained well within the limits established for comfort conditioning. Perimeter heating systems can be designed so that the following temperature coefficients may be maintained:  
(a) Floor surface temperatures can be maintained at 70F plus 2 deg in all usable areas.

- (b) Temperature gradients from floor to sitting level—30 inches above the floor—can be maintained at less than 2 deg.
- (c) Temperature gradients from floor to ceiling level can be maintained at less than 8 deg.
- (d) Temperature variations from outside wall areas to the center of rooms can be maintained at less than 2 deg.
- (e) Temperature variations between rooms can be maintained at less than 3 deg.

### Versatility

Clay pipe heating ducts can also be adapted for ventilation purposes. This is another advantage of the under-slab duct design—the required amount of ventilation air can be circulated through the same distribution ducts used for heating.

### Furnaces

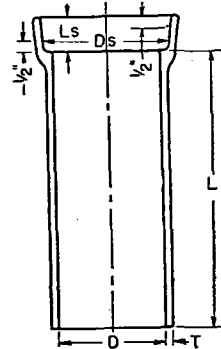
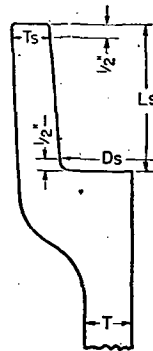
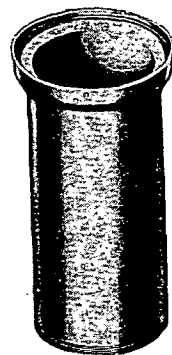
Although a down-flow type of furnace is generally associated with the perimeter warm air heating system when installed in basementless structures, all types of winter air conditioning units can be used. Successful installations have been made using up-flow types of equipment as well as horizontal units. When up-flow furnaces or horizontal suspended units are used, down-comer ducts are used to connect the warm air plenum of the furnace unit with the distribution plenum in the floor. Also, two or more furnaces can be installed—each unit having separate control for its own distribution system so that various sections of the structure can have individual temperature control. However, one unit sized for the entire heat loss can be also installed, using two or more bonnet outlets with automatically controlled dampers in each.

# National Clay Pipe Manufacturers, Inc.

Washington 6, D. C.

## VITRIFIED CLAY PIPE FOR UNDERFLOOR HEATING DUCTS

Conforming to ASTM Specifications C-13



| Size,<br>in.<br>(D) | Laying Length<br>(L) |                                                                | Maximum<br>Difference<br>in<br>Length of Two<br>Opposite<br>Sides,<br>in. | Outside<br>Diameter of<br>Barrel, in. |        | Inside<br>Diameter<br>of<br>Socket<br>at 1/2 in.<br>Above<br>Base, in.<br><br>(Ds) |        | Depth of<br>Socket, in.<br><br>(Ls) |       | Thickness of<br>Barrel, in.<br><br>(T) |        | Thickness<br>of Socket<br>at 1/2 in.<br>from Outer<br>End, in.<br><br>(Ts) |      |
|---------------------|----------------------|----------------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------------|--------|------------------------------------------------------------------------------------|--------|-------------------------------------|-------|----------------------------------------|--------|----------------------------------------------------------------------------|------|
|                     | Nominal,<br>ft       | Limit<br>of Minus<br>Variation,*<br>in. per<br>ft of<br>length |                                                                           |                                       |        |                                                                                    |        |                                     |       |                                        |        |                                                                            |      |
|                     |                      |                                                                |                                                                           | Min.                                  | Max.   | Min.                                                                               | Max.   | Nom-<br>inal                        | Min.  | Nom-<br>inal                           | Min.   | Nom-<br>inal                                                               | Min. |
| 4                   | 2, 2 1/2, 3          | 1/4                                                            | 5/16                                                                      | 4 7/8                                 | 5 3/8  | 5 3/4                                                                              | 6 1/8  | 1 3/4                               | 1 1/2 | 1/2                                    | 7/16   | 7/16                                                                       | 3/8  |
| 6                   | 2, 2 1/2, 3          | 1/4                                                            | 3/8                                                                       | 7 1/16                                | 7 7/16 | 8 3/16                                                                             | 8 5/8  | 2 1/4                               | 2     | 5/8                                    | 9/16   | 1/2                                                                        | 7/16 |
| 8                   | 2, 2 1/2, 3          | 1/4                                                            | 7/16                                                                      | 9 1/4                                 | 9 3/4  | 10 1/2                                                                             | 11     | 2 1/2                               | 2 1/4 | 3/4                                    | 1 1/16 | 9/16                                                                       | 1/2  |
| 10                  | 2, 2 1/2, 3          | 1/4                                                            | 7/16                                                                      | 11 1/2                                | 12     | 12 3/4                                                                             | 13 1/4 | 2 5/8                               | 2 3/8 | 7/8                                    | 1 3/16 | 5/8                                                                        | 9/16 |

\* There is no limit for plus variation.

# National Clay Pipe Manufacturers, Inc.

Washington 6, D. C.

### Storage

There are no storage problems, because vitrified clay pipe heating ducts can be exposed to weather in any season.

### Performance in Use

Clay pipe ducts have such advantages as permanence, resistance to shock loads, and resistance to corrosion from lime in the concrete. They create no odor as warm air flows through them during furnace operation. The smooth inner surface eliminates turbulence and minimizes register noise. The clean smooth surface of the Vitrified Clay Duct is free from dust.

### Design Data

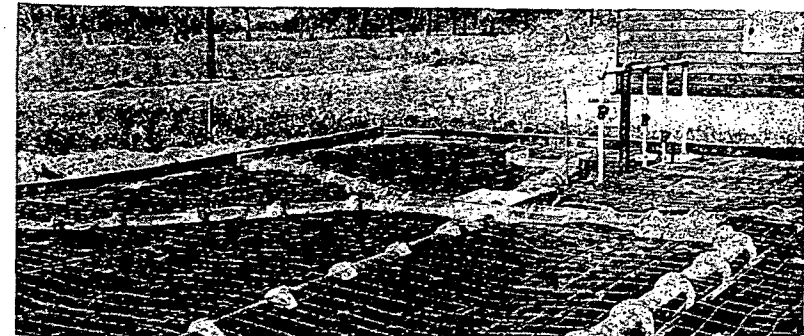
Detailed design recommendations have been prepared by the National Warm Air Heating and Air Conditioning Association and are contained in the new revised edition of *Manual 4* (\$1.50) and *Manual 9* (\$.75), which are available from the association's offices, 145 Public Square, Cleveland 14, Ohio. Manual No. 4 describes warm air perimeter heating systems as applied to structures without basements. Manual No. 9 contains detailed information on design and installation of warm air winter air conditioning systems and all necessary engineering data, tables, and recommendations for selection of the proper heating equipment.

### Case Histories

For data on actual case histories of Clay Pipe heating, ventilating, and air conditioning duct installations in homes, schools, churches, hospitals, factories, gasoline stations, garages, stores, and theaters, write the National Clay Pipe Manufacturers, Inc., 1820 "N" St., N.W., Washington 6, D. C.



Large diameter clay pipe heating duct and plenum connection used in commercial structure. This type of duct, when installed in garages and maintenance or repair shops, can be used for heating, ventilating, air conditioning, and removal of exhaust gases. When the registers are located under the windows, the warm air will blanket the glass area and eliminate frosted and wet windows, sills, and walls.



Clay Pipe Heating Ducts ready for the concrete pouring. Wire mesh may be installed at the contractor's discretion to reinforce the floor slab.

## National Clay Pipe Manufacturers, Inc.

Washington 6, D. C.

### Construction Data

The building site must be well-drained. If the natural ground-slope is not sufficient for good drainage, a simple network of Perforated Clay Pipe should be installed underground. The site should then be levelled and graded. All ground beneath the building should be cleared of organic material. A four to six inch layer of coarse fill is then laid—washed gravel, crushed rock, or stone that has been passed over a coarse screen. Cinders or fine sand should never be used for the fill.

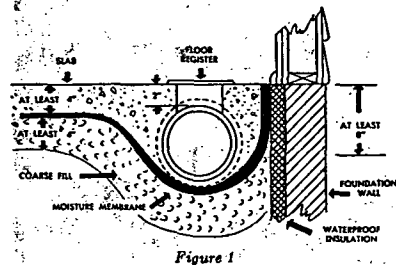


Figure 1

The fill must be covered with a moisture barrier before the slab is poured. This membrane should be the equivalent of a good grade of roll roofing at least 55 lb per 108 sq ft. Strips should be overlapped at least four inches and tarred. The barrier must completely cover the area within the foundation walls and extend up the walls to the top of the slab. See Figure 1.

Edge insulation must be placed completely around the concrete slab. Two-inch thick insulation is recommended, but one-inch is acceptable.

It is not necessary to anchor the Clay Pipe ducts to stakes, or to surround them completely with concrete (as with lighter materials). The Clay Pipe is laid directly upon the membrane, and gravel or sand is used to level it. Small depressions should be made in the sand or gravel so the pipe bells "hang free." This facilitates proper pipe alignment and prevents buckling at the joints. See Figure 2.

Registers must be located before the slab is poured. Wooden forms like those shown in Figure 3 are secured to the pipe by a wire wrapped around the duct.

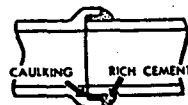
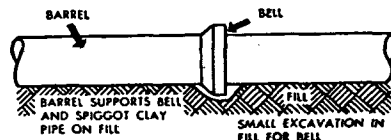


Figure 3

After the slab has hardened, the form can be removed and an opening cut into the pipe with a heavy hammer or bar. Some contractors prefer to retain the wooden register forms in the slab for register mounting frames.

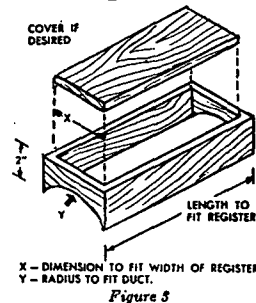


Figure 4

The Clay Pipe bell at the plenum should be butted firmly against the wooden forms of the plenum pit and the concrete poured around it. See Figure 4. The pit floor is poured after the wooden form is removed. The moisture membrane must extend under the pit floor. Recommended distance from the slab floor to the top of the pipe bell is five inches.

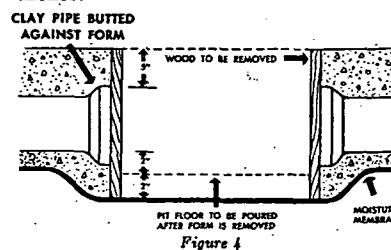


Figure 5

## National Clay Pipe Manufacturers, Inc.

Washington 6, D. C.

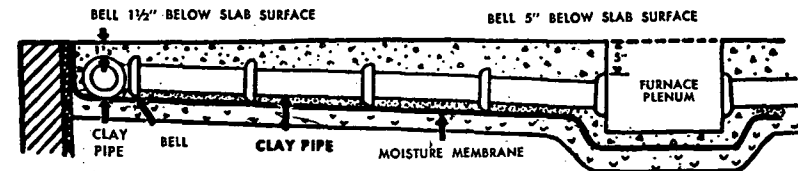
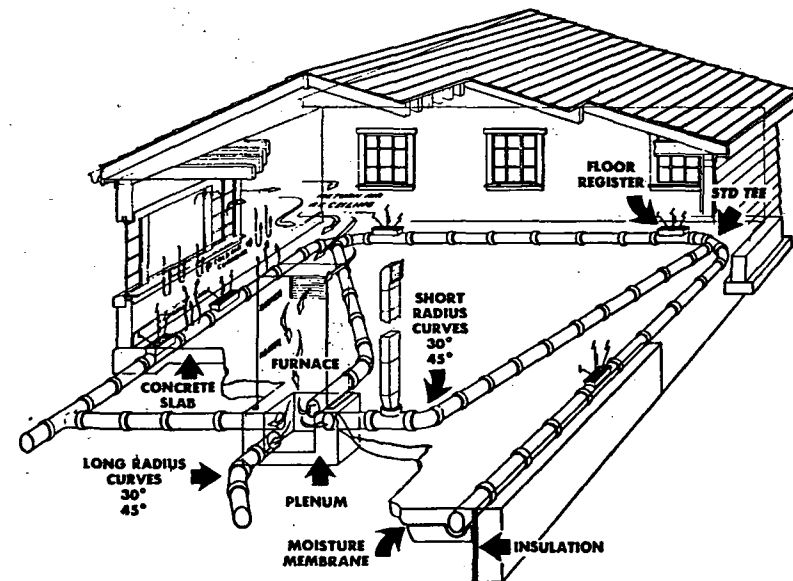


Figure 6

Clay Pipe in the Perimeter Loop should be installed so that the top of the bell closest to the perimeter will be 1½ inches below the slab surface. Feeder ducts should slope downward toward the plenum, so that the top of the bell next to the plenum will be five inches below the floor slab surface. See Figure 5. All Clay Pipe joints must be waterproof.

Care must be taken when the slab is poured not to puncture the moisture barrier or dislodge the ducts. Wheelbarrows should not be moved over the ducts without suitable planking. A strip of mesh should be placed over the top of the ducts to give added strength to the slab. Mesh may be extended over the entire slab at the contractor's discretion.



OTHER STANDARD FITTINGS—ELBOWS  
—REDUCERS—DOUBLE TEES AND WYES

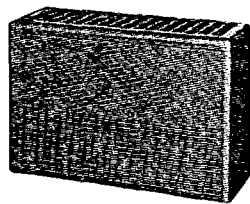
## Airtherm Manufacturing Company

728 S. Spring Ave.

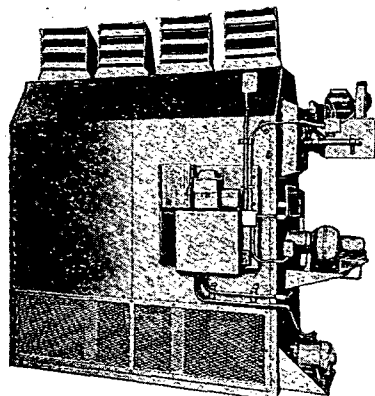
St. Louis 10, Mo.

Representatives in Principal Cities

For Heating Satisfaction—Think first of AIRTHERM

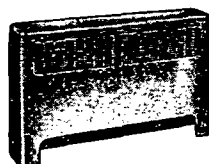


**AIRTHERM Cabinet Unit Heater**  
Combines 22 industry approved, performance proved features that guarantee maximum efficiency.



**AIRTHERM Gas or Oil Fired Space Heaters**

A complete heating, and heating and ventilating unit. Equipped with motors, burner and all safety and operating controls. Easy to install and operate. Heavy duty stainless steel combustion chamber. Capacities from 400,000 to 2,000,000 Btu per hour. Write for *Catalog 804*.



**AIRTHERM Convectors**

Airtherm Convectors are designed for easy installation and outstanding per-

formance. Copper coil for all hot water and two pipe steam systems. Produced in full range of types and sizes. Write for *Catalog 703*.



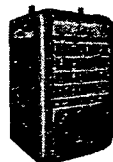
Vertical



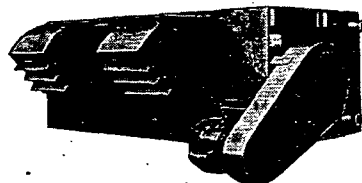
Horizontal

### AIRTHERM Steam Unit Heaters, Horizontal and Vertical Discharge

Horizontal models are produced in capacities from 18,000 to 270,000 Btu. Vertical models 32,000 to 350,000 Btu per hour. Write for *Catalog 1209 A*.



**AIRTHERM Gas Fired Unit Heaters**  
Efficient answer to heating needs where there is no steam supply. Compact, suspended, propeller fan units available from 25,000 Btu to 200,000 Btu. Write for *Catalog 500*.



**AIRTHERM Centrifugal Fan Unit Heaters**

For all types of heating, and heating and ventilating installations, in industrial and commercial buildings, auditoriums, gymnasiums, schools. Available with dampers, filters and non-freeze coils. Capacities up to 1,440,000 Btu per hour. Write for *Catalog 403*.

## AMERICAN-Standard

Plumbing & Heating Division

American Radiator & Standard Sanitary Corporation,

New York 18, N. Y.



**1. EMPIRE BOILER** For all types of gas. Made in a complete range of sizes for smaller homes and buildings with or without basements. Approved by *American Gas Association*. *I-B-R Ratings*: Steam—165 to 275 sq ft, Water—160 to 1,055 sq ft net installed radiation.

**2. G-4 BOILER** For all types of gas. For larger homes and small commercial establishments. Approved by *American Gas Association*. *I-B-R Ratings*: Steam—395 to 1390 sq ft, Water—725 to 2400 sq ft installed radiation.

**3. G-6 BOILER** For all types of gas. Designed for medium to very large buildings. Approved by *American Gas Association*. *I-B-R Ratings*: Steam—1520 to 13450 sq ft, Water—2615 to 21520 sq ft installed radiation.

**4. ARCOLINER PACKAGED OIL-FIRED HEATING UNIT.** Compact unit for small to medium sized homes. Wet base construction ideal for homes with or without basements. *I-B-R Ratings*: Steam—260 to 520 sq ft, Water—485 to 940 sq ft installed radiation.

**5. OAKMONT BOILER** Exclusively for oil firing. Also available as complete oil heating unit with Arcoflame Burner. *I-B-R Ratings*: Steam—390 to 810 sq ft, Water—715 to 1440 sq ft installed radiation.

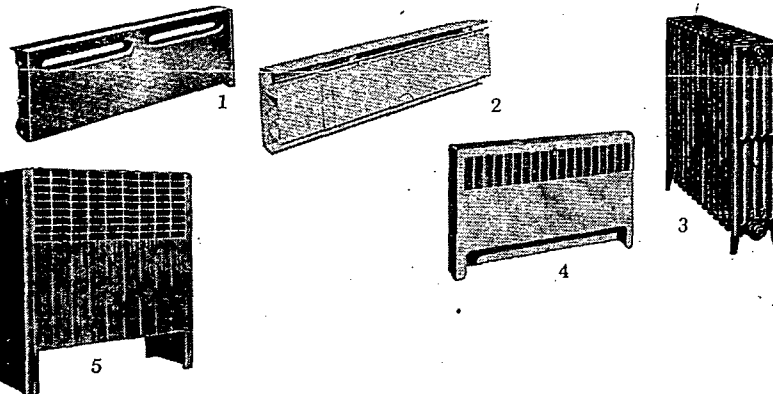
**6. EXBROOK BOILER** For oil or stoker. Sized for larger homes and buildings. Available with Arcoflame Burner as oil heating unit. *I-B-R Ratings*: Steam—775 to 1830 sq ft, Water—1380 to 3100 sq ft installed radiation.

**7. SEVERN BOILER** For all fuels. Efficient boiler with advanced features for convenience and economy. Available with Arcoflame Burner as oil heating unit. *Ratings*: Steam—400 to 780 sq ft, Water—730 to 1390 sq ft installed radiation.

**8. REDFLASH BOILER** For all fuels. Economical heat for any size or type of building. Attractive jacket, fully insulated. *Ratings*: Steam—770 to 9900 sq ft, Water—1230 to 15,840 sq ft installed radiation.

**9. WATER TUBE BOILERS** For oil or stoker. For medium to large buildings. *Ratings*: Steam—930 to 4600 sq ft, Water 1640 to 7360 sq ft installed radiation.





1. **RADIANTRIM PANELS** Replace ordinary baseboards. Cast iron panels provide all the advantages of both convected and radiant heat. For forced hot water or two pipe steam. Sheet metal accessories also available for complete installation.

2. **HEATRIM PANELS** Non-ferrous panels provide convected heat with forced circulation hot water systems only. Adaptable to mainless or series loop installations. Available in 4, 6 and 8-ft lengths. Two models: Model 75-A Standard, Model 75-B High Capacity.

3. **ARCO RADIATORS**—Highly efficient, slim tube radiators. Available in four widths—3, 4, 5 and 6 tubes—and four heights—19, 22, 25 and 32 in.

4. **CONVECTORS** With cast iron (Arco) or non-ferrous (Multifin) heating elements. Styles and sizes for every need. Special designs for hospitals, institutions, etc. Multifin Type K (shown) available in 63 packaged stock sizes.

5. **SUNRAD RADIATORS** Recessed or free-standing. Need no enclosure. Two sizes: 5 in. deep x 20 in. high and 7½ in. x 23 in. Inlet grilles if desired.

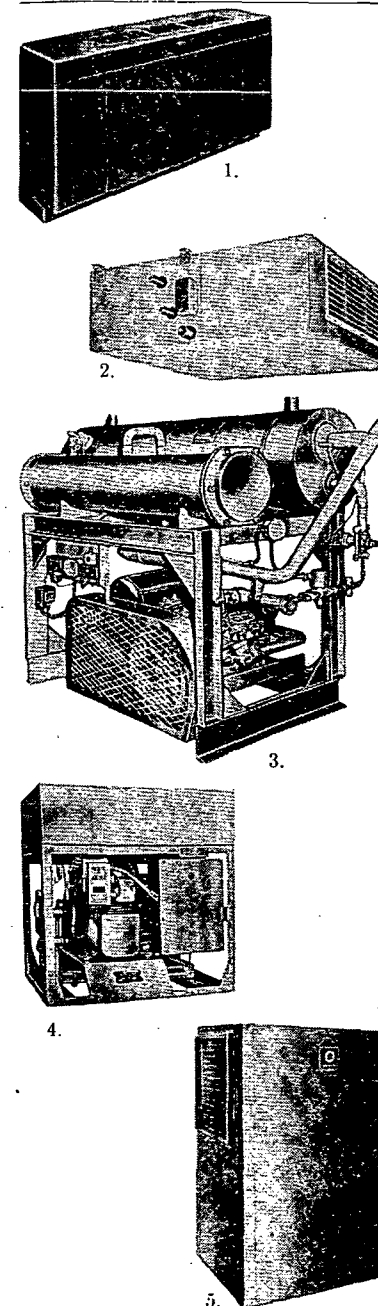
6. **AMERICAN STANDARD WATER HEATER**—Approved by A.G.A. Heats water automatically, stores it for instant use. White enameled jacket, gray trim. Thrifty and dependable. Three sizes—20, 30 and 40 gal.

7. **NEW STANFLAME CONVERSION BURNER** Gas fired. Vertical, upshot-type burner for boiler, furnace, or winter air conditioner. Fits round or square combustion chamber. Runner pilot igniter. Burns all gases. A.G.A. inputs of 60,000 to 325,000 Btu per hour.

8. **ARCOFLAME OIL BURNER**—Listed by Underwriters' Laboratories, Inc. Complies with Commercial Standard CS-75. Special flange types for oil heating units. Pedestal types for conversion. Capacities from 0.70 to 7 gal per hour.

9. **TEMTRIM**—Finned tube radiation for schools, hospitals, factories, offices, churches, theaters and similar buildings. For forced hot water and two-pipe steam installations. Available in two sizes: 1½ in. tube with 3¼ in. x 3¼ in. fins or 4¼ in. x 4¼ in. fins, and 2 in. tube with 4¼ in. x 4¼ in. fins; 3¼ in. size fins are spaced 24 and 34 fins per lineal foot; 4¼ in. fins are spaced 28 and 36 fins per foot. Three attractive covers in three tier heights—expanded metal grille, flat top cover, and sloping top enclosure. Heating element fabricated in lengths of 2 to 12 ft in 1-ft increments. Covers and enclosures are available in lengths of 1- to 6-ft in 1-ft increments. I-B-R approved.

**DETROIT HEATING CONTROLS AND ACCESSORIES**—A complete line of heating controls and accessories for all types of systems.



1. **VERTICAL REMOTAIRE ROOM CONDITIONER**—A remote type unit providing year-round air conditioning for central-plant, multi-room installations such as office buildings, apartments, hotels, schools, hospitals, motels and residences. Features individual room control. Available in 200, 300, 400, and 600 cfm sizes for free standing, partially recessed and fully recessed applications. Uses hot water for heating, chilled water for cooling, both supplied by remotely located water chiller and boiler and using the same piping system. Units are listed by Underwriters' Laboratories, Inc.

2. **HORIZONTAL REMOTAIRE ROOM CONDITIONER**—Similar in operation to Vertical Remotaire. Installed overhead either exposed or concealed in a closet, drop ceiling or furred space. Available in four sizes—200, 300, 400 and 600 cfm—and three models to meet every architectural requirement.

3. **PACKAGED WATER CHILLER—MODEL ACS**—Central chilled water source for medium and large air conditioning systems. Complete, packaged units; sizes 7.5, 10, 15, 20, 25, 30, 40, 50, 60 and 75 hp. Assembly consists of refrigerant compressor, compressor motor, evaporator, condenser, heat exchangers, controls, piping and framework. Units tested and given a holding charge of refrigerant prior to shipment.

4. **PACKAGED WATER CHILLER—WATER COOLED—MODEL PAS**—Central chilled water source for residential and small commercial air conditioning systems. Hermetically sealed. Available in 2 and 3 hp sizes. Assembly consists of steel framework enclosing a motor-compressor assembly, condenser and evaporator with connecting tubing, complete with operating charge of Freon-22 and all auxiliary components.

5. **PACKAGED WATER CHILLER—AIR COOLED—MODEL PAS-AC**—Completely factory-assembled 2 and 3 hp water chillers with air-cooled condenser. For residential and small commercial systems in areas where water is scarce. Has a permanently lubricated and hermetically sealed motor-compressor unit containing a 5-year warranty.



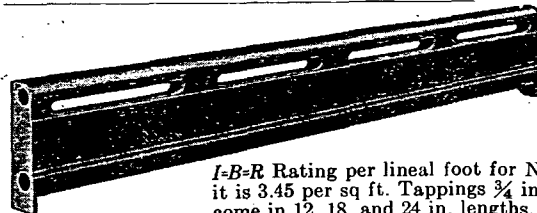


# Burnham Corporation

BOILERS and RADIATORS

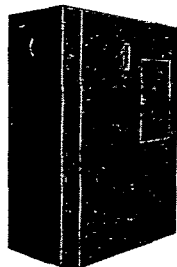
Irvington-on-Hudson, N. Y.

There's a Burnham for Every Purpose—Write for Descriptive Catalogs

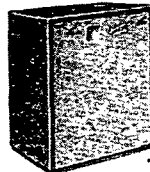


**Burnham BASE-RAY®**  
Radiant Baseboard  
— Two Sizes, No. 7  
and No. 9 (Cast Iron)

*I-B-R* Rating per lineal foot for No. 7 is 2.35 and for No. 9 it is 3.45 per sq ft. Tappings  $\frac{3}{4}$  in. top and bottom. Sections come in 12, 18, and 24 in. lengths. New matching sheet metal baseboard extensions and accessories available.



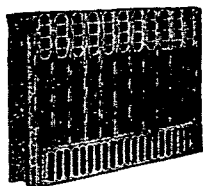
**PACEMAKER®** Boiler for oil firing. *I-B-R* Ratings 270 to 710 sq ft for Steam and 490 to 1270 for Water. A cast-iron vertical flue boiler. Can be equipped with tankless or storage type domestic hot water coils.



**New HOLIDAY** Cast-Iron Gas Boiler A.G.A. approved for manufactured, natural, mixed or LP Gases and *I-B-R* approved and rated for water from 300 to 1100 sq ft; for steam 160 to 610 sq ft supplied with or without domestic hot water.



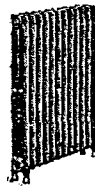
**PACE-PAK®** Boilers—*I-B-R* Net 565 sq ft and 810 sq ft for Water. Design same as PACEMAKER. Delivered in one crate ready for installation with all controls and wiring factory installed for assured performance.



Radiant



**YELLOW-JACKET** Boiler (shown with extended Jacket). All fuel, convertible. *I-B-R* Ratings 305 to 935 sq ft for Steam and 490 to 1600 sq ft for Water.



Slenderized

**BURNHAM RADIANT RADIATORS**—Two heights 20 and 23 in. Ratings 2.25 sq ft per section and 3.40 sq ft per section respectively.

**BURNHAM SLENDERIZED RADIATORS**—Three to six tubes in four heights 19 in. to 32 in. Ratings are from 1.6 sq ft per section to 3.7 sq ft per section.



# Burnham Corporation

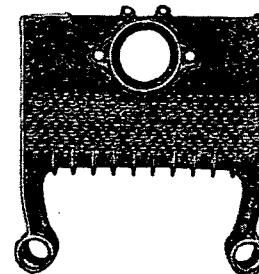
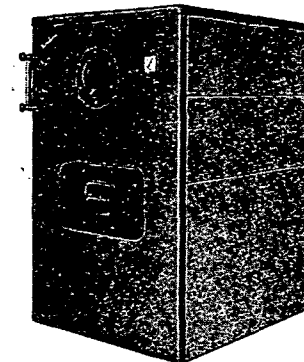
BOILERS and RADIATORS

Irvington-on-Hudson, N. Y.

There's a Burnham for Every Purpose—Write for Descriptive Catalogs

## PACE-KING® BOILER

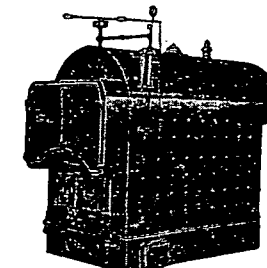
A new Burnham Series, exclusively oil fired, for apartment houses, schools, hospitals, commercial installations, etc. Its vertical flue design is engineered similar to PACEMAKER and PACE-PAK... low internal draft loss... lower stack temperatures... lower chimney design... no baffles used. Provided with tankless hot water heaters with capacities from 6 to 10 gpm. Available in 14 models with *I-B-R* ratings from 1100 to 4500 for Steam and 1925 to 7200 for Water. Built for safety and dependability according to the ASME Construction Code and the *I-B-R* Rating and Testing Code.



**PACE-KING SECTIONS** are designed with hundreds of efficient fins for fast heat exchange and fuel economy. Can easily be passed through existing doorways. Sections are reversible... this feature also allows wider choice of location since outlet connections and clean out panels can be placed on either side. Boiler can be fired from front or rear. Long water legs provide plenty of room for combustion.



No. 1, 2, 3 and 36 in. Series and 50 in. Twin Series—Famous Burnham 3-times-back-and-forth fire travel; for all fuels. 230 to 14,600 sq ft for Steam; 370 to 23,360 sq ft for Water.



**Welded Steel Boiler**—Compact type—Capacities from 2500 to 35,000 sq ft for Steam and 4800 to 56,000 sq ft for Water. Furnished for coal, oil or stoker firing. SBI Rated.

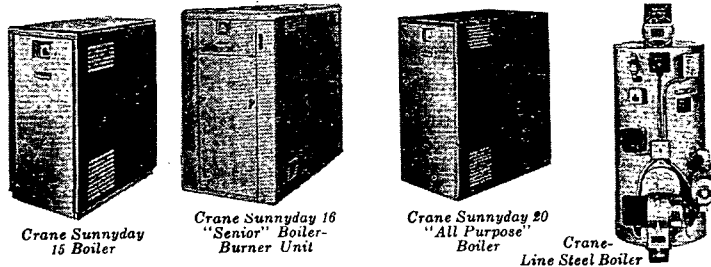
## Crane Co.



BOILERS, BASEBOARD, RADIATORS, FURNACES, AIR CON-  
DITIONERS, VALVES, FITTINGS, PIPE, WATER AND STEAM  
SPECIALTIES, CONTROLS AND PLUMBING MATERIALS

General Offices: 836 South Michigan Avenue, Chicago 5, Illinois  
Nationwide Service Through Branches, Wholesalers, Plumbing and Heating Contractors

**CRANE—A SINGLE SOURCE FOR EVERYTHING IN HOME HEATING**



Crane Sunnyday  
15 Boiler

Crane Sunnyday 16  
"Senior" Boiler-  
Burner Unit

Crane Sunnyday 20  
"All Purpose"  
Boiler

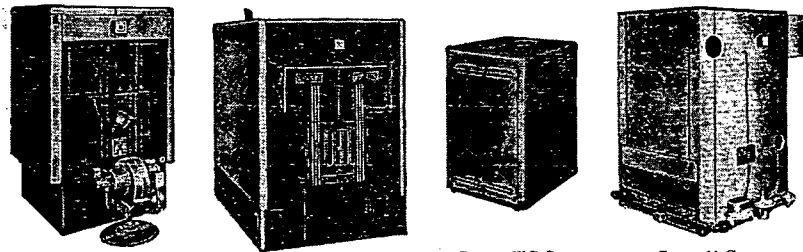
Crane-  
Line Steel Boiler

**CRANE SUNNYDAY 15**—All-new packaged cast iron boiler saves up to 15 percent on fuel. Nine firetube flues give greater heating surface in 20 per cent less space. Water, oil-fired, net  $I=B=R$  rating from 67,000 to 156,000 Btu.

**CRANE SUNNYDAY 16 "SENIOR"**—A packaged cast iron boiler for steam or hot water, designed for maximum efficiency with oil. Patented Sustained Heat Principle assures fuel economy. Water, net  $I=B=R$  rating from 126,000 to 239,000 Btu.

**CRANE SUNNYDAY 20 "ALL PURPOSE"**—Cast iron, completely packaged, all-fuel boiler for home or small commercial systems. Design improvements increase boiler efficiency. Water, oil fired, net  $I=B=R$  rating from 101,000 to 245,000 Btu.

**CRANE-LINE STEEL BOILER**—A complete line of new, assembled and wired, low-cost boilers. Accessory equipment and rectangular steel jacket available. Oil or gas. Four sizes. Oil fired, net  $SB$  rating 66,000 to 168,000 Btu per hour.



Crane 30 Boiler  
with Oil Burner

Crane 41 Boiler

Crane 2WG Gas  
Fired Boiler

Crane 60 Gas  
Fired Boiler

**CRANE 30**—Ideal medium-size cast iron boiler for larger homes, small commercial buildings. Easy-to-handle sections speed assembly. Water, oil fired, net  $I=B=R$  rating 201,000 to 736,000 Btu.

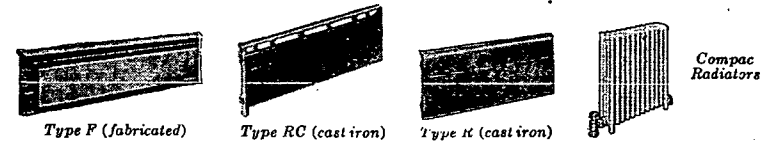
**CRANE 41**—New all-fuel boiler for institutions and other large buildings. Precision ground cast iron sections easy to assemble. Water, oil fired, net  $I=B=R$  rating 622,000 to 1,440,000 Btu.

**CRANE 2WG**—A completely assembled cast iron gas boiler only 33 inches high. Patented "staggered heat travel" fins set up unusual scrubbing action. Water, A.G.A. input 70,000 to 210,000 Btu per hr.

**CRANE 60**—Big new 6-inch gas boiler. Patented "staggered heat" travel surfaces capture all liberated heat. Steam, hot water, or large volume indirect water heating. Net A.G.A. ratings from 625,000 to 5,000,000 Btu input.

**VALVES—FITTINGS**—The complete Crane line of valves and fittings offers all necessary piping items for any heating system.

## Crane Co.



Type P (fabricated)

Type RC (cast iron)

Type R (cast iron)

Compac  
Radiators

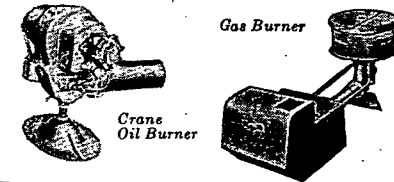
**CRANE RADIANT BASEBOARD** introduces an even distribution of radiant warmth at floor level, leaving entire floor area free from obstruction. If baseboard area is limited, Type R panels may be installed vertically or at ceiling level. Type RC provides radiant and convected heat. Type R provides radiant heat only.

**CRANE COMPAC RADIATORS**—Slender lines give pleasing modern appearance, require minimum space without sacrificing heat output. For free-standing or recessed installation, steam or hot water. Sizes up to 111 sq ft output  $I=B=R$  rated.

**WATER SPECIALTIES**—available to suit every installation—including water heaters, circulators and flow control valves.

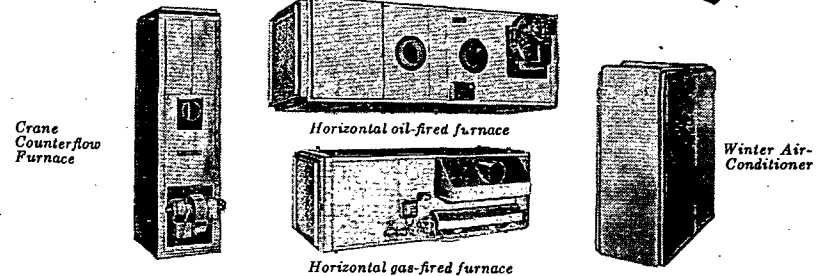
**CRANE OIL BURNERS** are newly engineered to provide automatic heating comfort at low fuel cost with a minimum of maintenance.

**GAS BURNERS** feature "Spreader Flame" principle of construction and operation that eliminates losses due to incomplete combustion or excess air.



Gas Burner

Crane  
Oil Burner



Crane  
Counterflow  
Furnace

Horizontal oil-fired furnace

Horizontal gas-fired furnace

Winter Air-  
Conditioner

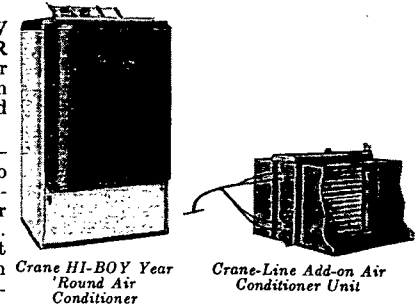
**CRANE-LINE COUNTERFLOW FURNACE** requires as little as  $2\frac{1}{4}$  sq ft of floor space with 1 in. clearance on sides, rear, top. Gas fired: five sizes, 65,000 to 140,000 Btu input. Oil fired: three sizes, 84,000 to 123,000 Btu at Bonnet.

**CRANE-LINE HORIZONTAL FURNACE** can be suspended in crawl space, from basement ceiling, or installed in an attic. Gas fired: two sizes, 65,000 to 85,000 Btu input. Oil fired: four sizes, 84,000 to 224,000 Btu at Bonnet.

**CRANE-LINE BASEMENT OIL-FIRED FURNACE** is a winter air-conditioning unit that heats, filters and provides forced circulation of heated air to all rooms. Gas fired: nine sizes, 70,000 to 250,000 Btu input. Oil fired: seven sizes, 84,000 to 224,000 Btu at Bonnet.

**CRANE HI-BOY AND COUNTERFLOW YEAR 'ROUND AIR CONDITIONER** Available in both water cooled and air cooled models. Two, three, and five-ton cooling capacities, with gas or oil-fired furnace.

**ADD-ON AIR CONDITIONER UNIT**—Converts any warm air heating system to year 'round use. Available in water-cooled models (2, 3 or 5-ton capacity) or air-cooled models (2 or 3-ton capacity). Charged with refrigerant and sealed at the factory, so you need no refrigeration serviceman when you make your installation.



Crane HI-BOY Year  
'Round Air  
Conditioner

Crane-Line Add-on Air  
Conditioner Unit



# National-U.S. Radiator CORPORATION

HEATING AND AIR CONDITIONING DIVISION

General Offices: Johnstown, Pa.

Cast Iron and Steel Boilers • Baseboard • Convectors • Radiators • Fintube  
Unit Heaters • Furnaces • Oil and Gas Burners • Air Conditioning  
Accessories

Nationwide distribution through Branches, Wholesalers, Plumbing and Heating Contractors



## NATIONAL-U. S. ALL-FUELS BOILERS (CAST IRON)

Designed especially to meet the special requirements of automatic firing... rugged cast iron construction. Provided with many features to insure high operating efficiency and maximum fuel economy. Convertible to any fuel or method of firing. Wide range of both storage and tankless water heaters available.

"27" Series... for medium to large size residential installations available in six sizes: Net Steam Ratings from 350 to 880 sq ft, and Net Water Ratings from 560 to 1560 sq ft.

"37" Series... for large residential and small commercial installations... available in nine sizes: Net Steam Ratings from 700 to 2300 sq ft, and Net Water Ratings from 1120 to 3835 sq ft.

"47" Series... for commercial, industrial and institutional installations... available in eight sizes: Net Steam Ratings from 2500 to 6000 sq ft, and Net Water Ratings from 4000 to 9600 sq ft.

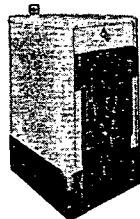
## NATIONAL-U. S. OIL HEATING BOILERS AND UNITS (CAST IRON)

Developed specifically for oil firing... the Oil Heating Units comprise a cast iron boiler, dependable oil burner, pre-cast combustion chamber and high quality controls. Oil Heating Boilers are designed for top performance with any oil burner. A wide range of both storage and tankless water heaters is available with all Units and Boilers.

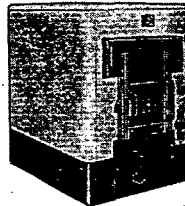
"10" Series... an economical wet base Boiler and Unit for installation in small and medium size residences... available in five sizes: Net Steam Ratings from 230 to 500 sq ft, and Net Water Ratings from 430 to 910 sq ft.

"12W" Series... priced low and styled right for installation in the small to medium size home... wet base design... available in four sizes: Net Water Ratings from 430 to 855 sq ft.

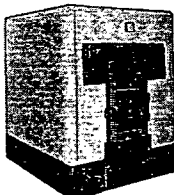
"12" Series... a popular wet base Boiler and Unit for the small to medium size home. Available in four sizes: Net Steam Ratings from 230 to 470 sq ft, and Net Water Ratings from 430 to 855 sq ft.



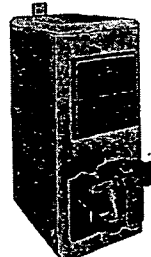
"27" Series



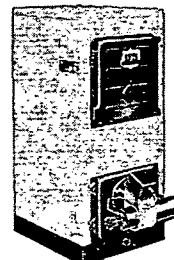
"37" Series



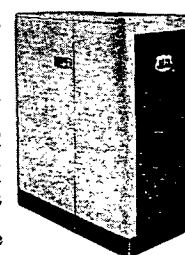
"47" Series



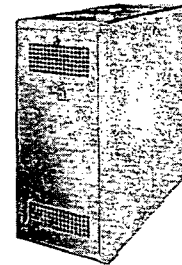
"10" Series



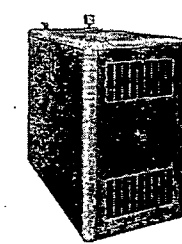
"12W" Series (with Flush Jacket)



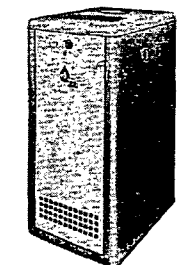
"12" Series (with Enclosing Jacket)



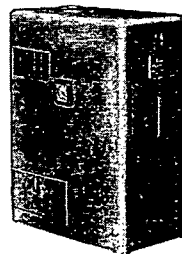
"20" Series



"40" Series



"11B" Series



"22", "33" and "44" Series

"20" Series... a larger wet base Oil Heating Boiler for residential installations... available in four sizes: Net Steam Ratings from 340 to 780 sq ft, and Net Water Ratings from 625 to 1370 sq ft.

"25" Series... a high capacity Oil Heating Boiler... wet base construction for residential, commercial and industrial installations... available in five sizes: Net Steam Ratings from 545 to 1985 sq ft, and Net Water Ratings from 985 to 3355 sq ft.

"37" Series... for large residential and small commercial installations... available in nine sizes: Net Steam Ratings from 700 to 2300 sq ft, and Net Water Ratings from 1255 to 3835 sq ft.

"46" Series... Boiler and Unit of special design for medium to large size residential installations... available in four sizes: Net Steam Ratings from 310 to 700 sq ft, and Net Water Ratings from 570 to 1255 sq ft.

## NATIONAL-U. S. GAS BOILERS

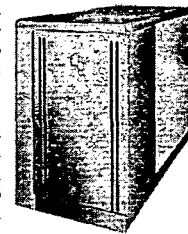
National-U. S. Gas Boilers are modernly styled, compact and designed exclusively for gas firing. Cast iron sections for long life, effective gas travel, dependable controls and many other feature-advantages contribute to efficient and economical operation... A.G.A. approved for all gases.

"11B" Series... a factory-assembled packaged boiler, economically priced... for small to medium size homes... available in seven sizes: Net Water Ratings from 185 to 725 sq ft.

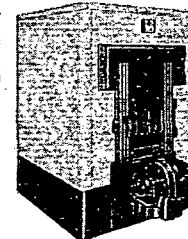
"16B" Series... dependable, efficient gas heating for residential and small commercial installations... can be equipped with water heater... available in twelve sizes: Net Steam Ratings from 295 to 2090 sq ft, and Net Water Ratings from 545 to 3510 sq ft.

"22", "33" and "44" Series... tapering zig-zag flue passages extract maximum heat-save fuel... to meet heating requirements of small residences up to commercial and industrial structures... available in twenty-one sizes: Net Steam Ratings from 110 to 1920 sq ft, and Net Water Ratings from 205 to 3245 sq ft.

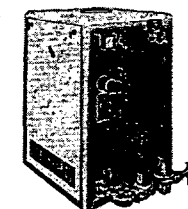
"66" Series... National-U. S. gas heating comfort for larger apartments, stores, hotels, hospitals, schools and other large installations... available in eighteen sizes: Net Steam Ratings from 1770 to 12950 sq ft, and Net Water Ratings from 3005 to 20720 sq ft.



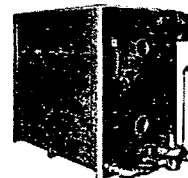
"25" Series



"37" Series



"16B" Series



"66" Series

### NATIONAL-U. S. STEEL BOILERS

National-U. S. Steel Boilers meet all the requirements of the SBI Testing and Rating Code and the ASME Boiler Construction Code. All are inspected and approved at the factory by a representative of a boiler insurance company.

17 and 24 in. Series . . . available as a Boiler or as a complete Oil Heating Unit—suited for small and medium size residential installations . . . available in four sizes: Net Steam Ratings from 320 to 700 sq ft, and Net Water Ratings from 580 to 1260 sq ft.

26, 29 and 39 in. Series . . . can be furnished as a Boiler or as a complete Oil Heating Unit for installation in medium residential to small commercial buildings . . . available in nine sizes: Net Steam Ratings from 700 to 3000 sq ft, and Net Water Ratings from 1260 to 5400 sq ft.

41 in. Series . . . a modern automatic heating boiler . . . for firing with oil burner, gas burner or stoker in commercial, institutional and commercial installations . . . available in four sizes: Net Steam Ratings from 3500 to 5000 sq ft, and Net Water Ratings from 6300 to 9000 sq ft.

Commercial Series . . . adaptable to either automatic or hand firing for the very largest installations . . . available in sixteen sizes: Net Steam Ratings from 2500 to 35000 sq ft, and Net Water Ratings from 4000 to 56000 sq ft.

### NATIONAL-U. S. PACKETS

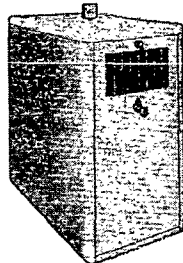
Compact, all-in-one, factory-assembled automatic oil or gas fired home heating Units for small installations. An integral tankless or storage heater provides domestic hot water. Furnished with either flush or enclosing jacket. Net Water Ratings: for gas—460 to 520 sq ft, for oil—495 to 580 sq ft.

The Packet, combined with National-U. S. Baseboard, provides a modern, low-cost, easy-to-install forced hot water heating system for homes, motels, diners and stores.

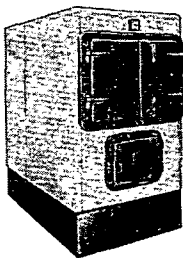
### NATIONAL-U. S. CONVERTORS

Art Convertor . . . a non-ferrous convertor for flush and semi or full-recessed installations. Aluminum fins bonded to copper tubing comprise the heating element. Enclosures are made in a variety of types for residential or commercial installations.

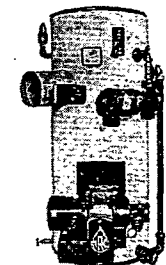
Aero Convertor . . . heating element is made of cast iron with fins cast integral with tubes. Adaptable to any type of hot water or steam heating system. Numerous types of enclosures can be furnished for residential or commercial installations.



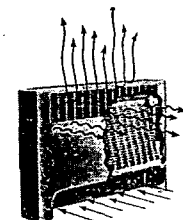
17 and 24 in. Series



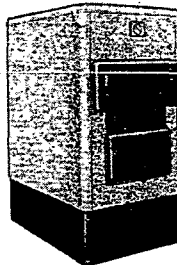
41 in. Series



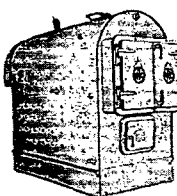
Model U Packet (with Flush Jacket)



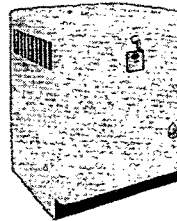
Aero Convertor



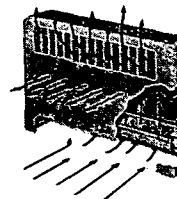
26, 29 and 39 in. Series



Commercial Series

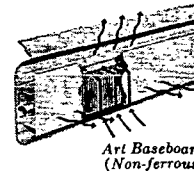


Model K Packet (with Enclosing Jacket)

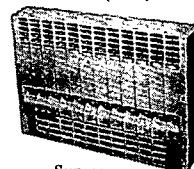


Art Convertor

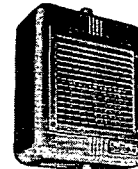
### NATIONAL-U. S. BASEBOARD HEAT DISTRIBUTING UNITS



Art Baseboard (Non-ferrous)



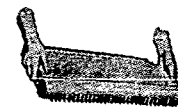
Sunray Radiator



Unit Heater



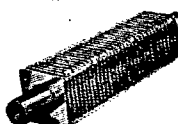
Conversion Oil Burner



Radiant Baseboard (Cast Iron)



Thin Tube Radiator



Pintube Radiation



Conversion Gas Burner

Three types of baseboard can be furnished: Art (non-ferrous), Radiant (cast iron), and steel . . . all combine the best features of radiant and convected heating—radiant heat at floor level and convected heat to banish drafts. For new or old buildings—residential or commercial. Ideal for remodeling old homes, and for basementless homes.

### NATIONAL-U. S. RADIATORS

Sunray Radiators . . . modern cast iron radiation for recessed or free-standing installations . . . available in 19, 20, 21 and 22½ in. heights . . . piping can be completely concealed by grilles.

Thin Tube Radiators. Compact, slender tube cast iron construction. Blend inconspicuously with most decorative schemes. Efficient and quick heating.

National-U. S. Unit Heaters for hot water and steam, also for gas firing—both types in a wide range of sizes.

National-U. S. Fintube Radiation . . . ideal where heating requirements are heavy and space limited. Available in two types: steel tubing with steel fins and copper tubing with aluminum fins. Sloping top, flat top and expanded metal grille covers can be furnished.

National-U. S. Oil Burners and Gas Burners are available in a number of sizes for conversion of either boilers or warm air furnaces to automatic firing.

### CAPITOLAIRE AIR CONDITIONING AND WARM AIR FURNACES

1. Hi-Boy Series available for all fuels.

Output: from 65,000 to 100,000 Btu/hr.

2. Lo-Boy Series available for all fuels.

Output: from 68,000 to 160,000 Btu/hr.

3. Horizontal Series available for gas and oil firing. Output: from 48,000 to 180,000 Btu/hr.

4. Hi-Cap Series available for all fuels.

Output: from 330,000 to 1,000,000 Btu/hr.

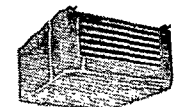
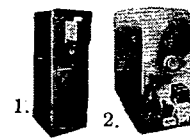
5. Suspended Air Conditioner, Model HRZ recessed with deluxe cabinet. Can be furnished with cabinet for duct mounting. Range from 300 cfm to 1750 cfm.

Floor Model, Fan Coil Unit, freestanding and concealed, Model VER, ¾, 1, and 1½ ton.

Packaged Chillers, water and air cooled condensers, 2 and 3 ton units (not shown).

6. Self-contained Hi-Boy, model COM . . . range from 2 to 15 ton.

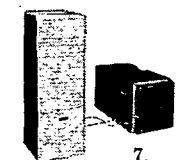
7. Residential Packaged Air Conditioner, air cooled (remote) and water cooled condenser. Range from 2 to 6 ton. Self-contained Hi-Boy, model US-AEC with built-in evaporative condenser . . . range from 3 to 60 ton. (Not shown).



5.



6.



7.

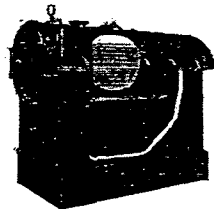


*Pacific Steel Boiler* DIVISION

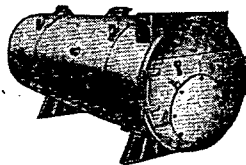
National-U. S. Radiator Corporation

Johnstown, Pennsylvania

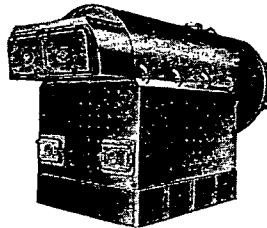
Sales Offices in Principal Cities



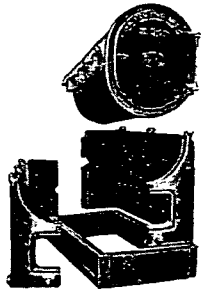
Pacific Standard Firebox Boilers



Pacific Scotch Marine Boilers



Pacific Front Smoke Outlet Boilers



Pacific Split-Firebox Boilers

#### SBI TABLE 1 BOILERS

A Complete Line of Low-Pressure  
Steel Heating Boilers For  
Commercial Application

All Pacific Commercial Boilers are built  
using the ASME Boiler Code Stand-  
ards as minimums, and rated in ac-  
cordance with Steel Boiler Institute code.

#### PACIFIC STANDARD FIREBOX BOILERS

Pacific Standard Firebox Boilers for  
mechanical firing, stoker, oil or gas are  
built in capacities of 2680 to 56830 sq ft  
for steam and in corresponding capacities  
for water. Design is of two types: Low  
Water Line and High Firebox.

Pacific Direct Draft and Smokeless  
Boilers for coal firing are built in cap-  
acities of 2200 to 35000 sq ft for steam and  
in corresponding capacities for water.

#### PACIFIC SCOTCH MARINE BOILERS

Pacific Scotch Marine Boilers for oil or  
gas firing. Capacities of 5470 to 42500  
sq ft SBI rating steam and in cor-  
responding capacities for water. Fully  
Wet Back.

#### PACIFIC FRONT SMOKE OUTLET BOILERS

Pacific Front Smoke Outlet Boilers for  
hand, stoker, oil or gas firing are built  
in capacities of 4000 to 42500 sq ft for  
steam and in corresponding capacities  
for water.

#### PACIFIC SPLIT-FIREBOX BOILERS

Low Water Line and High Firebox of  
Pacific Boilers are built in three sections  
—shell, firebox and base—and require  
minimum building opening. Where neces-  
sary, Pacific fireboxes can be split (as  
illustrated) to allow the boiler to be  
taken into the building in four sections,  
through any ordinary door or window.  
No cutting, no welding is required in  
assembling any Pacific Boiler.

Descriptive bulletins on  
Pacific Commercial  
Boilers will be mailed on request



*Pacific Steel Boiler* DIVISION

National-U. S. Radiator Corporation

Johnstown, Pennsylvania

Sales Offices in Principal Cities



#### SBI TABLE 2 BOILERS

A Complete Line of Residential Steel  
Boilers for Coal, Stoker, Oil or  
Gas Firing

All Pacific Residential Boilers are built  
using the ASME Code Standards as  
minimums, and are rated in accordance  
with Steel Boiler Institute code.

#### PACIFIC "PLATE FLUE" BOILERS

Pacific "Plate Flue" Boilers are designed  
for oil or gas firing and are built in 4  
sizes. Capacities range from 9600 to  
216,000 Btu/Hr steam and from 108,000  
to 243,000 Btu/Hr water. They are avail-  
able with either flush or extended  
jackets:

#### PACIFIC "O" SERIES BOILERS

Pacific "O" Series Boilers for residential  
application are designed for steam or  
water and for either automatic oil or  
gas firing. They are built in 7 sizes with  
capacities from 264,000 to 720,000 Btu/  
hr steam and from 297,000 to 810,000  
Btu/hr water. Available with flush  
jacket.

#### PACIFIC SERIES 700 BOILERS

Pacific Series 700 Boilers are designed  
for steam or water and for either stoker  
or hand firing. Capacities range from  
194,000 to 595,000 Btu/hr steam and  
from 219,000 to 670,000 Btu/hr water  
for hand fired models. Stoker fired  
models have capacities from 264,000 to  
720,000 Btu/hr steam and from 297,000  
to 810,000 Btu/hr water. All series 700  
Boilers available with flush jacket.

#### PACIFIC SERIES 33 BOILERS

Pacific Series 33 Boilers are designed for  
oil, gas, and stoker firing. Capacities  
range from 840,000 to 1,200,000 Btu/hr  
steam and from 945,000 to 1,350,000 Btu/  
hr water. Available with flush jacket.

Descriptive bulletins on  
Pacific Residential  
Boilers will be mailed on request



Pacific "Plate Flue" Boilers



Pacific "O" Series Boilers



Pacific Series 700 Boilers

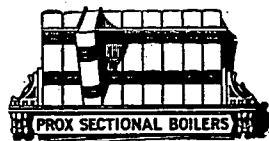


Pacific Series 33 Boilers

## Frank Prox Company, Inc.

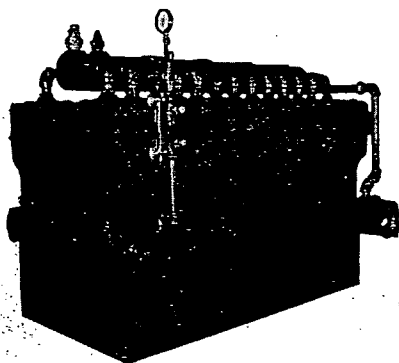


Office and plant  
1201 So. First St.  
Terre Haute, Ind.



### PROX BOILERS

For Large Installations in Schools, Theatres, Apartments, Churches, Hospitals, Hotels, Etc. Write for complete catalog.



The 40 Series—50-inch Water Line.

The fire travel is in three successive layers—full length of the boiler three times. Rotating action of hot gases in evenly shaped flues greatly increases effective heat absorbing capacity of the large heating surfaces.

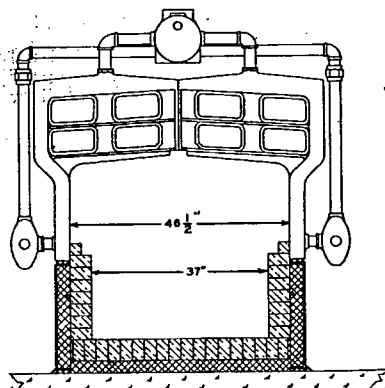
Independent connections to each individual section. Each section is a separate boiler with outside, accessible connections. No shut-downs. Guarantees service since any section can be plugged off and firing continued.

### The 40 Series DUPLEX ECONOMIC BOILERS FOR STOKER, OIL, OR GAS

Swinging connections! No vibration! No pulsation!

Plenty of room for stoker, oil burner, or gas conversion burner!

No iron to iron joints! Expansion and contraction troubles eliminated!



22 in. Cast Iron Base

| STEAM BOILER |                   | WATER BOILER |                   | Hydrostatically Tested ASME Standard<br>Maximum Allowable Working Pressure |                               |                               |
|--------------|-------------------|--------------|-------------------|----------------------------------------------------------------------------|-------------------------------|-------------------------------|
| Boiler No.   | Rating Feet (Net) | Boiler No.   | Rating Feet (Net) | Furnace Volume cu ft Above base                                            | Oil Delivery Rate Gals Per Hr | Coal Delivery Rate Lbs Per Hr |
| O40-S 6      | 2700              | O40-W 6      | 4100              | 15.8                                                                       | 7.4                           | 103                           |
| O40-S 7      | 3200              | O40-W 7      | 5100              | 20.0                                                                       | 8.8                           | 114                           |
| O40-S 8      | 3700              | O40-W 8      | 5900              | 24.3                                                                       | 10.2                          | 120                           |
| O40-S 9      | 4200              | O40-W 9      | 6700              | 28.6                                                                       | 11.5                          | 148                           |
| O40-S 10     | 4700              | O40-W 10     | 7600              | 32.9                                                                       | 13.0                          | 165                           |
| O40-S 11     | 5200              | O40-W 11     | 8300              | 36.1                                                                       | 14.4                          | 183                           |
| O40-S 12     | 5700              | O40-W 12     | 9400              | 39.4                                                                       | 15.8                          | 202                           |
| O40-S 13     | 6200              | O40-W 13     | 10200             | 44.3                                                                       | 17.2                          | 219                           |
| O40-S 14     | 6700              | O40-W 14     | 11000             | 48.6                                                                       | 18.6                          | 237                           |
| O40-S 15     | 7200              | O40-W 15     | 11800             | 51.0                                                                       | 20.0                          | 260                           |
| O40-S 16     | 7700              | O40-W 16     | 12700             | 55.3                                                                       | 21.4                          | 280                           |

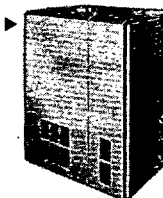
## The H. B. Smith Company, Inc.

Westfield, Mass.

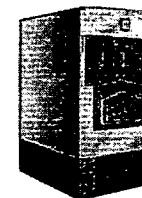
Branch Offices and Sales Representatives in Principal Cities

A complete line of modern cast iron sectional boilers for residential, commercial and industrial heating and for domestic hot water supply.

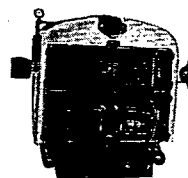
SMITH "CENTURY" GAS BOILER, A.G.A. approved, for steam or hot water heating. Input ratings from 138,000 to 745,500 Btu. Combines latest features of gas boiler design. Available with five sizes of built-in tank domestic hot water heaters, capacities to 168 gal, and eight sizes of tankless heaters, capacities to 8 gpm. Entire burner assembly mounted on wrought iron frame with casters for easy removal.



"100" and "2000" OIL BOILER-BURNER steam or water units for homes and small commercial installations. Furnished with line of tankless heaters with capacities up to 8 gal of hot water per minute. Net radiation to 1275 sq ft, steam; 2210 sq ft, water.



SMITH-MILLS BOILERS, Series 15-20-25; capacities 200 to 2275 sq ft steam radiation. This complete line of modern push nipple boilers is available in models for gas, oil, stoker or hand firing. Have provisions for built-in domestic hot water heaters and controls.

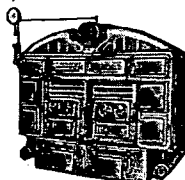


MILLS WATER TUBE BOILERS, Series 24-34-44; capacities 900 to 13,380 sq ft steam radiation. Independent header type construction. Tens of thousands are installed in schools, hospitals, apartment houses, stores and other commercial and public buildings. Models for hand and all types of automatic firing.

SMITH HY-TEST BOILERS for hot water supply are furnished in several models, and many sizes for tank capacities to 20,000 gal. Constructed of the finest quality grey iron castings, these Hy-Test units are carefully tested at extremely high pressures before shipment.



42 and 60 SMITH BOILERS, may be used in batteries for heating loads up to and over 100,000 sq ft steam radiation. Many of these large units installed in industrial plants furnish steam for processing requirements as well as for heating and domestic hot water.



STERLING FIN-TYPE RADIATORS for low-cost heat in public and commercial buildings, and baseboard convectors for homes, are distributed nationally by The H. B. SMITH COMPANY, Westfield, Mass.

Complete catalog information describing Smith boilers is filed in current issues of Sweet's "Architectural" and Domestic Engineering Catalog Directory.





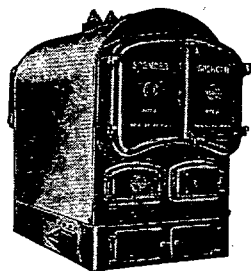
|                       |                     |
|-----------------------|---------------------|
| Sales Representatives |                     |
| ALLENTOWN, PA.        | CINCINNATI, OHIO    |
| ATLANTA, GA.          | CLEVELAND, OHIO     |
| BALTIMORE, MD.        | COLUMBUS, OHIO      |
| BINGHAMTON, N. Y.     | DALLAS, TEXAS       |
| BIRMINGHAM, ALA.      | DETROIT, MICH.      |
| BOSTON, MASS.         | GRAND RAPIDS, MICH. |
| CHICAGO, ILL.         | GREENSBORO, N. C.   |
| HARRISBURG, PA.       | MINNEAPOLIS, MINN.  |
| HOUSTON, TEXAS        | NASHVILLE, TENN.    |
| INDIANAPOLIS, IND.    | NEW HAVEN, CONN.    |
| KANSAS CITY, MO.      | NEW YORK, N. Y.     |
| KNOXVILLE, TENN.      | PHILADELPHIA, PA.   |
| MEMPHIS, TENN.        | PITTSBURGH, PA.     |
| MILWAUKEE, WIS.       | POCATELLO, IDAHO    |
| PORTLAND, ORE.        | RICHMOND, VA.       |
| ROCKFORD, ILL.        | SAN ANTONIO, TEXAS  |
| SEATTLE, WASH.        | SPokane, WASH.      |
| WASHINGTON, D. C.     |                     |

## STEEL AND CAST IRON HEATING BOILERS

FOR EVERY BUILDING . . . FOR EVERY FUEL

"LW," "A," "C," and "R" Series fully approved by Steel Boiler Institute

All products manufactured in strict accordance with the ASME code and carry the code seal. Every Spencer meets rated specifications, is easy to install, and assures economical operation.

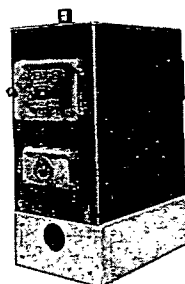


"A" Series

3,500 TO 42,500 SQUARE FEET, STEAM  
Steel Commercial Heating Boilers.—Exclusive peaked firebox design aids in making the "A" Boiler quick steaming and efficient. Space for either storage tank or instantaneous type service water coils. Larger sizes can be cut in half to move through narrow openings.

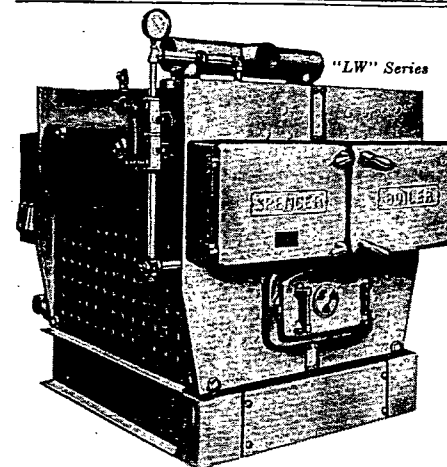
### 1,300 to 5,000 NET SBI STEAM

Steel Commercial and Residential Heating Boilers—For oil burner, stoker, or hand firing. With heavy-duty doors and frame precision-ground for airtight fit. Adaptable to front, rear, or side installation of oil burner or stoker. Available with domestic hot water coils and attractive insulated jacket.

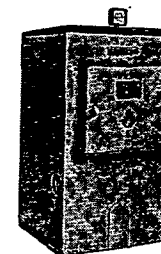


"C" Series

1538



"LW" Series



"R" Series

"LW" SERIES—3,500 to 42,500 SQUARE FEET, STEAM. New Divided Low-Waterline Commercial Boiler  
Flattened out to beat low headroom and excavation problems. Divided for easier entrance through narrow basement openings, yet 2 watertight sections require no welding.

Easier to install because of specially designed smokebox. Low stack designs possible because boilers designed to be installed with induced draft fans.

Both instantaneous or tank type service waterheating coils. Quickly convertible from mechanical to hand-firing.

"R" SERIES—320 to 1,100 SQUARE FEET, STEAM, NET LOAD  
Steel Residential Heating Boilers—Excellent for small homes requiring economical heat and instantaneous hot water. Available with attractive beauty jacket.



Suburban

### SUBURBAN

87,000 BTU NET SBI WATER RATING .  
Oil Fired Boiler Burner

Kitchen appliance beauty fits in anywhere. Quickly installed in minimum floor space, no special base required. Extra-high combustion chamber assures quiet, trouble-free operation. Easily cleaned and serviced.

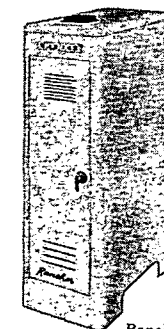
### RANCHER

1G SERIES: 40,000 TO 128,000 BTU

2G SERIES: 80,000 TO 232,000 BTU

Gas-Fired Boiler Burner

Extremely compact and efficient. A.G.A.-approved for manufactured, mixed or natural gases. Ease of installation, cleaning and service saves time and money. Gleaming white kitchen appliance beauty.



Rancher

1539





## WEIL-McLAIN COMPANY

General Sales Office: Michigan City, Indiana  
Distributors in all principal cities

### WEIL-McLAIN CAST IRON OIL-FIRED BOILERS

HR Series Heavy Duty boilers for horizontal rotary burners. Special steel front plate and section simplify rotary burner installation. Large fire box volume develops better combustion conditions—high base eliminates high brick foundation. These boilers are also available as all-fuel units.

Load range: steam 2,700-12,270 sq ft; water 4,450-19,630 sq ft.

### BOILER FOR OIL AND OIL HEATING UNITS

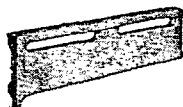
Designed specifically for efficient oil burning. Long flue travel extracts maximum heat. I-B-R. rated, ASME constructed. Available in residential sizes as complete package units for forced hot water systems.

Load range: Steam 285-3,400 sq ft; water 525-5,505 sq ft.

### WEIL-McLAIN CAST IRON GAS-FIRED BOILERS

A complete line of jacketed gas-fired boilers for residential, commercial and industrial applications. Cast iron construction for long life. Special design features assure efficient fuel combustion—longer fire travel through finned flues permits maximum heat absorption. A.G.A. approved for natural, mixed, manufactured or liquefied petroleum gases—ASME constructed.

Load range: steam 260-12,950 sq ft; water 300-20,720 sq ft.



Snug Baseboard Panel

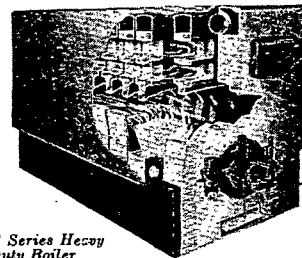
### Weil-McLain Snug Cast Iron Baseboards and Radiation

Snug Cast Iron Baseboard Panels provide a balanced combination of radiant convected heat which assures uniform temperature from floor to ceiling. Available in two heights—7½ in. x 2½ in. and 9¾ in. x 2½ in. Complete line of metal finishing accessories.

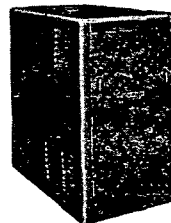
Solray Cabinet Radiators have attractive, easily cleaned cabinet top. Large waterways store heat for release when burner shuts off.

Raydiant Recessed Radiators are designed exclusively for recessing virtually flush in the wall—completely unobtrusive.

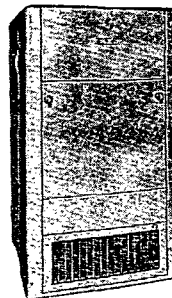
Junior Radiators offer modern slender-tube design—can be installed in open recess if desired.



"HR" Series Heavy  
Duty Boiler



Series "OB"  
Oil-fired Boiler



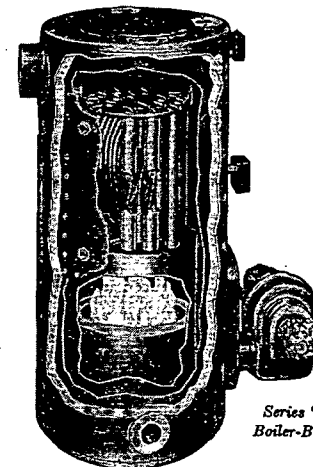
Type J Gas Boiler



## Aldrich Company



121 E. Williams St., Wyoming, Illinois



Series "B"  
Boiler-Burner

### Boiler-Burner Units, Domestic and Commercial Oil Burners

Aldrich Boiler-Burners are available in sizes for hot water heating, steam heating and hot water supply. Heavy duty double spiral hot water coils factory installed and tested in SC and WC models. Matched Aldrich Oil Burner with each unit, or choice of gas fired models.

Welded steel fire box lined with refractory of high deterioration resistance. Extra thick wool insulation minimizes heat loss. Easy access to fire box.

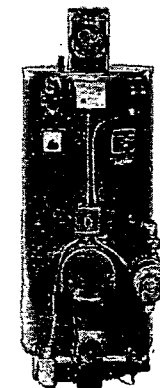
**ALDRICH GULF STREAM BOILER-BURNER PACKAGE**—Five sizes of compact, economical units designed for the small home, fully erected, wired, equipped. From 495 to 1260 sq ft of water radiation. Quick heating load pick-up means fuel saving. Efficient and economical in operation. Tankless hot water coil optional.

### SERIES "B" BOILER BURNER SPECIFICATIONS

| Size of Boiler            | Bantam  | 118     | 160     | 225     | 315     | 514     | 808     |
|---------------------------|---------|---------|---------|---------|---------|---------|---------|
| Rating Sq Ft Hot Water    | 660     | 750     | 1,000   | 1,500   | 2,100   | 3,300   | 5,000   |
| Rating Sq Ft Hot Water    | 440     | 500     | 650     | 1,000   | 1,400   | 2,200   | 3,333   |
| Rating Sq Ft Steam        | 425     | 500     | 630     | 935     | 1,275   | 2,025   | 3,000   |
| Rating Sq Ft Steam        | 285     | 333     | 420     | 620     | 850     | 1,350   | 2,000   |
| Rating Btu Per Hr (Max)   | 100,000 | 118,000 | 160,000 | 225,000 | 315,000 | 514,000 | 808,000 |
| Water Heater Delivery     | 93      | 125     | 190     | 280     | 425     | 610     | 850     |
| GPH @ 100° Rise           | 20      | 28      | 38.5    | 72      | 99      | 120     | 170     |
| Storage Capacity Gallons  | 1.00    | 1.25    | 1.65    | 2.75    | 3.65    | 5.7     | 9.00    |
| Firing Rate—GPH Maximum   | .65     | .75     | 1.25    | 1.75    | 2.4     | 3.7     | 6.00    |
| Firing Rate—GPH Minimum   | .75     | 1.00    | 1.35    | 2.00    | 2.6     | 4.5     | 7.5     |
| Firing Rate—GPH Best      | 75      | 100     | 135     | 200     | 260     | 450     | 750     |
| Model Burner Furnished    | CX1     | SAX1    | SAX2    | SAX3    | SAX3    | DX      | DX      |
| Sq Ft of Heating Surface  | 17      | 21      | 27      | 44      | 67      | 93      | 136     |
| Dia. Main Shell (Inside)  | 16½"    | 19"     | 21"     | 24½"    | 28"     | 32"     | 38"     |
| Height of Main Shell      | 42½"    | 46½"    | 50½"    | 58½"    | 66½"    | 86½"    | 70½"    |
| Dia. of Fire Box (Inside) | 12"     | 14½"    | 16"     | 19"     | 22½"    | 27"     | 32½"    |
| Height of Fire Box        | 21"     | 24"     | 24"     | 26"     | 26"     | 26"     | 26"     |
| Number of Tubes           | 16      | 16      | 20      | 30      | 42      | 60      | 94      |
| Length of Tubes           | 15½"    | 15½"    | 19½"    | 23½"    | 30½"    | 29½"    | 31½"    |
| Output Hot Water WC—GPM   | 3       | 1.75    | 2.00    | 2.66    | 5.25    | 6.50    | 7.25    |
| Coil @ 100° Rise SC—GPM   | 3       | 2.00    | 2.75    | 3.67    | 6.75    | 8.00    | 10.00   |

### GULF STREAM PACKAGE SPECIFICATIONS

| Boiler No.                          | C-10   | C-12   | C-14    | C-20    | C-25    |
|-------------------------------------|--------|--------|---------|---------|---------|
| Net Rating SBI Water Sq Ft          | 495    | 580    | 720     | 995     | 1,260   |
| Net Rating SBI Btu Per Hour         | 74,000 | 87,000 | 108,000 | 149,000 | 189,000 |
| Oil Firing Rate GPH                 | 1.00   | 1.10   | 1.35    | 2.00    | 2.50    |
| Output Tankless Coil GPM (FHA)      | 3      | 3      | 3       | 4       | 4       |
| Water Heater Delivery GPH—100° rise | 104    | 121    | 151     | 207     | 265     |
| Storage Capacity of Boiler—Gallons  | 19     | 23     | 29      | 31      | 39      |
| Heating Surface Sq Ft               | 16     | 19     | 24      | 32      | 41      |
| Number of Tubes                     | 20     | 20     | 20      | 32      | 32      |



Gulf Stream  
Packages

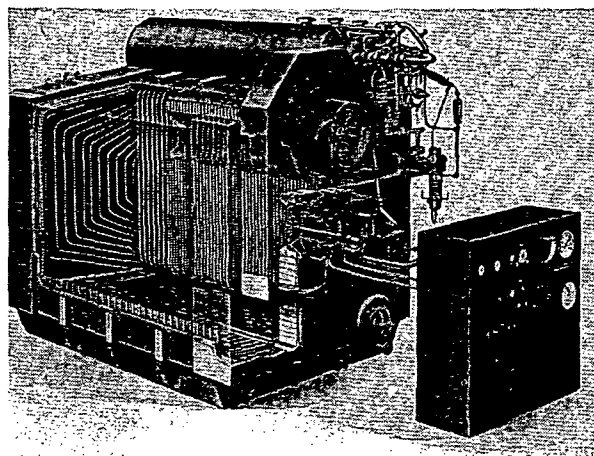


## The Babcock & Wilcox Co.

161 East 42nd Street, New York 17, N. Y.

Offices in All Principal Cities

Water-tube Boilers for Stationary Power Plants, and Marine Services... Superheaters... Economizers... Air Heaters... Pulverized-Coal Equipment... Chain Grate Stokers... Oil, Gas, and Multifuel Burners... Seamless and Welded Tubing and Pipe... Refractories... Process Equipment.



**B&W INTEGRAL-FURNACE BOILER, TYPE FM**

Shop-Assembled Steam Generator

B&W Type FM Boiler combines the benefits of package steam with cost-saving big-boiler advantages. This compact self-contained unit has been widely applied to heating services in hospitals, schools, colleges, and other buildings. It has also gained wide acceptance throughout a broad range of industries—supplying steam for combination services.

The Type FM Boiler is particularly suitable for small- and medium-sized plants where excessive fuel consumption and costly maintenance are often serious problems. And, even for some larger steam requirements, multiple-unit Type FM installations have proved more flexible in operation and more economical than one or more large boilers requiring costly field erection and close operating

supervision. A large part of the total FM capacity now in service or on order consists of multiple-unit installations.

The Type FM Boiler is fast steaming and features automatic operation with special safety provisions. It quickly responds to load changes and operates at high efficiency over the load range. This versatile unit burns gas and/or oil, separately or in combination, with quick and easy changeover accomplished at the control panel.

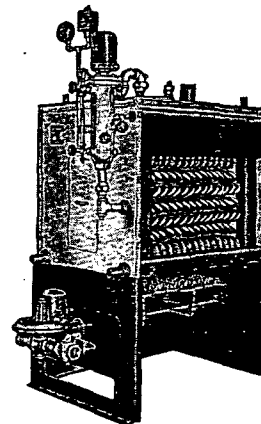
The Type FM Boiler is available in standard sizes for steam requirements to 40,000 lb per hr and for operating pressures to 235 psi. Many have been installed for higher pressures and with a moderate degree of superheat. *Details are given in Bulletin G-76—copies sent on request.*

1542

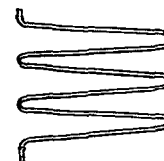
## Bryan Steam Corporation

Chili Pike, Peru, Indiana

Hot Water and Steam Boilers designed exclusively for oil or gas firing. Products include domestic hot water or vapor steam boilers, commercial low pressure heating boilers for hot water or steam, and high pressure boilers up to 50 hp



Bryan Copper Tube Boilers are engineered expressly for oil or gas firing, where the flame is either on at full intensity or entirely off. Such combustion characteristics call for a boiler that is able to capture heat units with utmost rapidity—and able to withstand sudden expansion and contraction. Average stack temperature of the Bryan is 412 degrees.



### BRYAN COPPER TUBES

The Bryan starts with copper tubes. Copper has a coefficient of heat transfer approximately 6 times that of iron or steel. Heat applied to a Bryan tube is therefore transferred to the water inside 6 times as fast.

The design of the Bryan tube is such that water circulates rapidly through all parts of the boiler. There is a veritable

nest of tubes directly over the flame where heat is most intense. These tubes break up the path of heat travel, reducing "surface film" to a minimum. Of the many advantages of Bryan Boilers, none is more important than the use of Copper Tubes for the heating surface. All gas fired heating boilers A.G.A. approved.



Domestic Boilers



Commercial Heating Boilers



High Pressure Boilers

### DOMESTIC BOILERS

The Bryan Domestic Boiler is available in 7 sizes for hot water radiation. 70,000 Btu's to 560,000 Btu's.

For steam radiation 5 sizes are available, 390 to 1560 sq ft of radiation.

All models come complete with built-in combustion chamber and flange mounted oil burners. In gas fired models the burner is built in.

### COMMERCIAL HEATING BOILERS

Any of the domestic Bryans may be used for small offices or buildings; but they are supplemented with three additional larger capacity boilers. These boilers are rated 2600 to 5000 sq ft of steam radiation or 4150 to 8000 sq ft of hot water radiation. They are used also for supplying hot water or low pressure steam in industrial applications.

### HIGH PRESSURE BOILERS

Bryan High Pressure Boilers are made 5-10-20-35- and 50 hp ratings. Every one carries the ASME stamp. They are made for high efficiency on long, hard pulls but are exceptionally useful in operations requiring fast, safe steam on short notice. Hospitals, dry cleaning plants, laundries, milk plants, tire repair shops and many others find them ideal for their operations.

1543

## Cleaver-Brooks Company

498 E. Keefe Ave., Milwaukee 12, Wisconsin



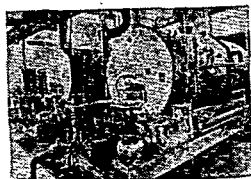
**Cleaver-Brooks BOILERS**—Steam or Hot Water, for Heating and Processing 15 to 600 hp, 15 to 250 psi. Oil, Gas, and Combination Oil & Gas Fired Models

### COMPLETE SELF-CONTAINED STANDARD SIZES

| HP                                               | 15     | 20   | 30   | 40   | 50    | 60    | 70    | 80    | 100   |
|--------------------------------------------------|--------|------|------|------|-------|-------|-------|-------|-------|
| Approx. Rated Capacity—lbs Steam Per Hour 212 F. | 515    | 690  | 1050 | 1380 | 1725  | 2070  | 2415  | 2760  | 3450  |
| Approx. Rated Capacity—lbs Steam Per Hour 212 F. | HP 125 | 150  | 200  | 250  | 300   | 350   | 400   | 500   | 600   |
|                                                  | 4300   | 5200 | 6900 | 8600 | 10500 | 12000 | 13800 | 17000 | 20700 |

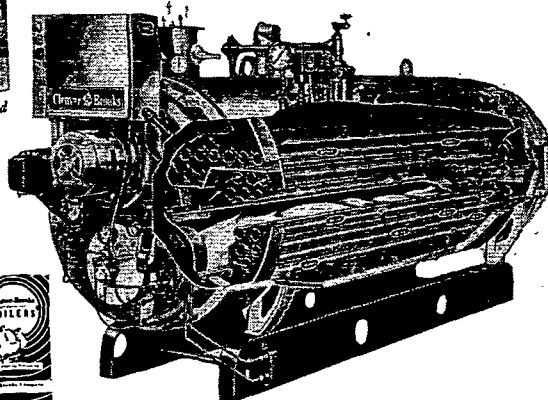
### CLEAVER-BROOKS BOILERS OPERATE AT A GUARANTEED MINIMUM 80 PER CENT EFFICIENCY

Cleaver-Brooks boilers are guaranteed to operate at fuel-to-steam efficiency of not less than 80 per cent, at ratings from 30 to 100 per cent and at the designated working pressure. Economical operation is assured by establishing an efficient flame, and utilizing forced draft to send the hot gases through four successive passes, thus absorbing maximum usable heat before combustion gases leave the boiler. Boilers are fully automatic in operation... meet ASME code requirements. Factory finished and tested under load conditions.



Available with "10-Second" Oil and Gas Fuel Interchange Feature

80 PER CENT EFFICIENCY RATINGS are established at the factory and can be maintained with relative ease after installation.



Write for complete Specifications, dimensions data, firing rates, etc. Catalog AD-157 sent on request.



### CLEAVER-BROOKS HELPS YOU SELECT THE EXACT STEAM BOILER YOU WANT TO MEET YOUR SPECIFIC NEEDS

**JOB RATED**—Each Cleaver-Brooks steam boiler is job rated to meet the steam requirements of your plant. A competent sales engineer helps analyze your load demands and takes into account these conditions:

- Pop valve settings • Per cent of total feed water returned as condensate • Temperature of condensate • Pressure of make-up water • Type of fuel available • Electric current characteristics • Space and machinery arrangement. Suggested boiler room layouts • Plant altitude above sea level • Maximum steam requirements in pounds per hour or boiler horsepower • Whether your steam load is constant or fluctuating, and the degree of fluctuation • The heating load requirements • Standby requirements • Steam pressure required at point of use • Future growth or expansion of plant facilities •

Look for the "CLEAVER-BROOKS" listing in the Boiler Section of your classified Telephone Directory for name of nearest distributor.

## Cyclotherm Division

National-U. S. Radiator Corporation

Sales and Executive Offices

Oswego, New York

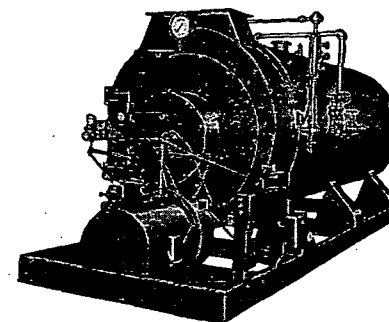
Factory Distributors throughout the United States

### CYCLOTHERM STEAM AND HOT WATER GENERATORS

... operate on Cyclonic Combustion principle. Completely automatic with full safety controls. Oil, gas or interchangeable gas and oil firing. Only four connections required.

The Cyclonic Combustion operating principle causes the fuel to be burned while spiraling at high velocity around the inside wall of the combustion chamber, forming virtually a tube of flame. This provides uniform and highly efficient heat transfer over the entire furnace wall without hot spots. Complete utilization of heat transfer areas provides quick heat as well as greater than 80 per cent efficiency with the reduced maintenance of a two-pass design.

18 to 80 hp models are equipped with "on-off" control; 100 to 500 hp models have modulated control. 80 hp units with modulating controls furnished at customers request. Automatic combustion safeguard, low water and other safety controls are included.



Sizes from 18 to 500 hp

### Pressure Range

Available in standard low pressure units or high pressures up to 200 psi. Hot water generators are also available in all sizes.

### Standard Burner Arrangements

| Fuel                         | Cyclotherm Model No. |
|------------------------------|----------------------|
| Light Oil, 1 to 3            | C-600 thru C-17,500  |
| Gas, mfd., mixed and natural | C-600 thru C-17,500  |
| Comb. lt. oil and gas        | C-600 thru C-17,500  |
| Heavy Oil, 5, 6 and Bunker C | C-2800 thru C-17,500 |
| Comb. hy. oil and gas        | C-2800 thru C-17,500 |

### STANDARD RATINGS AND DIMENSIONS

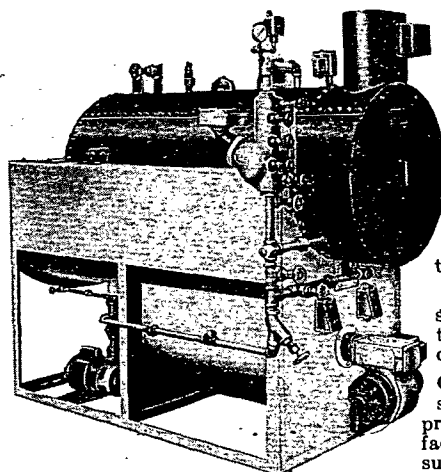
| Model No. | Max. hp Rating | Output Btu Per Hour | Steam Units        |                                     | Hot Water Units            |                         | Overall Dimensions (Inches) |         |       |
|-----------|----------------|---------------------|--------------------|-------------------------------------|----------------------------|-------------------------|-----------------------------|---------|-------|
|           |                |                     | Steam Per Hr (Lbs) | Equivalent Direct Radiation (Sq Ft) | Gallons per Hr (100° Rise) | Equip. Direct Radiation | Length                      | Height  | Width |
| C-600     | 18             | 603,000             | 620                | 2,513                               | 744                        | 4,020                   | 70 1/2                      | 45 1/4  | 36    |
| C-1000    | 30             | 1,005,000           | 1,035              | 4,188                               | 1,240                      | 6,700                   | 80 1/2                      | 55      | 45    |
| C-1400    | 40             | 1,340,000           | 1,380              | 5,583                               | 1,654                      | 8,933                   | 87 1/2                      | 57 3/4  | 48    |
| C-1725    | 50             | 1,675,000           | 1,725              | 6,980                               | 2,068                      | 11,167                  | 84                          | 57 1/4  | 48    |
| C-2100    | 60             | 2,010,000           | 2,070              | 8,375                               | 2,481                      | 13,400                  | 124 1/2                     | 64 3/4  | 51    |
| C-2800    | 80             | 2,680,000           | 2,760              | 11,167                              | 3,308                      | 17,887                  | 152                         | 66 1/4  | 56    |
| C-3500    | 100            | 3,350,000           | 3,450              | 13,959                              | 4,135                      | 22,333                  | 162 3/4                     | 73 1/4  | 65    |
| C-4400    | 125            | 4,187,500           | 4,315              | 17,448                              | 5,169                      | 27,917                  | 173 1/2                     | 84 1/2  | 70    |
| C-5200    | 150            | 5,025,000           | 5,175              | 20,938                              | 6,203                      | 33,500                  | 197 1/2                     | 91 1/4  | 78    |
| C-7000    | 200            | 6,700,000           | 6,900              | 27,917                              | 8,270                      | 44,687                  | 224 1/2                     | 98 3/4  | 85    |
| C-8700    | 250            | 8,375,000           | 8,625              | 34,836                              | 10,338                     | 55,833                  | 251 1/2                     | 98 3/4  | 85    |
| C-10500   | 300            | 10,050,000          | 10,350             | 41,975                              | 12,405                     | 67,000                  | 252                         | 102 1/2 | 90    |
| C-12000   | 350            | 11,725,000          | 12,075             | 48,854                              | 14,473                     | 78,167                  | 252                         | 102 1/2 | 90    |
| C-13800   | 400            | 13,400,000          | 13,800             | 55,833                              | 16,540                     | 89,333                  | 252                         | 102 1/2 | 90    |
| C-17500   | 500            | 16,750,000          | 17,250             | 69,792                              | 20,675                     | 111,667                 | 293 3/4                     | 102 1/2 | 90    |

# COLUMBIA Boiler Company of Pottstown

Pottstown, Pa.

Makers of steel power and heating boilers

## COLUMBIA'S H.R.T.\* OIL OR GAS FIRED BOILER



**ASME CODE CONSTRUCTED—**  
Available for pressures of 15 to 150 psi.

A complete, automatic power plant wherever steam is used for processing

**Horizontal Design for longer life:** The complete submersion of tubes protects them from water line corrosion.

**Dry Steam Assured:** Large steam space and greater liberation area virtually eliminate waste producing water carryover.

**Over-All Efficiency:** Factory installed, specially designed combustion chamber provides rapid heating refractory surfaces for peak combustion efficiency. Insulation, 7 inches thick in the combustion chamber proper, and 4 inches thick in the gas passage, keeps heat loss at a minimum. Special refractory brick heats up to great intensity to complete the combustion of previously unignited fuel particles. This complete combustion not only increases efficiency but makes for clean combustion. Soot accumulation on heating surfaces is minimized. Boiler tubes require less cleaning.

**Safety Assured:** Two pass updraft design lowers direct loss and reduces possibility of furnace pressure, pulsation or excessive combustion noises.

**Accessibility and easy Maintenance:** Simplified construction provides easy front and back access to the single bank of tubes. Entire unit can be gotten to for inspection of boiler and chamber by removing the covers.

Columbia h.r.t. boilers are fully automatic, compact, complete steam generators. Available in sizes ranging from two to sixty horsepower. Designed for firing with gas, light or heavy oils. A special Columbia unit makes possible the inter-changeable use of gas or oil.

**Overfiring Permitted:** Conservative ratings plus large combustion volume permit overfiring. This frequently eliminates the need for additional boiler capacity, allows for plant expansion.

**High Steam Output:** Columbia's h.r.t. boilers have an unusually large heating surface to produce more steam at higher efficiencies. More heat is converted into steam since it is proportioned to make maximum use of hot gases of combustion for the production of steam.

### SPECIFICATIONS AND DATA COLUMBIA HRT BOILERS FOR GAS, LIGHT OIL OR DUAL FUEL Horizontal Return Tubular Type

|                       | Boiler Size |         |         |         |         |           |           |           |           |  |
|-----------------------|-------------|---------|---------|---------|---------|-----------|-----------|-----------|-----------|--|
|                       | 4           | 6       | 8       | 10      | 15      | 25        | 35        | 50        | 60        |  |
| Hp Rating             | 6           | 8       | 10      | 15      | 20      | 30        | 40        | 102       | 102       |  |
| Length O.A.           | 55          | 69      | 69      | 84      | 84      | 100       | 100       | 102       | 102       |  |
| Width O.A.            | 29          | 33      | 33      | 39      | 39      | 45        | 45        | 52        | 52        |  |
| Height O.A.           | 44          | 50      | 50      | 64      | 64      | 68 1/2    | 68 1/2    | 80        | 80        |  |
| Water Heating Surface | 30          | 56      | 72      | 92      | 120     | 200       | 290       | 415       | 415       |  |
| Oil Firing Rate       | 2.00        | 3.00    | 3.5     | 5.00    | 7.00    | 10.00     | 12.00     | 18.00     | 18.00     |  |
| Gas Input             | 250,000     | 400,000 | 490,000 | 700,000 | 900,000 | 1,400,000 | 1,700,000 | 2,500,000 | 2,500,000 |  |
| Approximate Output    | 200,000     | 300,000 | 350,000 | 500,000 | 700,000 | 1,000,000 | 1,200,000 | 1,800,000 | 1,800,000 |  |

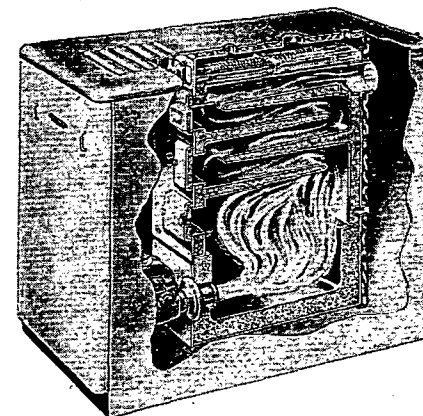
\* Horizontal return tubular type boiler

# COLUMBIA Boiler Company of Pottstown

Pottstown, Pa.

Makers of steel power and heating boilers

## STEEL, TUBELESS OIL-FIRED, WATER TUBE GAS-FIRED AND COAL-FIRED HEATING UNITS



**ASME CODE  
CONSTRUCTED**

Available with highly efficient, custom engineered gas or oil burners. Columbia steel boilers, gas or oil fired, have self contained large copper instantaneous tankless coils, supplying a continuous flow of year 'round domestic hot water.

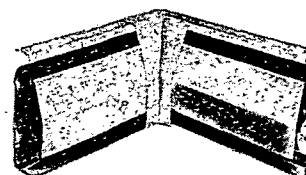
**Maximum operating efficiencies assured** by the balanced design of the boiler and burner; by the arrangement of the baffles which force the hot gases to travel four of five times the full length of the boiler.

**One piece electric welded construction:** Columbia offers a heating unit with full electric welded construction of heavy copper bearing steel, to assure lower heating cost and longer operating life. **Quiet operation:** Ample combustion space, the insulation and heavy steel jacket completely eliminate objectional noise.

**Dual Firing:** Columbia gas heating units may be easily converted for efficient oil firing.

|                         | MODEL NO. |         |         |         |         |         |         |
|-------------------------|-----------|---------|---------|---------|---------|---------|---------|
|                         | L-16      | L-18    | L-20    | L-22    | L-24    | *L-30   | *L-32   |
| Ratings—Oil Fired       |           |         |         |         |         |         |         |
| Input—Gals per Hr.      | 1.00      | 1.20    | 1.35    | 1.75    | 2.25    | 3.00    | 4.00    |
| Output—Btu per Hr.      | 105,000   | 120,000 | 150,000 | 210,000 | 270,000 | 330,000 | 450,000 |
| Installed Radiation     |           |         |         |         |         |         |         |
| Sq Ft Forced Water      | 580       | 720     | 990     | 1260    | 1620    | 1980    | 2700    |
| Sq Ft Gravity Water     | 510       | 640     | 880     | 1120    | 1440    | 1760    | 2400    |
| Sq Ft Steam             | 320       | 400     | 550     | 700     | 900     | 1100    | 1500    |
| Btu per hr Forced Water | 88,000    | 108,000 | 148,000 | 189,000 | 243,000 | 298,000 | 405,000 |
| Btu per hr Gravity      |           |         |         |         |         |         |         |
| Water                   | 77,000    | 96,000  | 132,000 | 168,000 | 216,000 | 264,000 | 360,000 |
| Btu per hr Steam        | 77,000    | 96,000  | 132,000 | 168,000 | 216,000 | 264,000 | 360,000 |

\* Constructed Water Tube Only  
\* Gas Fired Units A.G.A. and S.U.R. Approved for outputs from 72,000 to 172,000 Btu's per hour.  
\* Coal Hand Fired Conversion Units available in sizes L-18, L-22 and L-30



### COLUMBIA BASEBOARD RADIATION

- Suspended Element—no noise!
- Tension Fastening—no rattling!
- Low Angle Heat—no drafts!
- Pre-Punched Holes—fast installation!

## Combustion Engineering, Inc.

All Types of Fire Tube and  
Water Tube Boilers  
Mechanical Stokers

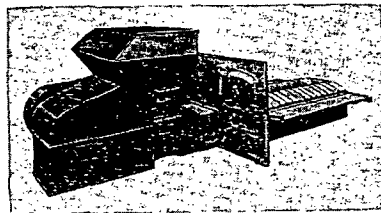


Complete Steam Generating Units  
Pulverized Fuel Systems

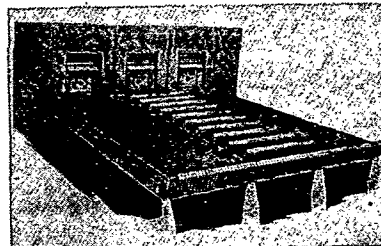
200 Madison Avenue, New York 16, N. Y.

Offices in all principal cities of the world

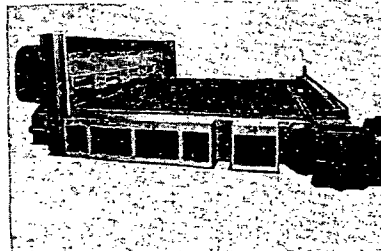
More than 20,700 C-E Stokers purchased to date



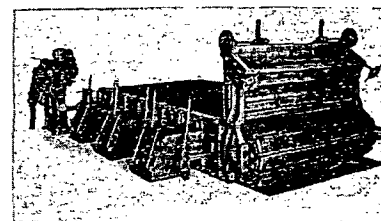
C-E Skelly Stoker



C-E Spreader Stoker—Dumping Grate Type



C-E Spreader Stoker—Continuous Discharge Type



C-E Traveling Grate Stoker

**C-E SKELLY STOKER**—A compact, self-contained unit with integral forced-draft fan, designed to burn either bituminous coal or anthracite. Alternate fixed and moving grate bars assure lateral distribution of fuel. Automatic control is standard equipment. Approximate capacity range—20 to 300 rated boiler horsepower.

**C-E SPREADER STOKER**—A simple, rugged overfeed stoker designed to burn a wide variety of coals. Revolving spreader blades feed fuel into the furnace in criss-crossing streams which assure uniform distribution. Fines are burned in suspension and the coarser coal on a grate which may be of either continuous discharge or dumping type. Rate of coal feed and air supply may be regulated over a wide range and are adaptable to automatic control. Applicable to boilers from about 100 boiler hp up.

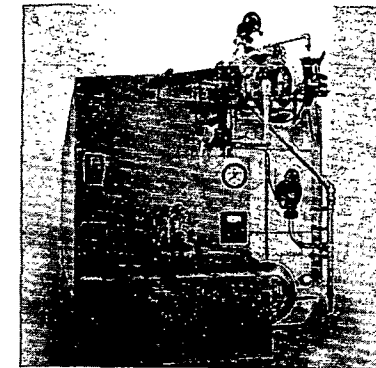
**C-E TRAVELING GRATE STOKERS**—Available in either bar or chain grate designs. These stokers are used for anthracite, coke breeze or free-burning bituminous coals. Available in either forced draft or natural draft designs. Application range from 150 boiler hp to units producing 275,000 lb steam per hr.

**OTHER TYPES**—The C-E line includes the Type E Underfeed Stoker available for use with boilers from 150 to 600 boiler hp. A single retort underfeed stoker, it is one of the best known and most widely used in the world. It burns a variety of bituminous coals and it is particularly adapted to coals having caking and coking characteristics.

### C-E PACKAGE BOILER, TYPE VP

For medium size and smaller plants . . . completely shop assembled . . . pressures to 500 psi . . . capacities from 4,000 to 40,000 lb per hr . . . oil or gas firing.

The VP is a completely packaged two drum vertical bent tube boiler with integral water-cooled furnace. Automatic controls provide protection from flame failure, high steam pressure and low water level; also adjust the air supply to the needs of fluctuating loads. Pressure fired, the unit requires no induced draft fan. Being self contained, it needs no special foundation and may be placed on a concrete slab or on a level floor. Only connections required are water, fuel, steam, electric and flue vent.

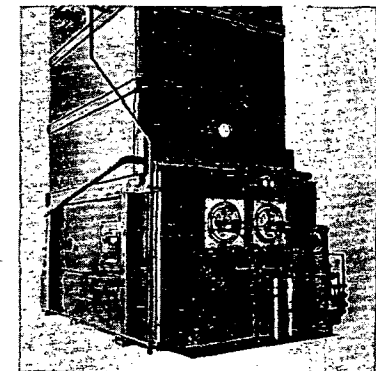


C-E Package Boiler, Type VP

### C-E LA MONT CONTROLLED CIRCULATION HOT WATER BOILER

For commercial or industrial heating or processing . . . capacities to 200 million Btu per hr . . . pressures to 300 psi . . . temperatures to 425 F . . . for coal, oil or gas firing.

Using high pressure, high temperature water in a closed system, this unit is ideally suited for those applications where high temperature water is preferred over steam. The C-E La Mont HT Boiler offers many advantages over other water systems—complete control, low pressure loss, single pass design with low draft loss, efficient heating surfaces and pressurized operation. It needs no induced draft fan or separate boiler pump.

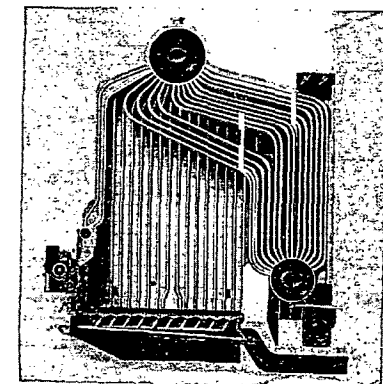


C-E LaMont Controlled Circulation Hot Water Boiler

### C-E VERTICAL-UNIT BOILER, TYPE VU-10

For medium-sized and smaller plants . . . pressure to 475 psi . . . capacity to 60,000 lb per hr, or more . . . suitable for any type of fuel.

A standard unit, the VU-10 is especially designed for industrial load conditions and plants having a limited number of operating personnel. It is of symmetrical design, and steam is released evenly across the full width of the unit. Gas flow is uniform, heat absorption is efficient and draft loss is low; it is essentially a "quick steamer." The boiler is bottom supported with no outside supporting steel. Type VU-10 boilers are adaptable to stoker firing or may be fired with oil or gas.



C-E Vertical Unit Boiler, Type VU-10

## The Dewey-Shepard Boiler Co.

Sales Office: 1311 N. Capitol Avenue, Indianapolis, Ind.  
STEEL FIRE TUBE BOILERS & HEATERS  
GAS & OIL FIRED

VERTICAL FIRE TUBE UNITS capacities 95,000 to 1,000,000 Btu  
ASME CODE CONSTRUCTED  
NATIONAL BOARD REGISTRATION AVAILABLE

All Dewey-Shepard boilers and water heaters (oil and gas fired) are built on the patented "Tube within a Tube" principle. All units are jacketed with fiber-glass insulation ready for instant hook-up.



- Oil Burners Underwriters Approved.
- Gas Burners A.G.A. Listed.
- Boilers Automatically Welded.
- Built-in Coils Optional.

### NET RATING

| Model | *Water, Sq Ft | Steam, Sq Ft |
|-------|---------------|--------------|
| B     | 560           | 350          |
| C     | 756           | 470          |
| D     | 840           | 520          |
| E     | 1120          | 700          |
| F     | 1400          | 875          |
| G     | 1640          | 965          |
| H     | 1960          | 1230         |
| I     | 2120          | 1330         |
| J     | 2750          | 1720         |
| K     | 3000          | 1895         |
| L     | 4480          | 2800         |
| M     | 5960          | 3730         |

Boiler ratings do not include allowance for Built-in Coils.

\* If piping and pick-up loss exceeds 20 percent of installed radiation, allow for such added loss.

### OIL and GAS BOILERS and WATER HEATERS

Dewey-Shepard's patented "Tube within a Tube" principle gives you 80 per cent or more heat absorption, resulting in pre-heating the incoming cold water before it comes in contact with the metal surfaces to which radiant heat is being applied. There is one square foot of heating surface for every gallon of water, transferring every possible unit of heat to the water, resulting in EFFICIENT, ECONOMICAL OPERATION . . . plus many other advantages for your customers, such as:

● LESS FUEL USED ● LOWER INSTALLATION COST ● NO LIME—NO SCALE ● 20 PER CENT LESS HEAT LOSS THROUGH THE STACK ● NO EXPANSION, CONTRACTION OR CONDENSATION ● CLEANEST HEAT POSSIBLE ● SUFFICIENT HOT WATER AT ALL TIMES

DEWEY-SHEPARD'S NEW OIL and GAS FIRED "COUNTER FLOW" BOILER Designed for use with Baseboard Radiation, Copper Convectors, and Radiant Panel with forced circulation and small pipe sizes.

### SPECIFICATIONS COUNTER-FLOW

| Output Net Btu      | Size                     | Weight |
|---------------------|--------------------------|--------|
| Model A Oil 90,000  | 19 in. x 19 in. x 31 in. | 400 lb |
| Model A Gas 80,000  | 20 in. x 20 in. x 34 in. | 275 lb |
| Model B Oil 135,000 | 19 in. x 19 in. x 38 in. | 450 lb |

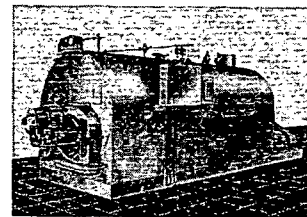


## Dutton Boilers

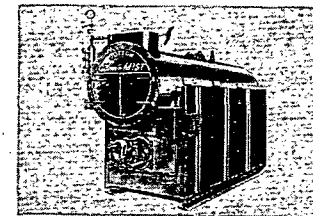
Division Hapman-Dutton Co.

639 Gibson Street, Kalamazoo, Michigan

Four types, many sizes . . . From 5 hp up . . . Firing with gas, light or heavy oil, stoker coal or by hand . . . For processing, power, high and low pressure steam and hot water heating . . . For Industrial Plants, Dairies, Laundry and Dry-Cleaning Plants, Chemical and Food Processing, Hotels, Schools, Institutions, etc.



Off-Center Firing With EconoTherm "Packaged" Models—Gas or Oil or Combination Gas-Oil.



Multiple Convertible Firing With The EconoMist "Packaged" Models.

EconoTherm Models are automatic, self-contained, "packaged" units with full safety controls. Of 3-pass fire-tube design, they feature a modified Scotch Internal Furnace located off-center. This firing creates rotary water circulation, resulting in more uniform water temperature, fast steaming, steady water line at all times, and high quality dry steam. Higher water column above furnace adds extra safety, efficiency.

Rotary combustion, large steam storage space, and five or more square feet of heating surface per rated hp combine to deliver guaranteed 80 per cent efficiency with dryness rating of 99 plus 0/0 dry steam under proper operating conditions.

Induced draft or forced draft fan available for positive, fast firing. Only a vent pipe is needed—no chimney or stack. Boiler shell is welded in one piece, X-ray inspected; complies with all ASME requirements. Every unit gets full running test. Certified ASME Data Report furnished.

EconoMist Models are automatic, "packaged" boilers featuring multiple convertible firing. They can be equipped for firing by hand, stoker, light oil, heavy oil, or gas, singly or in combinations. Can also be fired with by-products such as wood chips, sugar cane, corn husks, waste gas, etc.

EconoMist Models give you the dependability and simplicity of operation of H.R.T. design, plus greater combustion space, less heat loss. Installation, operation and maintenance costs are low. Welded boiler shell is X-ray inspected; complies with all ASME requirements.

Sizes from 15 to 105 hp are available as "packaged" units ready to connect or as basic units less refractory lining and accessories. Can be equipped with induced draft fan to eliminate need for stack or chimney. Conversion from one type of fuel to another is simple and inexpensive. Each unit is fully tested and certified ASME Data Report furnished when shipped as a packaged unit.

### ECONOTHERM—RATINGS AND CAPACITIES

| Equivalent Hp           | 20   | 25   | 30   | 40   | 50   | 70     | 80     | 100    |
|-------------------------|------|------|------|------|------|--------|--------|--------|
| Sq ft Water Heat. Surf. | 112  | 125  | 151  | 201  | 300  | 356    | 400    | 510    |
| Lbs Steam per Hr        | 700  | 773  | 1035 | 1728 | 2070 | 2450   | 2760   | 3754   |
| Equivalent Hp           | 125  | 150  | 180  | 200  | 250  | 300    | 350    | 400    |
| Sq ft Water Heat. Surf. | 650  | 814  | 905  | 1000 | 1252 | 1500   | 1750   | 2000   |
| Lbs Steam per Hr        | 4485 | 5617 | 6210 | 6900 | 8639 | 10,350 | 12,000 | 13,800 |

WRITE DIRECT OR CONTACT YOUR DUTTON REPRESENTATIVE FOR COMPLETE, DETAILED SPECIFICATIONS AND DATA DESCRIBING THESE AND OTHER DUTTON BOILERS.





Reg. U. S. Pat. Off.

## Fitzgibbons Boiler Company, Inc.

101 Park Avenue, New York 17, N. Y.

Sales Branches in Principal Cities

Member

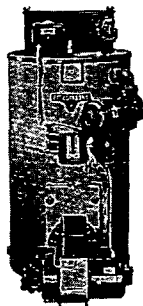
Manufactured at Oswego, N. Y.

Steel Boilers since 1886



Reg. U. S. Pat. Off.

**PRODUCTS—STEEL HEATING BOILERS AND BOILER UNITS** for all fuels and all heating systems. Capacities to meet requirements of any building. Built and rated according to ASME and SBI Codes and "Hartford" inspected.



### 770 SERIES UNITS

A completely pre-assembled and wired **OIL FIRED** unit for forced hot water heating systems in small homes. Combines the Fitzgibbons boiler, oil burner and **TANKSAVER®** with all the necessary controls and specialties into a coordinated unit that provides abundant heat and tankless hot water at low cost. 580 (87,000 Btu) and 720 (108,000 Btu) sq ft water—**SBI** Net Rating.

**GAS FIRED:** Available pre-assembled and wired, or as unassembled units. A.G.A. approved units, 96,000 and 124,000 Btu output.

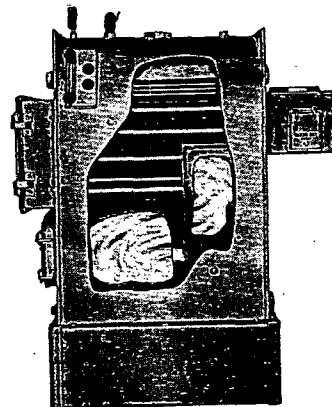
### R-Z-U JUNIOR® BOILER

The popular choice for a wide range of intermediate installations ranging from large residences to medium sized schools and commercial buildings. Large combustion area and two passes through 3 in. tubes account for efficient firing with oil, gas or coal. No rear or left side clearance necessary as all servicing can be done from the front. In eleven sizes from 264 to 1200 Mbh—**SBI** net. **FITZGIBBONS TANKSAVER®** available for service hot water.

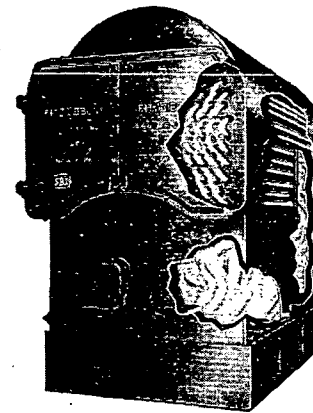


### "400" SERIES BOILER

The aristocrat of steel boilers for residences. Quick heating, low fuel consumption. Abundant hot water, winter and summer, without the need of a storage tank with the Fitzgibbons **TANKSAVER®**. In sizes from 400 to 900 sq ft steam, 720 to 1620 sq ft water—**SBI** Net Rating.



1552

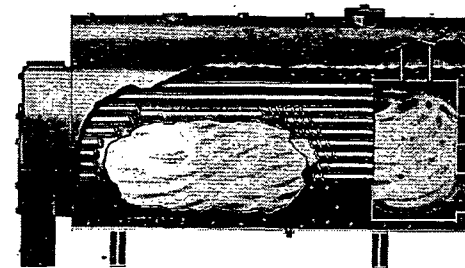


### "D" TYPE FIREBOX BOILER

For mechanical firing with oil, gas or stoker in ratings from 3650 to 60,700 sq ft steam, 876 to 14,570 Mbh EDR. 15 lbs Steam—30 lbs Water.

For hand fired coal in ratings from 3000 to 35,000 sq ft steam, 4800 to 56,000 sq ft water, 720 to 8400 Mbh EDR.

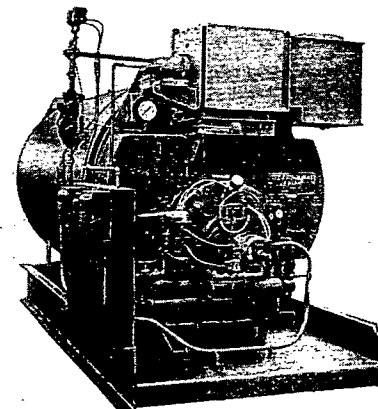
The steel boiler for heating apartments, office buildings, theatres, schools, hospitals and other large commercial buildings. Provides year 'round service hot water, without the need of a separate storage tank, with the Fitzgibbons **TANKSAVER®**, a copper coil submerged in the boiler water.



### "SCOTCH TYPE" BOILER

A Full Wet Back—Low Pressure Heating Boiler for oil and gas firing in sizes from 5470 to 60,700 sq ft steam, 1313 to 14,570 Mbh EDR. 15 lbs Steam—30 lbs Water. This compact, efficient Fitzgibbons

Boiler has the design advantage of complete water jacketing of all heating surfaces, including the rear furnace wall, thus eliminating usual rear dry-wall refractory lining and corresponding upkeep and repair expense.



### PACKAGED BOILER UNIT

Fully assembled and wired integrated unit for low pressure commercial applications. Fire tested and shipped as a unit ready for firing on the job. Boiler has full wet back construction that eliminates recurring expense for maintaining rear refractory. **SBI** ratings based on 8.2 sq ft heating surface per boiler hp with guaranteed gross outputs based on 5.0 sq ft of heating surface. Induced draft for quieter, cleaner operation. Thirteen sizes from 39 to 464 hp.

1553



**FARRAR & TREFTS DIVISION****ADSCO INDUSTRIES, INC.**

20 MILBURN ST. BUFFALO 12, N. Y.

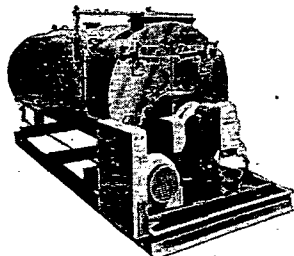
**FARRAR & TREFTS SALES OFFICES****Sales Offices:**

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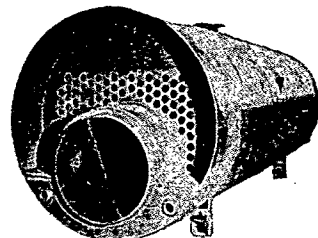
**SCOTCH WET BACK HEATING BOILERS**

Series 3000, for packaged heating units. These boilers can be used with any manufacturer's burner equipment. Two-pass design gives good distribution of heat transfer with low stack temperatures and permits easy access to tubes. Large water and steam space assures smooth operation, steady pressure, and constant heat. Among the features are:

Wet front furnace—Front end of furnace, with water all around, is flush with front of boiler. Burner can be connected to fire directly at water heating surface without heat loss.

Complete wet back—Entire combustion chamber is surrounded by water, for efficient and quick conversion of water to steam. There is no heat waste in rear; boiler room is cooler.

Sizes from 4200 to 70,000 sq ft of steam radiation.

**SCOTCH WET BACK HEATING BOILERS**  
Series 2600

Where economy of installation and operation are paramount and the space is small, F & T Series 2600 Boilers are ideal. No expensive foundations, pits, or external brick work are needed. Piping to boiler is easily installed, especially where headroom is at a minimum.

Steam space extends the entire length of the boiler, since the surface above the rear combustion chamber is covered with water. This provides large steam space and disengaging area.

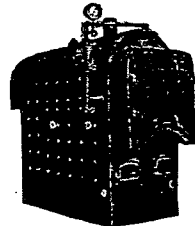
Series 2600 boilers are self-contained and can be moved easily and installed on two saddles. All parts are readily accessible for inspection and cleaning. Boilers can be furnished with special front furnace extension to suit burner requirements.

Sizes from 3160 to 42,500 sq ft of steam radiation.

**BISON COMPACT HEATING BOILERS**

Bison Compact Heating Boilers are designed to have a large furnace volume, ample water and steam storage, proper steam liberating surface and a balanced circulation. The result is a remarkably steady waterline.

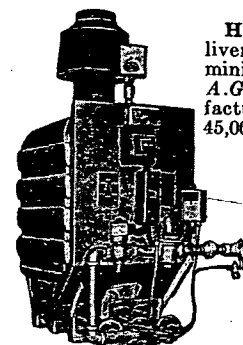
Original cost of Bison Compact Heating Boilers is low and they are easily installed. They come complete, ready for piping. Minimum brick work is required. These boilers are designed for mechanical firing with oil, gas or stoker, but can be made for hand firing with anthracite or bituminous coal. Sizes from 2680 to 42,500 sq ft of steam radiation.

**HYDROTHERM**

Northvale, New Jersey

**HYDROTHERM**

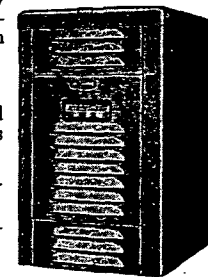
The "Packaged" Automatic Gas Heating Plant. For residential, commercial and industrial hot water systems.

Model R150 without jacket  
600 sq ft installed radiation.

HYDROTHERM is designed to deliver maximum hot-water heat with minimum fuel consumption. Fully A.G.A. approved for use on manufactured, natural and LP Gas ... from 45,000 to 500,000 Btu.

**Outstanding for:**

- Baseboard, convector and radiant panel heating systems
- Individual apartment heat
- Natural companion for central cooling system
- Booster service for 180 degree sterilizing water
- Volume hot water heating

Model R150 with jacket 425  
lbs, 16 in. x 31 in. x 27 in.

**CONSTRUCTION:** all cast iron Hydrotherm's unique absorption unit has deep ribbed horizontal sections, which are connected in zig-zag. This design affords maximum heat transfer surface for minimum water volume, resulting in greater efficiency and faster pick up. Hydrotherms are factory tested at 250 lb hydrostatic pressure and are ASME approved for 100 lb working pressure. Unit is fully wired and assembled for speedy installation. All controls including automatic gas control valve, Baco safety pilot, pressure regulator, aquastat and tridicator are enclosed in De Luxe jacket of Hammeroid finish.

**CAPACITY RANGE OF HYDROTHERMS**

| Model No. | SPACE HEATING<br>A.G.A. RATINGS     |               |                        |                               |               |                        | VOLUME WATER HEATING<br>GALLONS PER HOUR FOR<br>TEMPERATURE RISE SHOWN |     |      |      |      |                               |     |      |      |      |
|-----------|-------------------------------------|---------------|------------------------|-------------------------------|---------------|------------------------|------------------------------------------------------------------------|-----|------|------|------|-------------------------------|-----|------|------|------|
|           | Natural, Mixed and Manufactured Gas |               |                        | L.P. Gas (Propane and Butane) |               |                        | Natural, Mixed and Manufactured Gas                                    |     |      |      |      | L.P. Gas (Propane and Butane) |     |      |      |      |
|           | input Btu/Hr                        | output Btu/Hr | install- ed* radiation | input Btu/Hr                  | output Btu/Hr | install- ed* radiation | 60°                                                                    | 80° | 100° | 120° | 140° | 60°                           | 80° | 100° | 120° | 140° |
| M-45      | 45,000                              | 38,000        | 180                    | 42,000                        | 33,600        | 158                    | 72                                                                     | 54  | 43   | 36   | 30   | 67                            | 50  | 40   | 33   | 28   |
| M-72      | 72,000                              | 57,600        | 288                    | 72,000                        | 57,600        | 288                    | 115                                                                    | 86  | 69   | 57   | 49   | 115                           | 85  | 69   | 57   | 49   |
| M-85      | 85,000                              | 68,000        | 340                    | 85,000                        | 68,000        | 340                    | 136                                                                    | 102 | 81   | 68   | 58   | 136                           | 102 | 81   | 68   | 58   |
| R-100     | 100,000                             | 80,000        | 400                    | 100,000                       | 80,000        | 400                    | 160                                                                    | 120 | 96   | 80   | 68   | 160                           | 120 | 96   | 80   | 68   |
| R-120     | 120,000                             | 96,000        | 480                    | 110,000                       | 88,000        | 440                    | 192                                                                    | 144 | 115  | 96   | 82   | 176                           | 132 | 105  | 88   | 76   |
| R-150     | 150,000                             | 120,000       | 600                    | 145,000                       | 116,000       | 560                    | 240                                                                    | 180 | 144  | 120  | 103  | 232                           | 174 | 139  | 116  | 99   |
| R-170     | 170,000                             | 136,000       | 680                    | —                             | —             | —                      | 272                                                                    | 204 | 163  | 136  | 116  | —                             | —   | —    | —    | —    |
| L-200     | 200,000                             | 160,000       | 800                    | 200,000                       | 160,000       | 800                    | 320                                                                    | 240 | 192  | 160  | 137  | 320                           | 240 | 192  | 160  | 137  |
| L-250     | 250,000                             | 200,000       | 1,000                  | 225,000                       | 180,000       | 900                    | 400                                                                    | 300 | 240  | 200  | 173  | 360                           | 270 | 216  | 180  | 154  |
| R-300     | 300,000                             | 240,000       | 1,200                  | 290,000                       | 232,000       | 1,160                  | 480                                                                    | 360 | 288  | 240  | 206  | 464                           | 348 | 278  | 232  | 198  |
| R-340     | 340,000                             | 272,000       | 1,360                  | —                             | —             | —                      | 544                                                                    | 408 | 326  | 272  | 232  | —                             | —   | —    | —    | —    |
| L-400     | 400,000                             | 320,000       | 1,600                  | 400,000                       | 320,000       | 1,600                  | 640                                                                    | 480 | 384  | 320  | 274  | 640                           | 480 | 384  | 320  | 274  |
| L-500     | 500,000                             | 400,000       | 2,000                  | 450,000                       | 360,000       | 1,800                  | 800                                                                    | 600 | 480  | 400  | 346  | 720                           | 540 | 432  | 360  | 308  |

\* Indicates net load at 170°F water and includes pick-up and piping losses.



BOILER BUILDERS SINCE 1856

## THE INTERNATIONAL BOILER WORKS CO.

500 Birch St., East Stroudsburg, Pa.

Sales Offices in Principal Cities

### WATER TUBE BOILER DESIGN ASSURES...

- **QUICK STEAMING** ... due to rapid and directed water circulation.
- **MORE HEAT ABSORPTION** ... due to extra long three pass gas travel, across the entire bank of water tubes.
- **EASY CLEANING** ... free access to heating surfaces makes cleaning easy.

### INTERNATIONAL WATER TUBE BOILERS...

- Standard sizes: Heating Boilers 400-70,000 sq ft steam, Power Boilers 10-600 bhp.
- Steel Boiler Institute ratings.
- Heating Boilers 15 lbs steam-30 lbs water.
- All Boilers ASME standard
- For Oil, Gas, Stoker or hand fired Coal.

### INTERNATIONAL "COMPAK" PACKAGE BOILERS...

- Completely assembled factory fire-tested water tube package boilers.
- For low pressure and high pressure requirements.
- Oil, gas, or combination oil-gas fired.

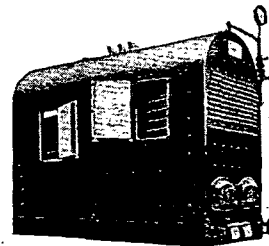
### INTERNATIONAL-LA MONT\* FORCED RECIRCULATION BOILERS

Specifically designed for ...

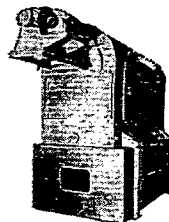
- High Temperature Water distribution systems.
- Hi-Temperature process systems employing Dowtherm, Aroclor, Socony Vacuum Heat Transfer Oil and other Thermal Liquids.

Write for complete catalog.

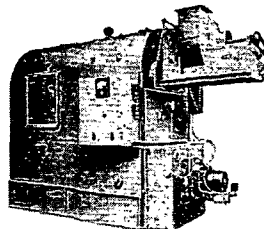
- Licensed under LaMont patents.



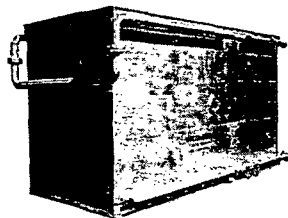
Large Heating Boiler-Type C



Induced Draft Units for Heat or Power



International "COMPAK" Package Boiler



International-LaMont High Temperature Water Generator

## Johnston Brothers, Inc.

ESTABLISHED 1864



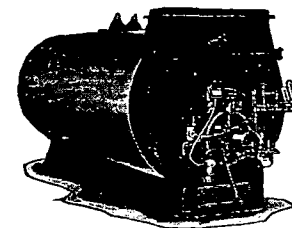
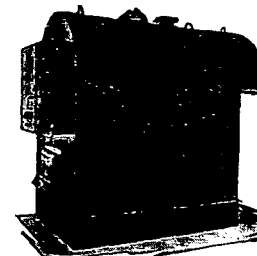
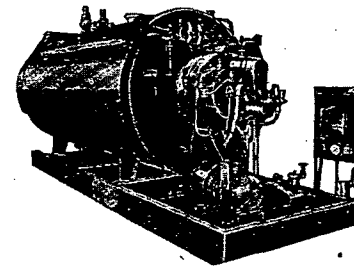
Ferrysburg, Michigan

Member



Reg. U. S. Pat. Off.

### "PACKAGED" STEAM BOILER UNIT FULLY AUTOMATIC HEAVY OIL AND/OR GAS



Standard Scotch Boiler  
Water-back Type,  
Natural Draft.

### WATER-BACK TYPE, FORCED DRAFT, THREE-PASS, TROUBLE-FREE, EFFICIENT.

Catalog-Rating guaranteed and at least 25 per cent overloads readily obtained.

**HIGH PRESSURE TYPE** from 60 to 800 hp and pressures of 125, 150 and 200 lb psi (250 lb available as a special)

**LOW PRESSURE TYPE** for heating; 15 lb pressure, and EDR rating from 2190 sq ft to 42,500 sq ft steam.

ASME Code construction. Underwriters' Laboratory and Factory Mutual Approved. Specification Forms in detail to exactly cover the requirements of any particular job will be furnished upon request and without any obligation whatever. Ask for *Bulletin 509 A*

Firebox Heating Boiler, Compact Type. Oil, Gas, Stoker or Hand Firing. Three-Pass, 15 lb pressure, ASME Code. Capacities 2190 to 42,500 sq ft, SBI rating. Ask for *Bulletin 1500*.

Also built for High Pressure (125 psi.) Ask for *Bulletin 702*.

### POWER, PROCESS, HEATING

25 to 300 hp and pressures 15 lb to 200 lb psi. For mechanical firing with Coal, Gas or Oil. Overloads up to 200 per cent of rating readily developed. Oil or Gas firing equipment and controls can be installed for completely automatic operation and in emergency or fuel scarcity, can be readily converted to Coal firing.

Ask for *Bulletin 4000 and 9000 and 9200*.



# KEWANEE BOILER DIVISION

of American-Standard

101 FRANKLIN STREET, KEWANEE, ILLINOIS



KEWANEE OFFERS A COMPLETE LINE of boilers for every type and size of building. All fuels can be used. The policy of Kewanee for more than eighty-five years has been to build boilers that can be depended on to deliver more than rated capacity. The Kewanee Reserve Plus rating certifies up to 50 per cent more power is built into every Kewanee boiler. This assures efficiency, low cost operation and low maintenance cost.

All Kewanee boilers meet or exceed the ASME Code for construction, and comply with the SBI Code for ratings.

1558

## SPECIFICATIONS KEWANEE "500" SERIES

| Boiler Number       | 576    | 577    | 578    | 579    | 580    | 581    | 582    | 583    | 584    | 585    | 586     | 587     | 588     | 589     | 590     |
|---------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|---------|---------|---------|
| Rating—horsepower   | 30     | 35     | 44     | 53     | 61     | 74     | 87     | 100    | 120    | 130    | 152     | 174     | 217     | 261     | 304     |
| —Btu per hour       | 4200   | 4800   | 5470   | 6800   | 7200   | 8600   | 10300  | 12150  | 15180  | 18220  | 21250   | 24200   | 30350   | 36430   | 42500   |
| Boiler Diameter     | 30 in. | 36 in. | 42 in. | 48 in. | 54 in. | 60 in. | 66 in. | 72 in. | 84 in. | 90 in. | 100 in. | 110 in. | 120 in. | 130 in. | 140 in. |
| Boiler Length       | 8-7    | 9-6    | 10-6   | 11-6   | 12-6   | 13-6   | 14-6   | 15-6   | 16-6   | 17-6   | 18-6    | 19-6    | 20-6    | 21-6    | 22-6    |
| Steam Supply Height | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2     | 7-2     | 7-2     | 7-2     | 7-2     |
| Water Line Height   | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1     | 6-1     | 6-1     | 6-1     | 6-1     |

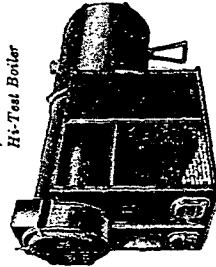
## SPECIFICATIONS KEWANEE HI-TEST BOILER

Mechanically Fired—oil, gas or stoker

| Boiler Number          | HT500  | HT600  | HT750  | HT1000 | HT1200 | HT1500 | HT2000 | HT2500 |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Rating—horsepower      | 61     | 73     | 81     | 122    | 152    | 182    | 243    | 304    |
| —Btu per hour          | 8100   | 9600   | 10800  | 16200  | 20250  | 24300  | 32400  | 38500  |
| Cylinder Diameter      | 20 in. | 24 in. | 28 in. | 36 in. | 42 in. | 48 in. | 54 in. | 60 in. |
| Boiler Length, ft.-in. | 5-6    | 5-6    | 5-6    | 6-6    | 7-0    | 7-0    | 7-6    | 8-0    |
| Steam Supply Height    | 3-5    | 3-5    | 3-5    | 3-5    | 3-5    | 3-5    | 3-5    | 3-5    |
| Water Line Height      | 2-5    | 2-5    | 2-5    | 2-5    | 2-5    | 2-5    | 2-5    | 2-5    |
| Water Line Height      | 2-5    | 2-5    | 2-5    | 2-5    | 2-5    | 2-5    | 2-5    | 2-5    |

Height figures do not include base.

Hi-Test Boiler



Heating Systems • Boilers, Steel

Mechanically Fired—oil, gas or stoker

Heavy Duty Two-Pass Tubular Boilers for High Pressure.

To cover a wide range of usage there are 8 sizes of Hi-Test 2-Pass Tubular Boilers for power or industrial Process Steam—61 to 304 hp—Streamline construction, quick steaming—compact. Joints are fusion welded. X-Ray checked. Designed for refractory lined fire-box, making it entirely self-contained.

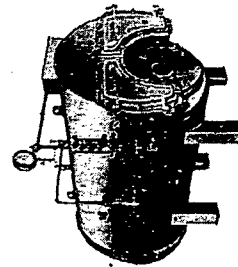
## KEWANEE SCOTCH TYPE BOILERS

For Commercial and Industrial Use

High and Low Pressure

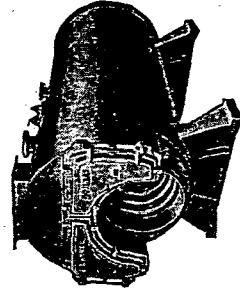
THERE ARE SIX SIZES of the Welded Scottie Jr., all capable of carrying large overloads without loss of efficiency—Under-slung design means more headroom—comes ready to hook up—easy to clean—rear combustion chamber has refractory lining installed at the factory. Can be ordered as packaged boiler burner unit.

LOW IN OPERATING COST YET HIGH IN EFFICIENCY—that's the M-800 Scotch type boiler for high and low pressure steam or hot water heating—burns oil or gas. There are 13 sizes from 5,470 to 42,500 sq ft high pressure steam, 125-150 lbs working pressure. Low pressure sizes from 1,313,000 to 10,200,000 Btu, 15 lbs steam or 30 lbs water.



Scottie Jr. 18 to 44 hp 185-160 lbs W.P.

Kewanee Boiler Div.  
of American-Standard



M-800 High Pressure

1559

## SPECIFICATIONS KEWANEE SCOTTIE JUNIOR Mechanically Fired—oil or gas

| Boiler Number         | HM-372-J | HM-373-J | HM-374-J | HM-375-J | HM-376-J | HM-377-J | HM-378-J | HM-379-J |
|-----------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Rating—horsepower     | 12       | 13       | 16       | 20       | 26       | 30       | 39       | 44       |
| —Btu per hour         | 1000     | 1000     | 1000     | 1000     | 1000     | 1000     | 1000     | 1000     |
| Boiler Shell Diameter | 3-6      | 3-6      | 3-6      | 3-6      | 3-6      | 3-6      | 3-6      | 3-6      |
| Boiler Length         | 6-10     | 6-10     | 6-10     | 6-10     | 6-10     | 6-10     | 6-10     | 6-10     |
| Steam Supply Height   | 3-10     | 3-10     | 3-10     | 3-10     | 3-10     | 3-10     | 3-10     | 3-10     |
| Water Line Height     | 3-10     | 3-10     | 3-10     | 3-10     | 3-10     | 3-10     | 3-10     | 3-10     |

## SPECIFICATIONS KEWANEE M-800 SERIES

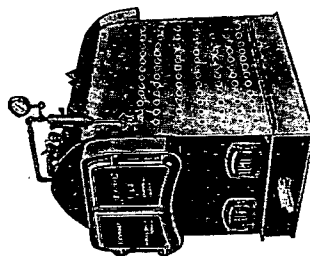
| Boiler Number              | HM-578 | HM-579 | HM-580 | HM-581 | HM-582 | HM-583 | HM-584 | HM-585 | HM-586 | HM-587 | HM-588  | HM-589  | HM-590  |
|----------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|---------|
| Rating—horsepower          | 30     | 35     | 44     | 53     | 61     | 74     | 87     | 100    | 120    | 130    | 152     | 174     | 217     |
| —Btu per hour              | 4200   | 4800   | 5470   | 6800   | 7200   | 8600   | 10300  | 12150  | 15180  | 18220  | 21250   | 24200   | 30350   |
| Boiler Diameter            | 30 in. | 36 in. | 42 in. | 48 in. | 54 in. | 60 in. | 66 in. | 72 in. | 84 in. | 90 in. | 100 in. | 110 in. | 120 in. |
| Boiler Length              | 8-7    | 9-6    | 10-6   | 11-6   | 12-6   | 13-6   | 14-6   | 15-6   | 16-6   | 17-6   | 18-6    | 19-6    | 20-6    |
| Steam Supply Height        | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2    | 7-2     | 7-2     | 7-2     |
| Water Line Height—low pr.  | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1     | 6-1     | 6-1     |
| Water Line Height—high pr. | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1    | 6-1     | 6-1     | 6-1     |

\* Water radiation 60 per cent more than steam.

Heating Systems • Boilers, Steel

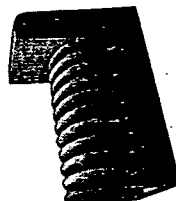
**KEWANEE TYPE "C" BOILER**  
With Corrugated Crown Sheet

Here is a compact boiler requiring a minimum of floor space yet produces steam in great amounts, at low cost, especially adaptable for heating large buildings at low cost without sacrificing efficiency, uses oil, gas, or stoker. Available in 13 sizes.



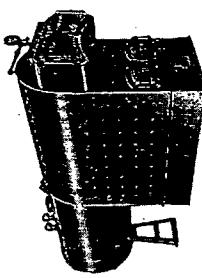
Type "C" Boiler

The Corrugated Crown Sheet, exclusive with Kewanee, has many advantages over conventional designs. Corrugations add strength and provide additional heating surface next to the fire. Being right-side-up eliminates pockets to collect sediment. Water circulating over the crown sheet makes it self-cleaning.



Corrugated Crown Sheet

**KEWANEE "5000" SERIES**



"5000" Welded Boiler

Features large heating surface, steam space, disengaging area, furnace volume and water content. All seams are welded. Fifteen sizes ranging from 4,250 to 42,500 sq ft steam.

1560

**SPECIFICATIONS KEWANEE TYPE "C"**

| Boiler Number                     | 7L78   | 7L79 | 7L80 | 7L81 | 7L82  | 7L83  | 7L84  | 7L85  | 7L86  | 7L87  | 7L88  | 7L89  | 7L90  |
|-----------------------------------|--------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| SBI Rating—steam radiation*—sq ft | 5470   | 6080 | 7290 | 8600 | 10330 | 12150 | 15190 | 18220 | 21260 | 24290 | 30380 | 36430 | 42490 |
| SBI Rating—Btu per hour           | 1459   | 1750 | 2040 | 2400 | 2779  | 3216  | 3843  | 4473  | 5100  | 5850  | 7000  | 8150  | 9300  |
| SBI Net Rating—steam*—sq ft       | 4000   | 5000 | 6000 | 7000 | 8000  | 9000  | 10000 | 11000 | 12000 | 13000 | 14000 | 15000 | 16000 |
| SBI Net Rating—Btu per hour       | 1000's | 1200 | 1400 | 1600 | 1800  | 2000  | 2200  | 2400  | 2600  | 2800  | 3000  | 3200  | 3400  |
| Boiler Width—ft.-in.              | 3-6    | 3-6  | 3-6  | 3-6  | 3-6   | 3-6   | 3-6   | 3-6   | 3-6   | 3-6   | 3-6   | 3-6   | 3-6   |
| Boiler Length—ft.-in.             | 8-2    | 8-2  | 8-4  | 8-4  | 8-4   | 8-4   | 8-4   | 8-4   | 8-4   | 8-4   | 8-4   | 8-4   | 8-4   |
| Boiler Height—ft.-in.             | 7-3    | 7-3  | 7-3  | 7-3  | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   |
| Boiler Supply Height—ft.-in.      | 7-3    | 7-3  | 7-3  | 7-3  | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   | 7-3   |
| Water Line Height—ft.-in.         | 6-4    | 6-4  | 6-4  | 6-4  | 6-4   | 6-4   | 6-4   | 6-4   | 6-4   | 6-4   | 6-4   | 6-4   | 6-4   |

\* Water radiation 60 per cent more than steam.

**SPECIFICATIONS KEWANEE "5000" SERIES**

| Boiler Number                     | 5176   | 5177 | 5178 | 5179 | 5180 | 5181 | 5182 | 5183 | 5184 | 5185  | 5186  | 5187  | 5188  | 5189  | 5190  |
|-----------------------------------|--------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|
| SBI Rating—steam radiation*—sq ft | 4250   | 4890 | 5530 | 6170 | 6810 | 7450 | 8090 | 8730 | 9370 | 10010 | 10650 | 11290 | 11930 | 12570 | 13210 |
| SBI Rating—Btu per hour           | 1000's | 1020 | 1158 | 1296 | 1434 | 1572 | 1710 | 1848 | 1986 | 2124  | 2262  | 2400  | 2538  | 2676  | 2814  |
| SBI Net Rating—steam*—sq ft       | 3800   | 4400 | 5000 | 5600 | 6200 | 6800 | 7400 | 8000 | 8600 | 9200  | 9800  | 10400 | 11000 | 11600 | 12200 |
| SBI Net Rating—Btu per hour       | 1000's | 960  | 1080 | 1200 | 1320 | 1440 | 1560 | 1680 | 1800 | 1920  | 2040  | 2160  | 2280  | 2400  | 2520  |
| Boiler Diameter—ft.-in.           | 3-6    | 3-6  | 3-6  | 3-6  | 3-6  | 3-6  | 3-6  | 3-6  | 3-6  | 3-6   | 3-6   | 3-6   | 3-6   | 3-6   | 3-6   |
| Boiler Length—ft.-in.             | 8-0    | 8-0  | 8-0  | 8-0  | 8-0  | 8-0  | 8-0  | 8-0  | 8-0  | 8-0   | 8-0   | 8-0   | 8-0   | 8-0   | 8-0   |
| Boiler Height—ft.-in.             | 7-1    | 7-1  | 7-1  | 7-1  | 7-1  | 7-1  | 7-1  | 7-1  | 7-1  | 7-1   | 7-1   | 7-1   | 7-1   | 7-1   | 7-1   |
| Boiler Supply Height—ft.-in.      | 7-1    | 7-1  | 7-1  | 7-1  | 7-1  | 7-1  | 7-1  | 7-1  | 7-1  | 7-1   | 7-1   | 7-1   | 7-1   | 7-1   | 7-1   |
| Water Line Height—ft.-in.         | 6-10   | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10  | 6-10  | 6-10  | 6-10  | 6-10  | 6-10  |

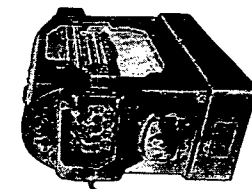
\* Water radiation 60 per cent more than steam.

**Mechanically Fired—oil, gas or stoker**

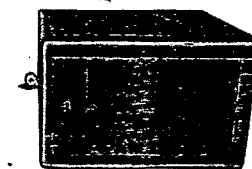
| Boiler Number                     | 7L86  | 7L87  | 7L88  | 7L89  | 7L90  |
|-----------------------------------|-------|-------|-------|-------|-------|
| SBI Rating—steam radiation*—sq ft | 21260 | 24290 | 27320 | 30350 | 33380 |
| SBI Rating—Btu per hour           | 5100  | 5850  | 6600  | 7350  | 8100  |
| SBI Net Rating—steam*—sq ft       | 14000 | 16000 | 18000 | 20000 | 22000 |
| SBI Net Rating—Btu per hour       | 3200  | 3600  | 4000  | 4400  | 4800  |
| Boiler Width—ft.-in.              | 6-0   | 6-0   | 6-0   | 6-0   | 6-0   |
| Boiler Length—ft.-in.             | 12-1  | 13-4  | 14-8  | 16-1  | 17-5  |
| Boiler Height—ft.-in.             | 11-2  | 11-2  | 11-2  | 11-2  | 11-2  |
| Boiler Supply Height—ft.-in.      | 9-5   | 9-5   | 9-5   | 9-5   | 9-5   |
| Water Line Height—ft.-in.         | 8-7   | 8-7   | 8-7   | 8-7   | 8-7   |

**Mechanically Fired—oil, gas or stoker**

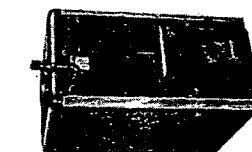
| Boiler Number                     | 5185  | 5186  | 5187  | 5188  | 5189  | 5190  |
|-----------------------------------|-------|-------|-------|-------|-------|-------|
| SBI Rating—steam radiation*—sq ft | 18220 | 21260 | 24290 | 27320 | 30350 | 33380 |
| SBI Rating—Btu per hour           | 4300  | 4800  | 5300  | 5800  | 6300  | 6800  |
| SBI Net Rating—steam*—sq ft       | 12000 | 14000 | 16000 | 18000 | 20000 | 22000 |
| SBI Net Rating—Btu per hour       | 2600  | 2800  | 3000  | 3200  | 3400  | 3600  |
| Boiler Diameter—ft.-in.           | 5-6   | 5-6   | 5-6   | 5-6   | 5-6   | 5-6   |
| Boiler Length—ft.-in.             | 14-4  | 16-1  | 17-5  | 18-9  | 20-3  | 21-7  |
| Boiler Height—ft.-in.             | 10-1  | 10-1  | 10-1  | 10-1  | 10-1  | 10-1  |
| Boiler Supply Height—ft.-in.      | 9-1   | 9-1   | 9-1   | 9-1   | 9-1   | 9-1   |
| Water Line Height—ft.-in.         | 8-0   | 8-0   | 8-0   | 8-0   | 8-0   | 8-0   |



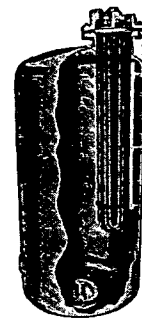
Square "R"



Round "R"



W Series



KEWANEE STORAGE WATER HEATERS

For installations where there are sudden demands for plenty of hot water and where exhaust or live steam is available. Capacities 95 to 2,240 gph. Equipped with supporting cradles.

**KEWANEE TYPE "R" RESIDENCE BOILERS**

Kewanee builds these smaller boilers with the same skill and engineering excellence as found in larger units. Ideally suited for medium and small size buildings and larger homes . . . and designed for oil, gas or stoker firing. Noted for dependability, economy, and ability to withstand many years of rugged service.

**SQUARE-HEAT TYPE "R"** comes in twelve sizes from 900 to 5,000 sq ft steam. Can be furnished with attractive jacket.

**ROUND TYPE "R"** available in 4 sizes from 400 to 900 sq ft steam. With Square or insulated round jacket. The W Series boilers are designed for forced hot water heating in small homes. 74,000 to 189,000 Btu. Occupy small space . . . sturdy steel jacket in two-tone green. Also available as oil or gas fired OW, GW Series boiler-burner units.

**DIRECT FIRED WATER HEATERS**

Ideal for any building requiring large quantities of hot water. 150 lbs hydro-static test for 100 lbs water working pressure. Easy to clean. The Tabasco Heater comes in five sizes to heat 165 to 700 gal of water 50 deg per hour. Burns any fuel.



**SQUARE-HEAT TYPE "R"**

| Boiler Number               | 3R1    | 3R2  | 3R3  | 3R4  | 3R5  | 3R6  | 3R7  | 3R8  | 3R9  | 3R10 | 3R11 | 3R12 | 3R13 | 3R14 | 3R15 |
|-----------------------------|--------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| SBI Net Rating—steam—sq ft  | 900    | 1100 | 1300 | 1500 | 1800 | 2200 | 2600 | 3000 | 3500 | 4000 | 4500 | 5000 | 5500 | 6000 | 6500 |
| SBI Rating—Btu per hour     | 210    | 260  | 310  | 360  | 420  | 480  | 540  | 600  | 660  | 720  | 780  | 840  | 900  | 960  | 1020 |
| SBI Net Rating—Btu per hour | 1000's | 100  | 120  | 140  | 160  | 180  | 200  | 220  | 240  | 260  | 280  | 300  | 320  | 340  | 360  |
| Heating Surface—sq ft       | 23     | 28   | 33   | 38   | 43   | 48   | 53   | 58   | 63   | 68   | 73   | 78   | 83   | 88   | 93   |
| Boiler* Shell Wid. o-ell    | 2-6    | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  |
| Boiler* Shell Lenth. o-ell  | 2-6    | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  |
| Boiler* Height—ft.-in.      | 2-6    | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  | 2-6  |
| Water Line Height—ft.-in.   | 4-7    | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  | 4-7  |

**W Series**

| Boiler Number               | W-1    | W-2 | W-3 | W-4 | W-5 |
|-----------------------------|--------|-----|-----|-----|-----|
| SBI Net Rating—steam—sq ft  | 400    | 500 | 600 | 700 | 800 |
| SBI Rating—Btu per hour     | 96     | 120 | 144 | 168 | 192 |
| SBI Net Rating—Btu per hour | 1000's | 10  | 12  | 14  | 16  |
| Heating Surface—sq ft       | 21     | 26  | 31  | 36  | 41  |
| Boiler* Shell Wid. o-ell    | 2-0    | 2-0 | 2-0 | 2-0 | 2-0 |
| Boiler* Shell Lenth. o-ell  | 2-0    | 2-0 | 2-0 | 2-0 | 2-0 |
| Boiler* Height—ft.-in.      | 2-0    | 2-0 | 2-0 | 2-0 | 2-0 |
| Water Line Height—ft.-in.   | 3-1    | 3-1 | 3-1 | 3-1 | 3-1 |

\* Jacket measurements for W Series.

\*\* For gas firing only.

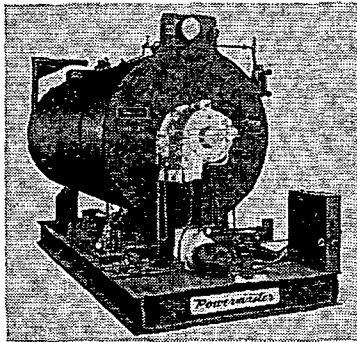
1561

# Orr & Sembower, Inc.

Established 1885

Morgantown Road, Reading, Pa.

## Powermaster® PACKAGED AUTOMATIC BOILERS



Powermaster boilers are modern, compact, self-contained, automatic units with an outstanding record for highly dependable and efficient performance in public buildings, hospitals, schools, apartments, industrial plants and other installations. Two models are available in standard sizes of 15 hp to 500 hp for steam generation to 250 psi, and for hot water to 30 psi. As delivered, Powermasters are completely factory-assembled on a structural steel base for simple installation. Both models are designed and built to ASME Boiler Code requirements, approved by Underwriters' Lab-

oratories, Inc., and fully guaranteed by Orr & Sembower, Inc. All units are thoroughly factory-tested under fire.

**Advantages**—Cost-saving installation... space-saving compactness... fuel-saving efficiency at all loads... fast steaming... instant response to load swings... clean, dry steam... hospital-clean operation... maintenance-saving accessibility... fully automatic operating and safety controls... one-source responsibility for complete unit... nation-wide factory trained service.

**Model 3 Powermaster (40-500 hp)** provides... Complete fuel flexibility: Light or heavy oil, any gas or combination oil and gas... Choice of: Air atomizing oil burner—pre-mix gas burner—combination oil and gas burner—all designed and built by O & S... full-range modulation... selection of automatic operating and safety controls... instant change from fuel to fuel.

**Model 4 Powermaster (15-100 hp)** provides... Choice of fuels: Light distillate—natural gas—manufactured gas—combination oil and gas... Choice of: Mechanical pressure atomizing oil burner—pre-mix gas burner—combination oil and gas burner—all designed and built by O & S... dependable on-off and low-fire start burners... selection of automatic operating and safety controls... quick change from fuel to fuel.

| BOILER<br>Hp | OUTPUT                         |                         |                         | OVERALL DIMENSIONS |        |        |         |                      | WEIGHT<br>Lb | Fuel Consump. (100%<br>of rating) |                     |  |
|--------------|--------------------------------|-------------------------|-------------------------|--------------------|--------|--------|---------|----------------------|--------------|-----------------------------------|---------------------|--|
|              | Lbs<br>Steam/<br>Hr at<br>212F | EDR<br>(Water)<br>Sq Ft | EDR<br>(Steam)<br>Sq Ft | Length             | Width  |        | Height  | #2 Oil<br>Gal/<br>Hr |              | #6 Oil<br>Gal/<br>Hr              | Gas<br>Cu Ft/<br>Hr |  |
|              |                                |                         |                         |                    | Oil    | Gas    |         |                      |              |                                   |                     |  |
| 15           | 517                            | 3,336                   | 2,085                   | 7' 0"              | 3' 7"  | 4' 0"  | 5' 4"   | 2,700                | 4.7          | —                                 | 628                 |  |
| 20           | 690                            | 4,448                   | 2,780                   | 7' 11"             | 3' 7"  | 4' 0"  | 5' 4"   | 2,900                | 6.2          | —                                 | 837                 |  |
| 30           | 1,035                          | 6,672                   | 4,170                   | 8' 9"              | 4' 1"  | 4' 6"  | 6' 2"   | 3,750                | 9.4          | —                                 | 1,255               |  |
| 40           | 1,380                          | 8,896                   | 5,560                   | 10' 2"             | 4' 9"  | 5' 3"  | 6' 9"   | 6,350                | 12.5         | 10.8                              | 1,673               |  |
| 50           | 1,725                          | 11,120                  | 6,950                   | 11' 8"             | 4' 9"  | 5' 3"  | 6' 9"   | 6,750                | 15.6         | 13.5                              | 2,091               |  |
| 60           | 2,070                          | 13,344                  | 8,340                   | 10' 6"             | 5' 9"  | 6' 3"  | 7' 4"   | 7,900                | 18.7         | 16.1                              | 2,510               |  |
| 70           | 2,415                          | 15,568                  | 9,730                   | 11' 6"             | 5' 9"  | 6' 3"  | 7' 4"   | 8,500                | 21.9         | 18.8                              | 2,928               |  |
| 80           | 2,760                          | 17,792                  | 11,120                  | 11' 9"             | 6' 2"  | 6' 10" | 8' 1"   | 10,700               | 25.0         | 21.5                              | 3,346               |  |
| 100          | 3,450                          | 22,240                  | 13,900                  | 11' 3"             | 6' 7"  | 7' 3"  | 8' 8"   | 12,500               | 31.2         | 26.9                              | 4,183               |  |
| 125          | 4,312                          | 27,800                  | 17,375                  | 13' 1"             | 6' 7"  | 7' 3"  | 8' 8"   | 14,000               | 39.1         | 33.6                              | 5,229               |  |
| 150          | 5,175                          | 33,360                  | 20,850                  | 14' 7"             | 7' 11" | 8' 9"  | 9' 5"   | 17,350               | 46.9         | 40.4                              | 6,274               |  |
| 200          | 6,900                          | 44,480                  | 27,900                  | 18' 7"             | 7' 11" | 8' 9"  | 9' 6"   | 22,100               | 62.5         | 53.8                              | 8,366               |  |
| 250          | 8,625                          | 55,600                  | 34,750                  | 15' 7"             | 8' 1"  | 8' 11" | 9' 11"  | 25,560               | 78.1         | 67.3                              | 10,457              |  |
| 300          | 10,350                         | 66,720                  | 41,700                  | 17' 5"             | 8' 1"  | 8' 10" | 9' 11"  | 33,700               | 93.8         | 80.7                              | 12,548              |  |
| 350          | 12,075                         | 77,840                  | 48,650                  | 17' 9"             | 9' 0"  | 9' 10" | 10' 11" | 36,000               | 109.4        | 94.2                              | 14,639              |  |
| 400          | 13,800                         | 88,960                  | 55,600                  | 18' 11"            | 9' 1"  | 9' 10" | 10' 11" | 37,000               | 125.0        | 107.7                             | 16,731              |  |
| 500          | 17,250                         | 111,200                 | 69,500                  | 19' 7"             | 9' 1"  | 10' 0" | 11' 8"  | 45,000               | 156.3        | 134.6                             | 20,914              |  |

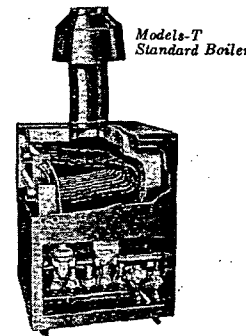


# Raypak Company, Inc.

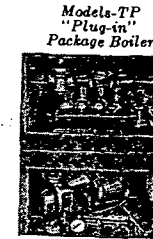
2416 Chico Avenue, El Monte, Calif.

HOT WATER BOILERS • Gas fired • Copper Water Tube

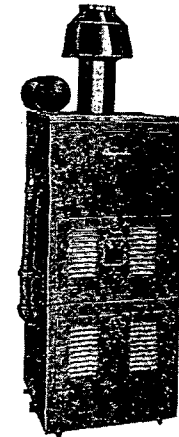
All models approved by A.G.A.  
Complies with ASME Code for low-pressure hot water boilers.



Models-T  
Standard Boiler



Models-TP  
"Plug-in"  
Package Boiler



## SPECIFICATIONS

|           | Btu<br>input | Btu<br>output | EDR        | 60° rise | 100° rise | Weight  |
|-----------|--------------|---------------|------------|----------|-----------|---------|
| Model 75  | 75,000       | 60,000        | 400 sq ft  | 120 gph  | 72 gph    | 125 lbs |
| Model 110 | 110,000      | 88,000        | 586 sq ft  | 176 gph  | 106 gph   | 160 lbs |
| Model 160 | 160,000      | 128,000       | 853 sq ft  | 257 gph  | 154 gph   | 195 lbs |
| Model 225 | 225,000      | 180,000       | 1200 sq ft | 360 gph  | 216 gph   | 225 lbs |

All models listed also available as packaged "plug-in" boilers for central heating, including expansion tank, transformer DPST relay, air vent, automatic fill, thermometer, pressure gauge, relief valve and high head circulator; all piped, wired and jacketed. Special packaging for swimming pool direct heating with self-contained independent electrical system, thermometer and low-water cut-off.

## COMPACTNESS FEATURED

All three Raypak models are similar in exterior appearance to those illustrated with controls concealed and protected and are available in every Btu size. Raypak is quiet-engineered, a packaged boiler of single-shell construction with heavy 18-gauge baked enamel jacket.

Model 75 is designed primarily for central heating. All models are adaptable to radiant heating, swim pools, (included sensitive pressure detector for low-water cut-off), air conditioning, volume supply and baseboard radiation.

## EXTRA ADVANTAGES

Quiet efficient modulating gas valve operates at any temperature, sizes the boiler for the job. Heavy wall monolithic cast insulated refractory keeps outside cool to touch. Integral copper fin tube heat exchanger in grid form, extra heavy headers, concealed and

protected controls, electric diaphragm main gas valve are features of all models. Raypaks are condensate protected with clean air foil transfer surfaces. Minimum pressure drop is assured, plus equal tube flow.

## RADIANT HEATING, BASEBOARD RADIATION AND AIR CONDITIONING COIL UNITS

Model-T and -TP, designed primarily for residential and small commercial heating, combine on-off firing with gas modulation... turns off and on at lowest flame for quietness and to minimize excessive firing. Model-75 preferred in group construction installations for lightness (125 pounds) and easy one-man installation. Occupies only 1½ sq ft of floor space or can install elevated. Controls concealed—no installation clutter. All models have 100 per cent copper waterways, preventing electrolysis, rust, ferric corrosion or water discoloration.

# THE TITUSVILLE IRON WORKS CO.

TITUSVILLE, PENNSYLVANIA

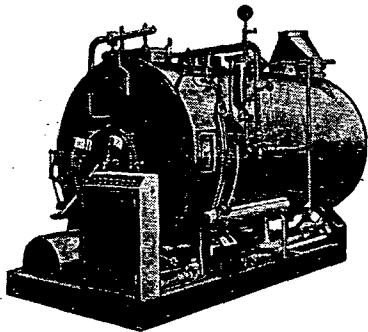
DIVISION OF STRUTHERS WELLS CORPORATION

Designers and Manufacturers of



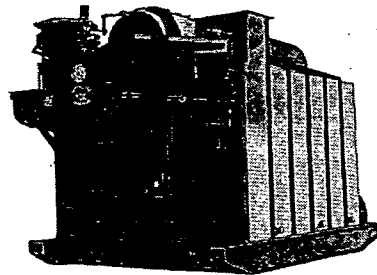
Dependable **A.S.M.E. CODE** **BOILERS...since 1860**

## PACKAGE BOILERS



Type Designation Ticosteam

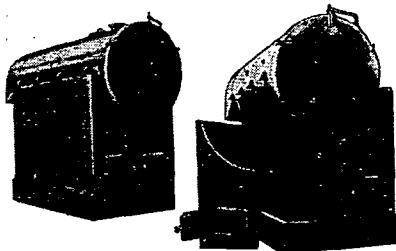
The Ticosteam Generator is a packaged steam power plant, completely equipped at the factory, tested and certified. Essentially the unit is a three-pass, constant furnace pressure, forced draft, fire tube, horizontal boiler, with burners of special design using any desired type of gas, fuel oil, or combination of the two. Built in sizes from 20 hp to 350 hp, this unit provides outstanding economy in operation, with thermal efficiencies of not less than 80 per cent.



Type Designation WTP

The Titusville Type WTP Water Tube Steam Generator is completely shop-assembled, ready for operation as soon as service connections are made. The Type WTP features forced draft, pressurized furnace operation, and requires no high stack or induced draft fan. It is adapted for firing with heavy oil, light oil, natural gas, coke oven gas or manufactured gas, and combinations of these fuels. Capacities are from 7,500 to 40,000 lbs of steam per hour.

## TYPE CM SPLIT FIREBOX BOILER

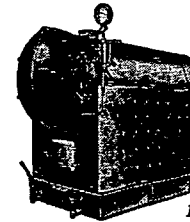


Designed for replacement installations where entrance conditions are not sufficient to accommodate standard boilers, the Titusville Type CM Split Firebox Boiler offers maximum utility and convenience. Separating into four basic sections (see cut), the Split Firebox CM Boiler can be taken easily through narrow doors and passageways impossible to negotiate by standard models, without damage or alterations to building. Wide range of sizes and capacities.

# THE TITUSVILLE IRON WORKS CO.

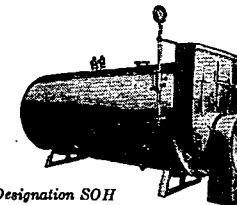
Titusville, Pennsylvania

## LOW PRESSURE HEATING BOILERS



Type Designation CM

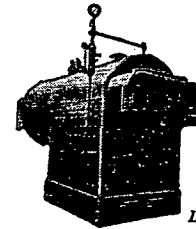
Titusville Compact Steel Heating Boilers built in 22 sizes ranging from 129 square feet to 3571 square feet heating surface, and maximum steam working pressure 15 psig.



Type Designation SOH

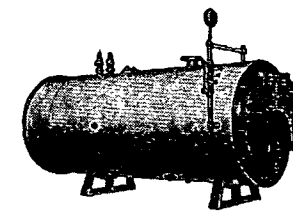
Titusville Scotch Marine Heating Boilers built in 22 sizes from 129 square feet to 3571 square feet heating surface, and maximum steam working pressure 15 psig.

## HIGH PRESSURE FIRETUBE BOILERS



Type Designation WP

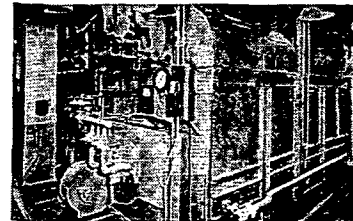
Titusville All-Welded Portable High Pressure Firebox Boilers built in 12 sizes ranging from 250 square feet to 2500 square feet heating surface, steam pressure 100 psig, 125 psig and 150 psig.



Type Designation Wee Scot to 50 HP, SP above 50 HP

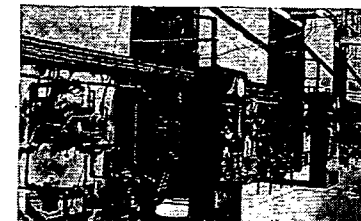
Titusville Scotch Marine Power Boilers built in 13 sizes ranging from 97 square feet to 3000 square feet heating surface. Pressures 125 psig and 150 psig.

## WATER TUBE BOILERS



Type Designation Ticotherm

Titusville Ticotherm Steam Generators built in 13 standard sizes ranging from 1000 square feet to 5000 square feet heating surface. Pressures 160 psig, 200 psig, 250 psig and higher.



Type Designation TDL

Titusville Three Drum Low Head Water Tube Boilers built in numerous sizes ranging from 729 square feet to 6109 square feet heating surface. Pressures 150 psig, 200 psig, 250 psig and higher.

Descriptive technical literature is available on request.



## Preferred Utilities Manufacturing Corp.



1860A Broadway, New York 23, N. Y.

Sales Offices in Principal Cities

Unit Steam Generators • Oil, Gas and Combination Burners  
Draft-A-Justors • Fuel Oil Heaters • Heating Accessories

### PREFERRED UNIT STEAM GENERATOR

The fully automatic "package" boiler of outstanding reputation for producing steam or hot water at a low overall operating cost. Burns oil, gas or both fuels in combination with equally high efficiency.

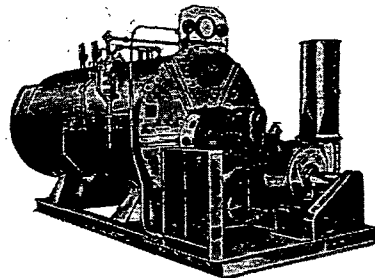
Factory fire-tested before shipment, every Preferred Unit is certified to operate at a guaranteed thermal efficiency of 80 per cent or more. Its fast steaming means faster response to fluctuating boiler loads.

The unit, fully piped and wired, is mounted on a heavy H-beam base so that no excavation or special foundation, frequently a major item of installation cost, is necessary. It occupies about half the space needed by ordinary boilers of equivalent output. No ugly, costly stack is needed.

Capacity—20 to 600 bhp, 15 to 250 psig (see table).

#### Preferred's 25 Year Features

- 1—5 sq ft of Heating Surface per boiler horsepower for reliable, economical, continuous steam production.
- 2—Four-Pass Gas Travel for uniform heat distribution, quick steaming; clean heat transfer surfaces minimize tube cleaning; lower stack temperature.
- 3—Down Draft Design for guaranteed high operating efficiency and low off-period losses.
- 4—Induced Draft for smoother starting, higher combustion efficiency, less refractory maintenance.
- 5—Intermediate Furnace Position protects tube areas and safeguards shell from unequal heating.
- 6—Expansile Precipitator, installed in flue gas offtake, prevents rapid build-up of non-combustible deposits.
- 7—Staggered Tubes insure thorough heat wiping of the entire tube circumference at all times; makes possible faster heat pick-up rate.
- 8—Anti-Stress Deck keeps the sections of the rear tube sheet, above and below water line, in close balance, preventing unequal stress action within the area.



19 Standard Sizes

| BHP Rating | Max. Rated Capacity Lbs Steam per hr at 212 F. | BHP Rating | Max. Rated Capacity Lbs Steam per hr at 212 F. |
|------------|------------------------------------------------|------------|------------------------------------------------|
| 20         | 690                                            | 200        | 6900                                           |
| 30         | 1035                                           | 250        | 8625                                           |
| 40         | 1380                                           | 300        | 10350                                          |
| 50         | 1725                                           | 350        | 12075                                          |
| 60         | 2070                                           | 400        | 13800                                          |
| 70         | 2415                                           | 450        | 15525                                          |
| 80         | 2760                                           | 500        | 17250                                          |
| 100        | 3450                                           | 550        | 18975                                          |
| 125        | 4313                                           | 600        | 20700                                          |
| 150        | 5175                                           |            |                                                |

9—Dual Purging Action removes gas vapors from the entire vessel before and after firing.

10—Horizontal Rotary Burner for oil, gas or combination—starts, ignites, follows the load, shuts off, cleans and purges itself automatically.

For detailed information write for Bulletin 2000.

#### Other Preferred Products

Horizontal Rotary Burners for oil (7½ to 175 gph); for gas and oil (15 to 90 gph-oil) and (2050 to 12,300 cfm of 1050 Btu gas).

"Thermopak" completely integrated oil or gas combustion system for existing boilers of 20 to 525 bhp.

Pump and Heater Sets for preheating oil, 110 to 1200 gph.

Draft-A-Justors, barometric type for controlling stack draft.

Fuel Oil Heaters, Combustion controls, Oil Valves, Gauges, Boiler Accessories.

## Vapor Heating Corporation

80 East Jackson Blvd., Chicago 4, Illinois

NEW YORK • ST. PAUL • WASHINGTON • PHILADELPHIA • ATLANTA • SAN FRANCISCO  
HOUSTON • RICHMOND • LOS ANGELES • ST. LOUIS

### VAPOR MODULATIC STEAM GENERATORS

#### Industrial Type

A compact steam generator—a safe, dependable, push-button "boiler plant" you merely set and forget!

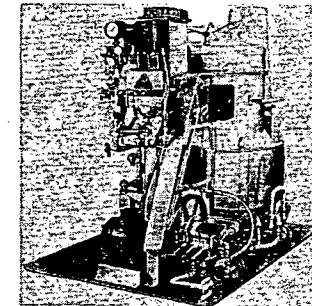
It's the answer to your plant expansion—to steam for any use. Moving a desk makes room, or any corner will do. Needs no enclosure, special foundation, expensive stack. Operation is clean, quiet, automatic. Two-minute steam from cold-starts ends early reporting and standby.

Saves time, saves fuel

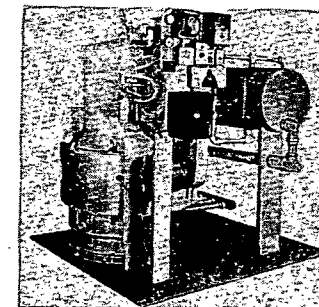
Modulatic tracks fluctuating steam demand, up or down, with speed and accuracy. Fuel consumption is exactly proportional to volume of steam used. Shipped complete, passes through plant-type doorways.

Sizes, 10 to 160 hp. Pressures to 1000 psi. Multiple installations can have a single automatic control that cuts whole units "in" or "out" according to steam demand. Oil, gas, or flip-switch combination burner. Vapor Modulatic Steam Generators are built to conform to both the ASME Power Boiler Code and ASME Heating Boiler Code.

Drum-Type for heating, low pressures. Full Modulatic advantages of compactness, quick steaming, and high efficiency incorporated into a heating boiler with controls materially simplified. Reduced cost, reliable performance, minimum maintenance. Especially designed for operating pressures below 15 psi.



Industrial Type



Drum Type

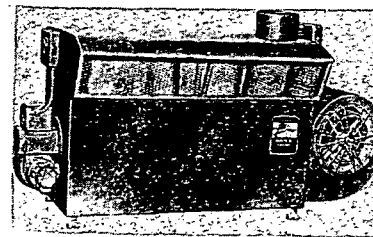
### VAPOR WAIKIKI HEATER

Gives a flood of hot air at the touch-of-a-button for every conceivable use. Sets on floor, shelf; hangs from ceiling; burns kerosene, fuel oil, gas. Plugs into 110-volt, a-c outlets.

Versatile, simple to service

Permits simple connection to exhaust vent or stack, or including combustion products in forced air circulation. Burner and blower are outside-mounted—no moving parts inside the unit.

Shipped fully assembled and wired. Output: 2400 cfm. Compactly quality-built for efficient performance with extra large heat transfer area.



Two sizes: 145,000 and 200,000 Btu per hour.



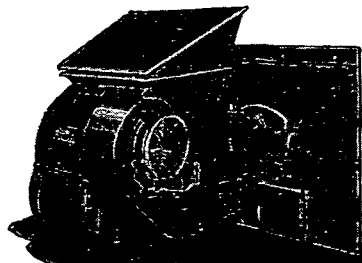
**DETROIT**  
SINCE 1898  
**STOKERS**

## DETROIT STOKER COMPANY

General Motors Building - Detroit, Michigan

### Detroit LoStoker (Underfeed type)

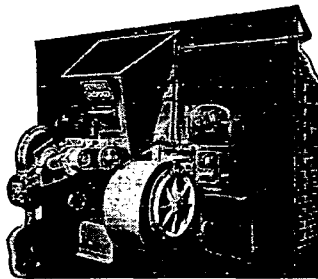
Compact firing unit—single retort—mechanically driven—plunger feed—side cleaning stoker. Sizes and capacity for all heating boilers, from 50 to 150 horsepower rated capacity. Now available with Detroit Adjustable Feed—provides automatic control of coal and air. Efficient and dependable operation assured.



*Detroit LoStoker—a great coal saver. Easily installed. Thousands in operation. Write for catalog.*

### Detroit UniStoker (Underfeed type)

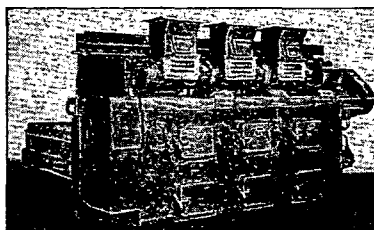
Plunger feed, side cleaning, compact unit type. For boilers of 125 to 250 hp rated capacity. Detroit Adjustable Feed keeps air supply in ratio to coal feed. May be motor or steam turbine driven automatically controlled. Readily installed with existing boilers to provide automatic heat at low cost.



*Detroit UniStoker with Adjustable Feed provides a wide range of coal feed control.*

### Detroit RotoStoker (Spreader type)

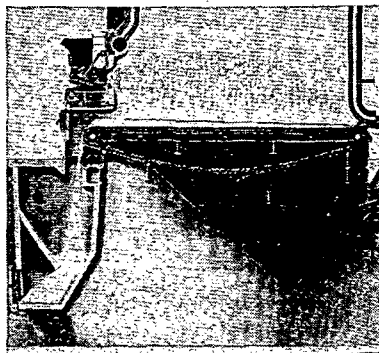
Built with stationary, hand or power dumping grates or continuous cleaning grates. Wide range of sizes. Burns all bituminous coals without special preparation, but with high thermal efficiency. Responsive to fluctuating loads.



*Detroit RotoStoker (CC) is a new type with continuous ash discharge at the front. For steaming capacities approximately 5,000 to 75,000 lbs. Smoke-free operation at light loads.*

### Detroit RotoGrate (Large spreader type)

For medium and large heating and power boilers up to 400,000 lbs steam per hour. Forward moving grates continuously and automatically discharge ash at the front. Combustion loss in ash usually less than two per cent.



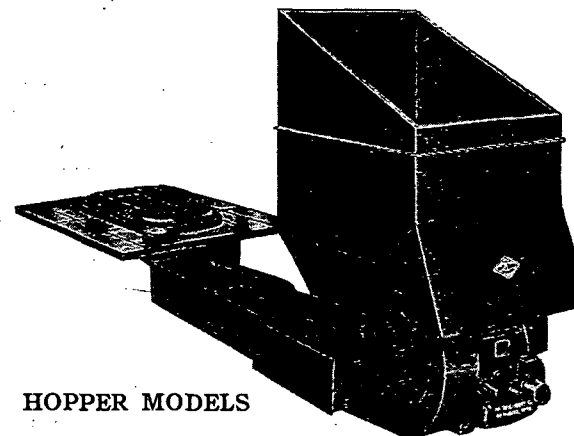
*Detroit RotoGrate Stoker burns all grades of coal. Permits higher burning rates. Responds quickly to changes in load. Burns wood and other refuse separately or in conjunction with coal.*



## The Will-Burt Company

Orrville, Ohio

COMMERCIAL • INDUSTRIAL • RESIDENTIAL  
AIR-CONTROLLED BITUMINOUS STOKERS



### HOPPER MODELS

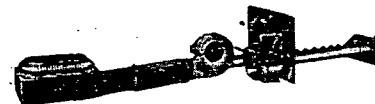
Patented automatic air control insures delivery of correct quantities of air to meet constantly changing fire-bed conditions, eliminates need for banked firing methods and prevents back-smoking. If overload occurs, shear pin and auto-

matic switch protect stoker against damage. Strong, cast iron hopper base with heavy gage rust-resisting steel hopper.

Will-Burt hopper type stokers are available in 20 to 750 lbs per hr capacities.

### BIN FEED MODELS

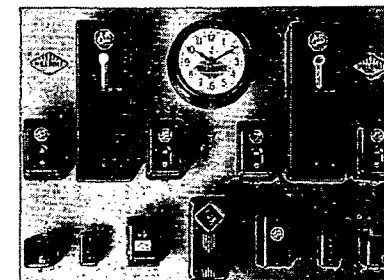
Like the hopper models, Will-Burt bin-feed stokers offer all the advantages of



automatic air control and the patented protective shear pin and switch. Patented flange and set screw locking device prevent coal screw from disengaging from drive shaft. Precision machined power unit. Capacities from 20 to 750 lbs per hr.

### PANEL BOARDS

Prewired, pretested control panel boards provide an interconnected control system for stokers to be operated by either a common operating and/or individual holdfire control, depending on the setting of the safety switch, off-on switch and timeswitch cycle. Mounting wall brackets are provided. Not illustrated, but available are control cabinets with controls mounted and wired on a sub-panel and completely enclosed in a heavy steel cabinet.



Write for your free copy of the Will-Burt Engineers and Architects Manual.

# McDonnell & Miller, Inc.

Safety Devices for Steam and Hot Water Heating Boilers and Hot Water Tanks

3500 N. Spaulding Ave., Chicago 18, Illinois



The McDonnell line consists of the following safety devices: (1) For Low Pressure Steam Boilers . . . Boiler water feeders, low water fuel cut-offs and combined feeders and cut-offs; (2) For Higher Pressure Steam Boilers . . . Pump controls, low water fuel cut-offs and low water alarms for pressures to 150 lbs, and receiver make-up water feeders; (3) For Hot Water Space Heat-

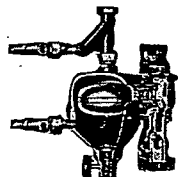
ing Boilers . . . ASME pressure relief valves, boiler water feeders, low water fuel cut-offs and combined feeders and cut-offs; (4) For Domestic Hot Water Tanks and Heaters . . . ASME pressure relief valves, temperature relief valves and combination T & P relief valves. McDonnell also manufactures liquid level controls for humidifying pans and many other applications.

## (1) LOW PRESSURE STEAM BOILERS

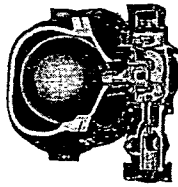
### Service Recommendations

| Boiler Size                                            | Maximum Steam Pressure | McDonnell Product to Use     |                     |
|--------------------------------------------------------|------------------------|------------------------------|---------------------|
|                                                        |                        | For Automatically Fired Jobs | For Hand Fired Jobs |
| Boiler Water Feeders and Feeder Cut-Off Combinations   |                        |                              |                     |
| Up to 5000 sq ft                                       | 25 lbs                 | No. 47-2                     | No. 47              |
| Above 5000 sq ft                                       | 35 lbs                 | No. 51-2                     | No. 51              |
| Any size                                               | 75 lbs                 | No. 53-2                     | No. 53              |
| Low Water Fuel Cut-Offs (for Automatically Fired Jobs) |                        |                              |                     |
| Any size                                               | 20 lbs                 | No. 67                       |                     |
| Any size                                               | 50 lbs                 | No. 63                       |                     |

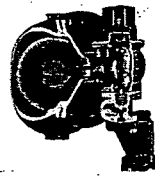
### McDONNELL Boiler Water Feeders and Feeder Cut-off Combinations



McDonnell No. 47-2



McDonnell No. 51-2

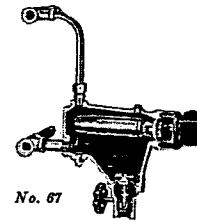


McDonnell No. 53-2

McDonnell No. 47-2 Feeds water when necessary to maintain safe water level in boiler. If water level for any reason falls into emergency zone, cut-off switch cuts burner circuit until emergency has passed. Has "Quick-Hook-Up" for installation in gage glass tapplings; "cool" feed valve; extra-deep sediment chamber; stainless steel valve and seat; ASME approved blow-off valve. Also available for hand fired jobs without No. 2 Switch, as No. 47 Feeder.

McDonnell No. 51-2 is same as No. 47-2, except it has greater feeding capacity for larger boilers, and is installed with 1 in. equalizing pipes instead of "Quick-Hook-Up." Also available for hand fired boilers without No. 2 Switch, as No. 51 Feeder.

For boilers operating at higher pressures, from 35 to 75 lbs, use McDonnell No. 53-2 (or No. 53, without switch).



No. 67

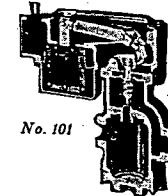
**McDonnell Low Water Cut-offs**  
For automatically fired steam boilers of any size  
Maximum steam pressure, 20 lbs.

No. 67 has McDonnell "Quick-Hook-Up" for installation in gage glass tapplings; deep sediment chamber with large opening blow-off valve; packless non-binding construction; adjustable terminal box; snap-action twin switches. One switch can sound low water alarm, or control McDonnell No. 101 Electric Water Feeder; second switch cuts burner current if water level drops into emergency zone.

No. 61 has same mechanism as No. 67 but has larger body for installation with 1 in. equalizing pipes.

69 Series "Built-ins" meet same operating conditions, fit 2 1/4 in. tapplings provided by many boiler manufacturers. Order by boiler make, model.

**McDonnell No. 101 Electric Boiler Water Feeder**  
For boilers up to 5000 sq ft capacity.

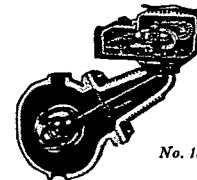


No. 101

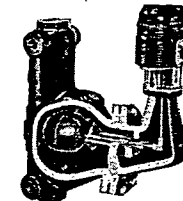
For use with No. 67 Low Water Cut-off, No. 61 or "Built-ins" which are standard equipment on many modern heating boilers. Its use converts cut-off into feeder cut-off combination.

## (2) HIGHER PRESSURE STEAM BOILERS

**McDonnell Pump Control, Low Water Fuel Cut-Off and Alarm Switch**



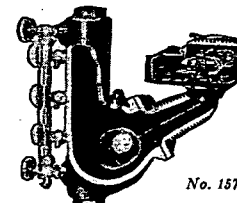
No. 150



No. 192

**Maximum boiler pressure, 150 lbs.**  
The McDonnell No. 150 has two switches; one controls electric feed pump or electric valve in line to steam pump; second stops burner on greater float drop and completes alarm circuit. Underwriters' Laboratories approved. No. 150 has automatic reset; for manual reset order no. 150-M.

**Maximum boiler pressure, 250 lbs.**  
The No. 192 is a totally new kind of control. Introduces a new principle of repulsion magnetic switching. Has junction box totally sealed from float chamber; remarkable heat dissipation meets new Underwriters' Laboratories standards for use of 75 deg C. wire. Water column body has all tapplings for steam trim. For manual reset order No. 192-M.



No. 157

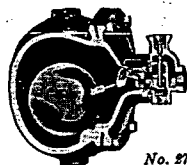
No. 157 is the same as No. 150 but has integral water column which simplifies installation and has all tapplings for steam trim. No. 157 has automatic reset; for manual reset order No. 157-M (Tri-cocks and gage glass not included.)



No. 92

No. 92 is same as No. 192 but without water column body; is installed with 1 1/4 in. equalizing tapplings. For manual reset order 92-M.

## McDONNELL No. 27 Make-up Water Feeder for Receivers



No. 27

Teams up with McDonnell No. 150 or No. 157—assures an adequate minimum supply of water in receiver at all times. Features large feeding capacity, well-guided valve action, all-brass construction of valve assembly. Models also available without float bowl for mounting right inside of receiver. Maximum receiver pressure, 35 lbs; maximum supply pressure, 100 lbs.

(3) HOT WATER SPACE HEATING BOILERS  
Service Recommendations

## Boiler Water Feeders and Feeder Cut-off Combinations

| Boiler Size (Btu/hr Output)   |                               |                               | Maximum Boiler Pressure | McDonnell Product to Use     |                     |
|-------------------------------|-------------------------------|-------------------------------|-------------------------|------------------------------|---------------------|
| Differential Pressure 10 lbs* | Differential Pressure 20 lbs* | Differential Pressure 30 lbs* |                         | For Automatically Fired Jobs | For Hand Fired Jobs |
| 1,000,000                     | 1,400,000                     | 1,800,000                     | 30 lbs                  | No. 247-2                    | No. 247             |
| 2,000,000                     | 3,000,000                     | 3,750,000                     | 35 lbs                  | No. 51-2                     | No. 51              |
| 2,800,000                     | 4,300,000                     | 5,600,000                     | 35 lbs                  | No. 51-S-2                   | No. 51-S            |
| 2,100,000                     | 2,800,000                     | 3,300,000                     | 75 lbs                  | No. 53-2                     | No. 53              |

\* Differential Pressure equals water supply pressure less boiler pressure.

## Low Water Fuel Cut-off (only) (for Automatically Fired Jobs)

McDonnell No. 63. For boilers of any size. Maximum Boiler Pressure, 50 lbs.

## ASME Safety Pressure Relief Valves

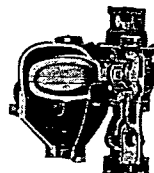
| Boiler Size (Btu/hr Output) | Opening Pressure | McDonnell Product to Use |
|-----------------------------|------------------|--------------------------|
| 303,000                     | 30 lbs           | No. 230 3/4 In.          |
| 743,400                     | 30 lbs           | No. 230 1 In.            |
| 1,025,100                   | 30 lbs           | No. 230 1 1/2 In.        |
| 1,488,000                   | 30 lbs           | No. 230-M1               |
| 1,928,400                   | 30 lbs           | No. 230-M2               |

## McDONNELL Boiler Water Feeders and Feeder Cut-off Combinations

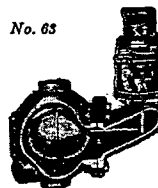
Experience has shown that hot water heating boilers, just like steam boilers, can run into low water trouble—as a result of leakage in the system, prolonged discharge from pressure relief valves, or simple negligence. Best answer is a McDonnell feeder cut-off combination for automatically fired boilers, and a boiler water feeder for hand fired jobs. No. 247-2 is a modification of the dependable 47-2, but without "Quick-Hook-Up." No. 51-2 and No. 53-2 are larger capacity and higher pressure feeder cut-off combinations. (No. 47-2, 51-2 and 53-2 are described under "Low Pressure Steam Boilers.")

## McDONNELL No. 63 Low Water Fuel Cut-off

Suitable for boiler pressures to 50 lbs, the No. 63 is ideal for cut-off service on hot water boilers. Has time-tested No. 2 low water cut-off switch, center pivoted bellows construction. Underwriter's Laboratories approved. Can also be used on steam boilers.

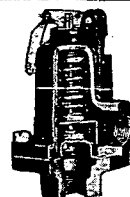


No. 247-2

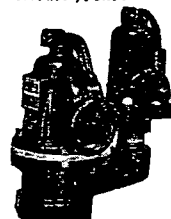


No. 63

## McDONNELL 230 Series ASME Pressure Relief Valves for Hot Water Space Heating Boilers



No. 230 3/4 Inch



Manifold Type 230 Series

The 230 Series was developed to provide dependable protection against over pressure at a moderate price. Each valve in the series conforms to ASME Boiler Code in every respect, and has been certified, and Btu-rated by the National Board of Boiler and Pressure Vessel Inspectors. All operating parts are of noncorrosive materials. Valve seat is brass, valve disc of silicone. Testing lever is independent of valve action, cannot interfere even if tied down. All connections are internal tappings.

Five sizes are available, three individual valves and two manifold valves. These manifold valves offer two units, set to open at progressively higher pressures, on a common manifold; they have the advantage of keeping discharge from larger boilers in step with the actual need, avoiding water waste when only a small discharge to take care of thermal expansion is required.

(4) DOMESTIC HOT WATER TANKS AND HEATERS  
Service Recommendations

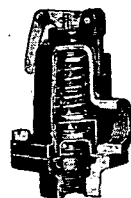
## ASME Safety Pressure Relief Valves

| Opening Pressure | Capacity Btu/hr | McDonnell Product to Use |
|------------------|-----------------|--------------------------|
| 75 lbs           | 502,000         | No. 230-75               |
| 100 lbs          | 640,000         | No. 230-100              |
| 125 lbs          | 783,000         | No. 230-125              |
| 150 lbs          | 925,000         | No. 230-150              |

## McDONNELL 230 Series Pressure Relief Valves

## For Hot Water Tanks and Heaters

Used to guard against dangerous over-pressure, the McDonnell 230 Series valves conform to the ASME Boiler Code and have been tested and Btu-rated by the National Board of Boiler & Pressure Vessel Inspectors. Available with four standard opening pressures. Construction features non-corrosive materials for all operating parts, independent action test lever, internal tappings for connections. For larger hot water tanks, two and three valve assemblies are available, up to 125 lbs maximum pressure.



No. 230-75

## McDONNELL No. 201 Temperature Relief Valve

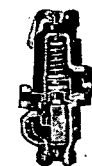
Safeguards hot water tanks and heaters against excessive temperature. A.G.A. listed for heat input to 1,200,000 Btu/hr. Vernatherm element provides positive operation, drip tight reseating. Extra connection for fixture flow simplifies pipe hook-up, improves operation. In regular or dip tube models.

## McDonnell No. 202 Combination P-T Relief Valve

Combines working mechanisms of 230 Series and No. 201; safeguards hot water tanks against both pressure and temperature. Bears the ASME symbol. Pressure side is steam-rated by the National Board of Boiler & Pressure Vessel Inspectors—650,000 Btu/hr at standard 125 lbs opening pressure. Temperature side is listed by A.G.A. for heat input to 750,000 Btu/hr. Opening pressures of 75 and 100 lbs also available.



No. 201



No. 202

## Pennsylvania Separator Co.

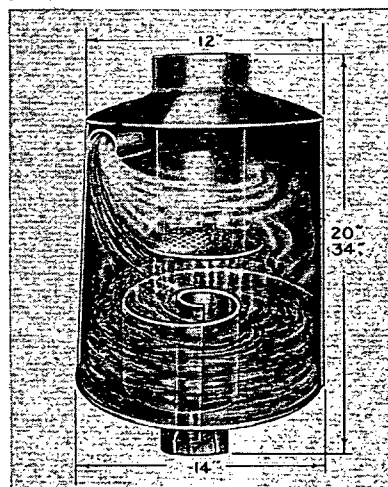
Box 348H, Brookville, Pa.

Mfgs. of Boiler Blow-down SEPARATORS

Pennsylvania's Separators utilize the velocity of the boiler blow-down injected tangentially into the tapered cylinder to separate heavier water-suspensions from flash which is forced to center vent. Thus excess pressure and temperature are removed by venting, leaving remaining water and suspensions acceptable to most drains. Water suspensions are directed by Spiral Baffle

to drain. When requested, units will bear ASME Code Stamps at extra cost. The unit meets national and most state and local requirements. Stainless Steel "Striking Plate" reinforces Separator at blow down entry to greatly extend life of unit. State boiler operating pressure and blow down valve size when making inquiry.

Consult the table for size. Prices and additional information on request.

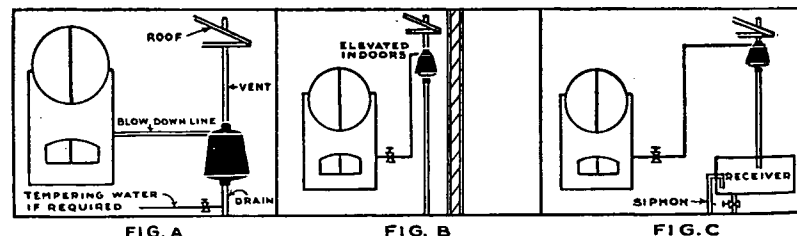


### SEPARATOR INLET SIZE TO EQUAL BOILER BLOW-DOWN VALVE SIZE

| AVAILABLE SIZES |       |      |
|-----------------|-------|------|
| Inlet           | Drain | Vent |
| 1"              | 2"    | 2½"  |
| 1¼"             | 2½"   | 3"   |
| 1½"             | 3"    | 4"   |
| 2"              | 4"    | 6"   |
| 2½"             | 4"    | 6"   |

DIMENSIONS  
TOP—12"  
BOTTOM—14"  
HEIGHT—(20") (34")

### SUGGESTED HOOK-UPS



A popular and simple installation with the Separator installed below the blow-down valve. It provides ready drainage and blow-downs at all pressures or from a dead boiler.

Elevated Separator installation when boiler room floor space is not available. May be installed indoors or outdoors for Separator is self draining—no freezing.

Where Receivers are required, they may be open tanks, or vented closed tanks 4"-6" vent. Manual or siphon drainage may be provided.

## Packard Water Conditioner Division, Inc.

Packard Manufacturing Company

Post Office Box 719

Jacksonville 1, Florida

The Packard Water Conditioner eliminates and prevents corrosion and scale formation in boilers and water systems. It is an important commercial application of nuclear physics principles to the effective treatment of boiler feed waters—without the use of chemicals. The Packard Water Conditioner prevents scale and corrosion by imparting added energy to the atoms of the water solution.

The unit is easily installed. It has no moving parts and requires no expensive maintenance or servicing either in the form of labor or added chemicals.

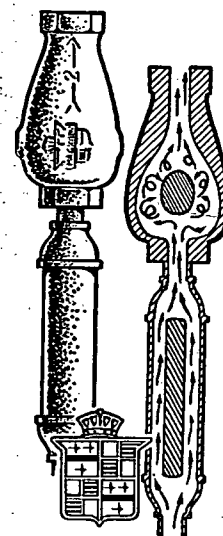
Use of the Packard Water Conditioner reduces operating costs and increases plant efficiency, minimizes shutdowns for maintenance and repair.

Laboratory and field tests substantiate the theoretical and practical value of the device.

Complete boiler protection is assured by installing Packard Water Conditioners to treat both the raw water and condensate return lines. Flow rates should be carefully determined and provision made for variations in pumping capacity caused by changes in back pressure. All feed water will be conditioned when a single Packard Water Conditioner is installed between the feed pump and the boiler. Capacity of the Conditioner should be great enough to handle the maximum output of the pump.

The Packard Water Conditioner is manufactured in sizes handling from 6.5 to 1760 gpm for connection with corresponding standard iron pipe ranging from ¾ in. to 12 in., as shown in chart below.

Conditioners are guaranteed for a period of ten years.



### SPECIFICATIONS\*

| Capacity GPM | Industrial Price | Engineering Data           |          |                  | Number to Carton | Shipping Weight Each |
|--------------|------------------|----------------------------|----------|------------------|------------------|----------------------|
|              |                  | Type                       | Diameter | Connection (IPS) |                  |                      |
| 6½           | \$199.50         | Screwed                    | 3½"      | 1"               | 6                | 9 lbs                |
| 13           | 299.50           | "                          | 4"       | 1½"              | 6                | 18 lbs               |
| 26           | 449.50           | "                          | 4"       | 1½"              | 4                | 23 lbs               |
| 40           | 595.00           | "                          | 5½"      | 1½"              | 4                | 65 lbs               |
| 52           | 875.00           | "                          | 5½"      | 2"               | 1                | 80 lbs               |
| 80           | 1295.00          | "                          | 5½"      | 2½"              | 1                | 85 lbs               |
| 106          | 1725.00          | One Screwed<br>One Flanged | 8½"      | 3"               | 1                | 185 lbs              |
| 185          | 2895.00          | Flanged                    | 9½"      | 4"               | 1                | 300 lbs              |
| 265          | 3395.00          |                            | 19"      | 5"               | 1                | 730 lbs              |
| 440          | 4185.00          |                            | 20"      | 6"               | 1                | 750 lbs              |
| 660          | 5150.00          |                            | 24"      | 8"               | 1                | 1110 lbs             |
| 990          | 5895.00          |                            | 30"      | 10"              | 1                | 1780 lbs             |
| 1760         | 7625.00          | "                          | 36"      | 12"              | 1                | 2390 lbs             |

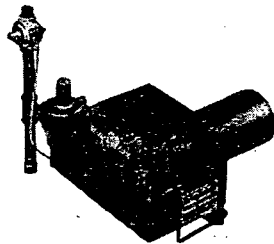
\*NOTE: All sizes 200 PSI WP on all screwed. All others 150 PSI WP. For all sizes up to 40 inches write factory. For heavy duty units to withstand pressure up to 1,000 lbs, add 25 per cent to cost.



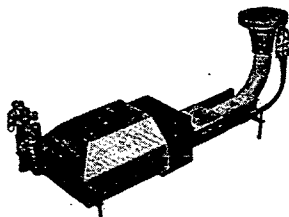
## Gordon-Piatt Inc.

P. O. Box 914 Winfield, Kansas

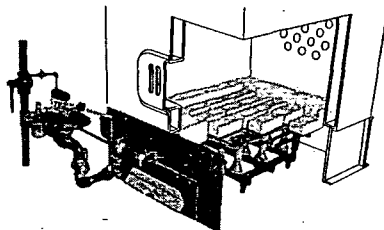
Combustion Engineering



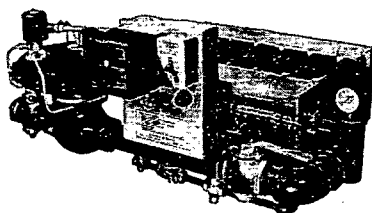
GPH Inshot Burner



GPV Upshot Conversion Burner



Glow Top Burner



Type H Inshot Burner

**GORDON & PIATT** are combustion engineers, specializing in the design and manufacture of a complete line of Domestic, Commercial and Industrial Burners. Engineering Service available for customer convenience.

**GPH-INSHOT GAS CONVERSION BURNER**, designed to replace Gun-Type Oil Burners without alteration of combustion chamber. Four inch tube; 75,000 to 150,000 Btu hr input; A.G.A. Listed. See Cat. GPH-1

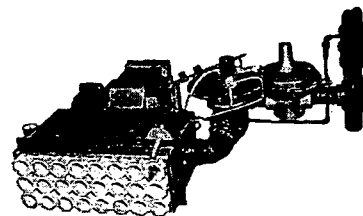
**GPV-UPSHOT GAS CONVERSION BURNER**, for Domestic Heating Plants. Annular Slot Head. No Burner parts in flame, adjustable length, 75,000 to 350,000 Btu hr A.G.A. Listed. See Cat. GPV-1.

**GLOW TOP BURNER** to convert large Commercial Heating Plants and Power Boilers. Standard firebrick completely covers cast ports. Shape and capacity flexible. 45 sizes listed in Cat. GT 55-1. Other sizes on application.

**TYPE H INSHOT ATMOSPHERIC BURNER**, for Marine Boilers and other applications where horizontal flame is indicated. 30 sizes listed in Cat. H-1, others on application.

**TURBO-FIRE POWER TYPE GAS BURNER**. Refractory nozzles and distinctive air distribution giving desired flame characteristics. Factory assembled with prewired control panel. Sizes listed to 18,000,000 Btu hr in Cat. FG-1.

Also available dual fuel, gas-oil and gas-gas combination units. Write for details.



Turbo-Fire Power-Type Burner

## Roberts-Gordon Appliance Corp.

CONVERSION

GAS BURNERS

DEPARTMENT HVG

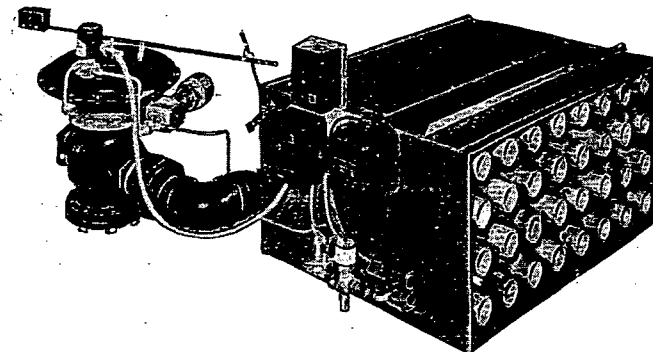


GAS HEATING

EQUIPMENT

Buffalo 6, N. Y.

**NEW! MULTURI (Multiple Venturi) GAS BURNER**



Especially designed for **HARD-TO-FIRE**

• **SCOTCH MARINE BOILERS • STEEL FIRE BOX BOILERS AT HIGH FIRING RATES AT HIGH EFFICIENCY**

A Premix Type Gas Burner, ideal for commercial and industrial size boilers and warm air furnaces. Gives maximum performance from hard-to-fire Scotch Marine and steel fire box boilers. Flame characteristics make the burner appropriate for units with extensive refractory surface. Suitable for any gas at 4 in. gas pressure or more. Permits high firing rates at high efficiency. Simple to install, adjust, and operate. Completely Factory Wired and Assembled . . .

Ready for Immediate Installation!

**MULTURI BURNERS** are available in standard modular units of 6 to 54 mixers. Capacities from 1,200,000 to 10,800,000 Btu/hr. Special units of higher capacities can be furnished. Write or phone us for detailed information.

**NEW! COMBINATION GAS-OIL BURNERS**

362,000 to 4,300,000 Btu/hr.

25 1/10 to 30 Gallons of Oil

Completely Automatic Switch-over from 1 Fuel to Another. Write or phone for details.

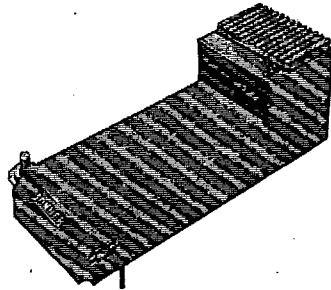
**ROBERTS-GORDON APPLIANCE CORP., DEPARTMENT HVG • BUFFALO 6, N. Y.**



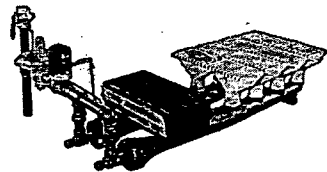
## The Sonner Burner Company

Designers and Manufacturers of Gas Conversion Burners and Unit Heaters

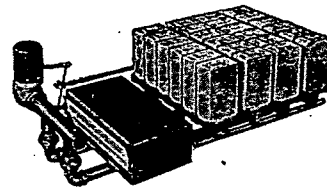
Offices and Factories: Winfield, Kansas



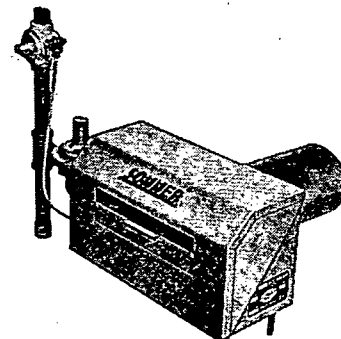
Type L-52 Heat Machine



Type LV SONNER Burner



Type D SONNER Burner



Type X-54 Burner

Sonner Gas Conversion Burners are a product of a quarter century of specialization in design and manufacture. A wide range of designs provides a Sonner Burner for domestic, commercial or industrial use. Consult Sonner Engineering for advice.

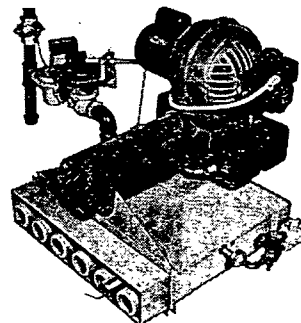
**TYPE L-52 HEAT MACHINE** is designed specifically for the conversion of residential heating plants to gas. Completely automatic burner is A.G.A. listed. Available in two sizes with capacities ranging from 75,000 to 400,000 Btu/hr. See Cat. 52-L-2.

**TYPE LV SONNER BURNER** for large heating and power boilers, handles a wide range of fuels. Standard assemblies from 320,000 to 7,200,000 Btu/hr are described in Cat. 52-LV-1. Step fired assemblies are described in Cat. 50-LVS-1.

**TYPE D SONNER BURNER** offers complete flexibility for all types and sizes of boilers and plants. Type "D" Burner Units can be readily manifolded into exactly the correct size and shape of burner for any kind of firebox. See Cat. 49-D-1.

**TYPE X-54 SONNER BURNER** specifically designed for replacing gun type oil burners in domestic furnaces or oil boilers. A.G.A. listed with inputs ranging from 75,000 to 175,000 Btu/hr. See Cat. 54-X-1.

**GAS OIL UNIT FOR COMMERCIAL AND INDUSTRIAL BOILERS**, two fuel burning units each designed for one fuel—natural gas, light fuel oils. Standard assemblies 280,000 to 2,800,000 Btu/hr input. See Cat. 52-CU-1.



Sonner Gas Oil Unit

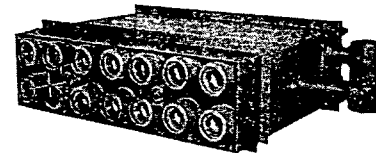
## The Webster Engineering Company

115 South Frisco St., P.O. Box 2168

Tulsa, Oklahoma

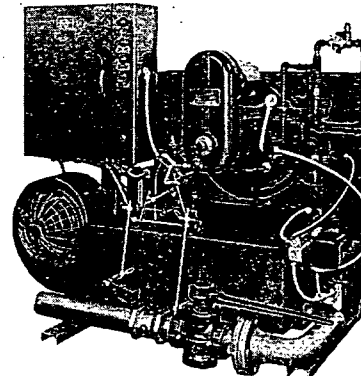
Division of

SURFACE COMBUSTION CORPORATION, TOLEDO, OHIO



WEBSTER  
KINETIC\*

Low Pressure Atmospheric Gas Burner with full venturi mixers and Meehanite alloy flame retention nozzles. Compact and easy to install, the assemblies are available in any desired size and shape.



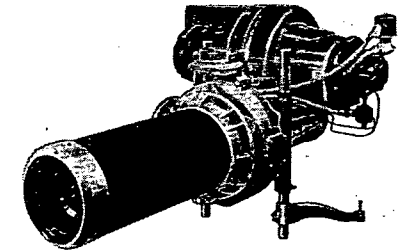
WEBSTER ROTONETIC\*

Dual Fuel Burner utilizing low pressure gas and any grade of commercial fuel oil under forced draft. Completely assembled, wired and tested at the factory; the units are available to 400 horsepower.

**WEBSTER ALSO MANUFACTURES:** Series F600 and Series 650 Vertical Gas Burners for Heating and Power Boilers. Series 340 Gas Burners for Vertical Boilers. Series VI and Webster Rectilinear High Pressure Inspirators for Boilers, Kilns, Stills, Dryers, Etc. Series 200 and Series R Combination Gas and Oil Burners for Power Boilers.

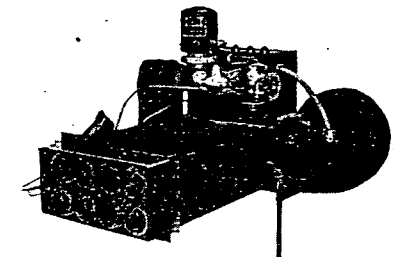
SALES and SERVICE IN ALL PRINCIPAL CITIES

\* Trade Mark



WEBSTER CYCLONETIC\*

The Webster Cyclonetic\* Dual Fuel Burner is designed to operate on either gas or light oil with only the flick of a switch necessary to change from one fuel to another. Employing 100 per cent forced draft, the Cyclonetic\* provides fully automatic operation on both fuels with complete programming and safety built in. Capacities from 675,000 to 4,000,000 Btu/hr.



WEBSTER DYNETIC\*

Forced Draft Gas Burner. A completely packaged unit available from 800,000 to 14,000,000 Btu/hr with low pressure gas.

## Cleaver-Brooks Company

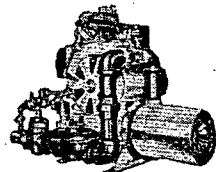
498 E. Keefe Ave., Milwaukee 12, Wisconsin



Cleaver-Brooks oil, gas and combination oil and gas burners for commercial, industrial and institutional applications.

Use the most available and most economical fuel in your area. Burn oil, gas or combination oil or gas with equal efficiency.

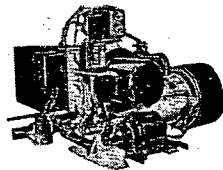
Cleaver-Brooks conversion burners can be installed as easily as domestic burners to fire any acceptable boiler. Recommended for buildings containing over 1500 sq ft of radiation—or if 45 tons of coal or more than 6000 gallons of oil are burned per year.



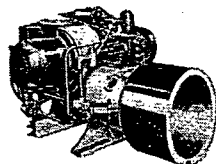
GAS

Uses natural, mixed or manufactured gas. 9 models available.

### COMBINATION LIGHT OIL OR GAS



Combination burners have same Btu output, burning gas or oil as regular HEV-E-OIL burners.



OIL

15 models available. Burners equipped with automatic electric ignition. Motor starter delayed until oil at nozzle is heated. No expensive pilots needed.

#### SPECIFICATIONS, RATINGS AND CAPACITY

| Oil                          | Models                    |                           |                           |                  |                  |                  |
|------------------------------|---------------------------|---------------------------|---------------------------|------------------|------------------|------------------|
|                              | AL2-C<br>AM2-CH<br>AM2-CF | AL3-C<br>AM3-CH<br>AM3-CF | AL4-C<br>AM4-CH<br>AM4-CF | AM5-CH<br>AM5-CF | AM6-CH<br>AM6-CF | AM7-CH<br>AM7-CF |
| Max. oil (gph)               | 5                         | 11                        | 17.5                      | 25               | 40               | 60               |
| Min. oil (gph)               | 1                         | 1                         | 3                         | 5                | 6                | 8                |
| Max. boiler rating           | 1750                      | 3800                      | 6100                      | 8750             | 14000            | 21000            |
| Net standing Steam radiation |                           |                           |                           |                  |                  |                  |
| Net standing Water radiation | 2800                      | 6000                      | 9800                      | 14000            | 22400            | 33600            |

Fuel oil No. 1, 2, 4 or 5 with maximum point of 10 F and maximum viscosity of 300 SSU at 100 F.

| Gas                       | G2-H<br>G2   | G3-H<br>G3   | G4-H<br>G4   | G5        | G6        | G7        |
|---------------------------|--------------|--------------|--------------|-----------|-----------|-----------|
|                           | GL2-H<br>GL2 | GL3-H<br>GL3 | GL4-H<br>GL4 | GL5       | GL6       | GL7       |
| Combination Light Oil/Gas |              |              |              |           |           |           |
| Combination               |              | AMG<br>3-H   | AMG<br>4-H   | AM<br>5-H | AM<br>6-H | AM<br>7-H |
| #5 Oil/Gas                |              | AM<br>G3     | AM<br>G4     | AM<br>G5  | AM<br>G6  |           |

#### Specifications for Gas

|                                             | 7200 | 1500 | 2500 | 3600 | 5700  | 8600  |
|---------------------------------------------|------|------|------|------|-------|-------|
| Max. Btu (in 1000's) Gas burned             |      |      |      |      |       |       |
| Max. recommended connected load (EDR Steam) | 1750 | 3800 | 6100 | 8750 | 14000 | 21000 |

#### Specifications for Light Oil (Capacity in gph)

|                     | 5  | 11 | 17½ | 25 | 40 | 60 |
|---------------------|----|----|-----|----|----|----|
| Max. Oil cap. (gph) |    |    |     |    |    |    |
| Min. Oil cap. (gph) | 4½ | 10 | 5   | 8  | 13 | 12 |

#### Specifications for No. 5 Oil (Capacity in gph)

|                     | 11 | 17½ | 25 | 40 | 60 |
|---------------------|----|-----|----|----|----|
| Max. Oil cap. (gph) |    |     |    |    |    |
| Min. Oil cap. (gph) | 1  | 3   | 5  | 6  | 8  |

ALC Burners use Honeywell RA 817A stack-mounted relay.

AMCH Burners use Honeywell R890C electronic relay—delayed start with thermostat, post purge and high-low air solenoid valve.

AMCF Burners use combustion controls Fireye FJ-2 electronic relay with immediate shut-down on flame failure, and non-return of ignition to meet Factory Mutual requirements.



## Enterprise Engine & Machinery Co.

A SUBSIDIARY OF GENERAL METALS CORPORATION

18th & Florida Streets, San Francisco 10, California

Distributors in Principal Cities

### ENTERPRISE HORIZONTAL ROTARY BURNERS—OIL, COMBINATION OIL—GAS

BURNER CAPACITIES—150,000 BTU OIL  
1,000 BTU GAS

| BURNER SIZE | MOTOR HP | OIL U. S. GALS. PER HR. | GAS CU FT PER HOUR | BOILER HP | STEAM EDR 240 Btu | HOT WATER EDR 150 Btu | LBS STEAM PER HOUR |
|-------------|----------|-------------------------|--------------------|-----------|-------------------|-----------------------|--------------------|
| AA          | ¼        | 4                       | 600                | 13        | 1,800             | 2,880                 | 450                |
| A           | ½        | 7                       | 1,050              | 23        | 3,200             | 5,120                 | 795                |
| EC          | ¾        | 15                      | 2,250              | 50        | 6,950             | 11,120                | 1,270              |
| C           | 1        | 20                      | 3,000              | 67        | 9,310             | 14,900                | 2,310              |
| F           | 1½       | 28                      | 4,200              | 93        | 12,930            | 20,700                | 3,270              |
| G           | 2        | 35                      | 5,250              | 118       | 16,125            | 25,800                | 4,000              |
| H           | 3        | 50                      | 7,500              | 168       | 23,075            | 36,900                | 5,725              |
| J           | 4        | 70                      | 10,500             | 233       | 32,300            | 51,800                | 8,040              |
| K           | 5        | 100                     | 15,000             | 333       | 46,200            | 74,000                | 11,490             |
| L           | 7        | 135                     | 20,250             | 450       | 62,550            | 100,000               | 15,525             |
| M           | 10       | 200                     | 30,000             | 666       | 92,575            | 148,100               | 22,975             |

All maximum capacities are necessarily approximate. Burners installed with adequate draft provisions and correct furnace volume, properly designed, will develop capacities indicated, at sea level.

#### APPLICATION

Enterprise Horizontal Rotary Burners are specifically designed for Commercial and Industrial use. Commercial heating includes heating plants in all types of buildings larger than private homes, including apartment houses, hotels, hospitals, schools, greenhouses, public buildings, offices, manufacturing plants. Industrial applications include furnaces, kilns, driers, etc.

#### MULTIPLE TYPES

**Manual**—To be started, regulated and stopped by operator.

**Semi-Automatic**—Started and stopped by operator, but automatically regulated by temperature or pressure control.

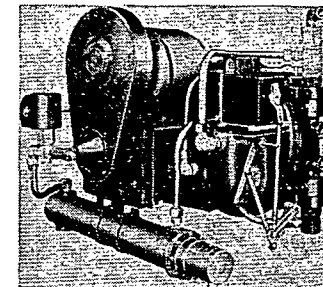
**Full-Automatic**—Burner automatically starts, stops, and is regulated to provide desired temperatures or steam pressure. Fixed fire start available on smaller sizes. Low fire start for high-low or full modulating control on all sizes.

All burners available with either **Standard gear pump** or **P. D. Metering Pump** or **Non-pump** (for use with separate pump set).

Any grade of fuel oil is burned efficiently—No. 6 (Bunker C) fuel is burned by burners equipped with oil heating system.

#### COMBINATION OIL-GAS BURNERS

All of the above types of burners are incorporated in combination type burner



to burn either fuel oil or gas. Gas may be natural, manufactured, or L. P. gas.

#### STANDARD EQUIPMENT

All full-automatic burners are furnished with: V-Belt drive, with known advantages of standard electric motors. Gas-electric ignition—dual ignition on sizes G to M.

Interconnected linkage to provide proportionate mixing of oil and air or gas and air at all firing rates.

Optional open type or angular vane air nozzles for flame control.

Copper tubing—provides free flow of oil with minimum connections.

Operating and combustion safety controls—oil burners, temperature or electronic type—Combination Oil-Gas burners, electronic controls exclusively.

#### SPECIAL FEATURES

The **Enterprise P. D. Metering Pump** provides exact delivery of oil to the burner by positive displacement, rather than through a metering valve. This definitely insures correct oil supply and air proportioning regardless of the viscosity of the oil, resulting in high efficiency.

**Burner hinges** are provided with leak-proof "O" rings rather than conventional packing glands.

#### FULLY APPROVED

All Enterprise Burners have been tested, approved, and listed as standard by **Underwriters' Laboratories, Inc.** and by other recognized boards and bureaus of safety, measures, and controls.

**ENGINEERS** will be provided with complete engineering information, either by manufacturers or qualified distributors, upon request.

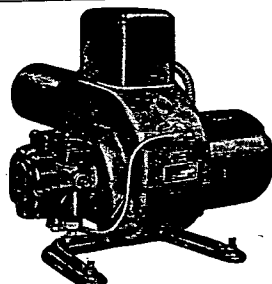


S. T. Johnson Co.

Builders of fine Oil  
Burners...since 1903  
Residential  
Commercial  
Industrial

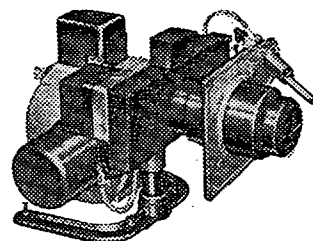


940 Arlington Ave.  
Oakland 8, California  
Church Road,  
Bridgeport, Pennsylvania



**BANKHEAT BURNER**

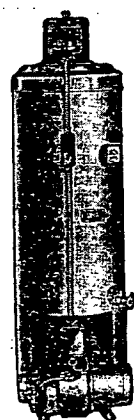
Pressure - atomizing, fully - automatic.  
Built with top quality safety and operating controls. A time-tested burner notable for its economy, dependability and efficiency. Highly adaptable. Ideal for "conversions." Bankheat Burners power the complete Johnson units shown below.



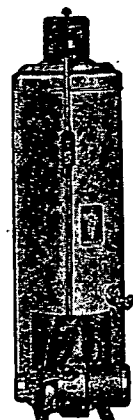
**BANKHEAT OIL-and-GAS BURNER**  
In areas where low-cost gas is available on a part time basis Bankheat Dual-Fuel Oil-and-Gas Burners offer the utmost possible economy and efficiency. They are equipped with fine electronic automatic controls.

| SIZE  | CAP. GPH |      | MAX BOILER RATING |       |    |
|-------|----------|------|-------------------|-------|----|
|       | Min.     | Max. | Steam             | Water | HP |
| BH-0  | .8       | 2.25 | 900               | 1450  | 6½ |
| BH-0A | 1.0      | 3.0  | 1300              | 2100  | 9  |
| BH-1A | 2.0      | 5.5  | 2300              | 3650  | 16 |
| BH-2  | 3.0      | 7.5  | 3100              | 4950  | 22 |
| BH-2A | 4.0      | 10.0 | 4150              | 6650  | 30 |
| BH-3  | 5.0      | 15.0 | 6200              | 9900  | 45 |
| BH-3A | 7.5      | 18.0 | 7500              | 12000 | 54 |

| SIZE | MAX FIRING RATE |                  | MAX BOILER OUTPUT |             |    |
|------|-----------------|------------------|-------------------|-------------|----|
|      | Oil gph         | Gas CFH 1000 Btu | Steam Sq Ft       | Water Sq Ft | HP |
| 0    | 2¼              | 315              | 900               | 1450        | 6½ |
| 0A   | 3               | 420              | 1300              | 2100        | 9  |
| 1A   | 5½              | 770              | 2300              | 3650        | 16 |
| 2    | 7½              | 1050             | 3100              | 4950        | 22 |
| 2A   | 10              | 1400             | 4150              | 6650        | 30 |
| 3    | 15              | 2100             | 6200              | 9900        | 45 |
| 3A   | 18              | 2520             | 7500              | 12000       | 54 |



Heatlux House Heaters  
85000 and 160000 Btu



Aqualux Water Heaters,  
Cap. 100 to 640 Gph



Econolux House Heaters,  
Steam or Hot Water,  
150000 Btu



Aerolux 65-U Warm  
Air Heaters, 50000 to  
65000 Btu

S. T. Johnson Co.

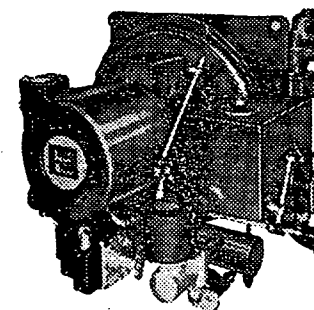
Builders of fine  
Oil Burners...since 1903  
Residential  
Commercial  
Industrial



940 Arlington Ave.  
Oakland 8, California  
Church Road  
Bridgeport, Pennsylvania

**MODEL 53 fully AUTOMATIC  
METERING PUMP BURNER**

This revolutionary new heavy-duty Johnson Burner will automatically maintain a fixed Air-Fuel Ratio regardless of variations in oil temperature and viscosity. This fact explains why the Model 53 Burner is so remarkably successful at starting up and operating automatically even when the oil in tank and lines is cold and difficult to pump.



Model 53 Metering Pump Oil Burner

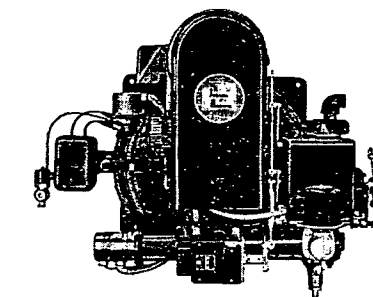
The Model 53 Burner is built with a positive-displacement Metering Pump, a 3-Way Magnetic Oil Valve and a high efficiency Suction Pump. Because it keeps fuel and maintenance costs down to a minimum, the Model 53 is exceptionally economical to own and operate. And already it has achieved an enviable reputation for dependability and faithful performance.

Model 53 Burners are available in 8 sizes as listed below, with either Direct Drive or Belt Drive. Dual-Fuel Oil-and-Gas models are also available as shown at the bottom of this page.

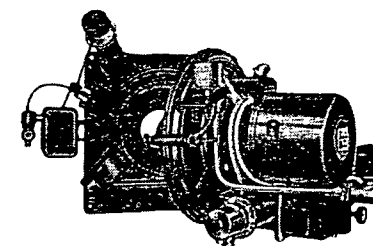
| SIZE AND BHP | MOTOR HP | GPH OIL | SQ FT STEAM RADIATION |
|--------------|----------|---------|-----------------------|
| 25           | ¼        | 7½      | 3500                  |
| 50           | ¼        | 15      | 7000                  |
| 75           | ¼        | 22½     | 10500                 |
| 100          | ¾        | 30      | 14000                 |
| 150          | 1½       | 45      | 21000                 |
| 200          | 2        | 60      | 28000                 |
| 300          | 3        | 90      | 42000                 |
| 400          | 4        | 120     | 56000                 |

**MODEL 53 METERING PUMP  
DUAL-FUEL fully AUTOMATIC  
OIL-and-GAS BURNER**

Offers a choice of fuels in addition to the other advantages of the new Model 53...thus making it possible in many areas to effect worth while fuel economies.



Model 53 Metering Pump Oil Burner with Belt Drive



Model 53 Metering Pump Dual-Fuel Oil-and-Gas Burner

## Ray Oil Burner Co.

Since 1872

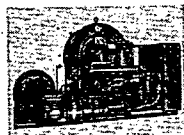
1301 San Jose Avenue  
San Francisco 12, Cal.



Atlantic Seaboard Division  
629 Grove Street  
Jersey City 2, N. J.

There is a RAY Burner for every Heating Purpose.

### RAY FORCED DRAFT PACKAGED BURNER



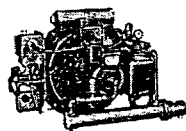
FD-ARC Size #6 fully automatic, combination gas-oil, Forced Draft Packaged Burner.

A factory assembled unit readily applied to any type of boiler designed for forced draft operation. Fully automatic operation on oil, gas or combination gas-oil.

The combination gas-oil unit includes a rotary oil burner, integrated ring type gas burner, secondary air control with a forced draft fan, windbox, refractory support ring, completely wired control panel and pre-piping completely factory assembled for quick and easy installation to the boiler.

Oil components may be selected to burn any grade of oil with the secondary air control providing increased efficiency even with the difficult-to-burn catalytic residual #6 fuel oils. From 83 to 540 equivalent boiler horsepower.

### RAY COMBINATION OIL-GAS BURNERS



ARC-144 Model 50 for heavy oil and low pressure gas.



Type PC for oil and low pressure gas.



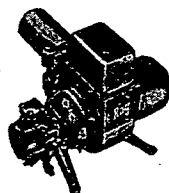
Type AR-HN Combination Oil and High Pressure Gas.

**ARC-MODEL 50.** Consists of a rotary type oil burner of Ray conventional design coupled with a gas housing for low pressure gas, from 2 in. WC to 10 in. WC. The gas burner parts provide for the introduction of gas in a manner which fully utilizes the energy in the high pressure air supplied by the rotary burner fan. Gas and primary air are intimately combined, in two stages, before mixing with the secondary air which is introduced through a vaned annular opening concentric with the nozzle. Change-over requires less than one minute. Available to burn any grade of oil in 9 sizes with capacities to 31,500,000 Btu/hr.

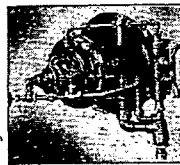
**TYPE HN** for gas pressures above 1 lb/sq in. may be used alone or in combination with a Ray Oil Burner. Built in ten sizes; in capacities to 48,000,000 Btu/hr.

**TYPE PC.** Combination gas-oil burner of the pressure atomizing type. Available in three sizes with capacities from 560,000 to 2,500,000 Btu/hr.

### RAY DOMESTIC AND MARINE BURNERS



Fully Automatic, Type JP, #2 or lighter oil.



Steam Turbine Drive, Type TG, all grades oil. Tested and approved for U. S. Navy Service.



Ray Warm Air Oil Furnace

**RAY PRESSURE ATOMIZING OIL BURNERS** Fully automatic for No. 2 oil, or lighter. AC or DC; capacities 1 to 18 gallons per hour.

**WARM AIR FURNACES** Built in five sizes, with input capacities of 105,000; 140,000; 230,000; 350,000; 450,000 Btu.

**RAY OIL WATER HEATERS** Five sizes. Capacities: 35, 45, 60, 75 and 100 gal. Maximum recovery rates: 100 to 240 gph.

## Ray Oil Burner Co.

Since 1872

1301 San Jose Avenue  
San Francisco 12, Cal.

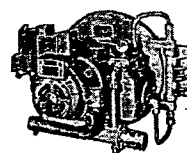


Atlantic Seaboard Division  
629 Grove Street  
Jersey City 2, N. J.

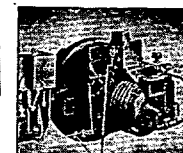
Distributors in  
All Principal Cities of the World

Consult your local  
Telephone Directory

**Products:** A complete line of Horizontal Rotary and Pressure Atomizing Oil Burners; Combination Oil-or-Gas Burners; Industrial Gas Burners; Forced Draft, packaged Burners; Oil Burning Water Heaters; Warm Air Furnaces.



Type AR-144 Size 10 for No. 6 oil. Available in 10 sizes from 2 to 110 gph. Fully automatic.



Fully Automatic Type AR-134, for No. 5 oil.



1 to 1000 Boiler hp Type AG. Manual, Semi-automatic control.



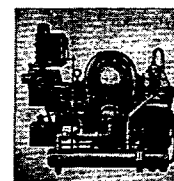
Type ARJP, Fully Automatic for heavy oil where gas for ignition not available.

### RAY HORIZONTAL ROTARY OIL BURNERS

Built in fully automatic, semi-automatic and manual types; in sizes from 1 to 1000 Boiler hp; to burn all grades of fuel oil.

Standard models include both direct and belt drives—the latter being recommended for use where other than 50 or 60 Cycles AC, or only DC is available. Types for straight electric or straight gas ignition; pump or gravity feeds. Direct drive types include a steam turbine driven model.

All fully automatic types for heavy oil incorporate the Ray Dual Pump and Reservoir, with the Ray VISCOSITY Valve, a patented, exclusive feature which automatically meters the correct amount of fuel at all times, regardless of changes in viscosity of the oil due to temperature variations. All larger sizes employ dual ignition system, consisting of dual high-voltage transformers, dual electric ignitors and dual gas valves. Fully automatic sizes 9 and 10 include as standard equipment electronic pilot and flame failure control.



Type BR-144, Belt Drive, Fully Automatic, Available in 8 sizes. Capacities from 2 to 110 gph.

### HOURLY CAPACITY RATINGS of RAY OIL BURNERS

| Burner Size | Model | Oil Capacity U. S. Gallons |      | Equivalent Boiler HP |      | Equivalent Lbs. Steam Generated* |       | Heat Capacity Input Thou. Btu Oil or 1000 Btu Gas |       | Equivalent Sq. Ft Steam Radiation |        |
|-------------|-------|----------------------------|------|----------------------|------|----------------------------------|-------|---------------------------------------------------|-------|-----------------------------------|--------|
|             |       | Min.                       | Max. | Min.                 | Max. | Min.                             | Max.  | Min.                                              | Max.  | Min.                              | Max.   |
| JP          | 1/4   | 1                          | 3    | 3                    | 9    | 110                              | 325   | 140                                               | 420   | 440                               | 1300   |
| 0-P         | 1/4   | 1                          | 4    | 3                    | 12   | 110                              | 430   | 140                                               | 560   | 440                               | 1750   |
| 1-P         | 1/4   | 3                          | 8    | 9                    | 25   | 325                              | 860   | 420                                               | 1120  | 1300                              | 3500   |
| 2-P         | 1/4   | 8                          | 18   | 25                   | 55   | 860                              | 1950  | 1120                                              | 2500  | 3500                              | 7900   |
| 0           | 1/4   | 2                          | 5    | 7                    | 16   | 230                              | 580   | 300                                               | 750   | 938                               | 2340   |
| 1           | 1/4   | 4                          | 11   | 13                   | 35   | 460                              | 1270  | 600                                               | 1650  | 1880                              | 5160   |
| 2           | 1/4   | 5                          | 15   | 17                   | 50   | 580                              | 1740  | 750                                               | 2250  | 2340                              | 7030   |
| 3           | 1/4   | 8                          | 25   | 27                   | 83   | 930                              | 2900  | 1200                                              | 3750  | 3750                              | 11720  |
| 5           | 1     | 10                         | 35   | 33                   | 116  | 1160                             | 4050  | 1500                                              | 5250  | 4690                              | 16400  |
| 6           | 1 1/4 | 12                         | 60   | 40                   | 165  | 1400                             | 5800  | 1800                                              | 7500  | 5620                              | 23500  |
| 7           | 2     | 15                         | 70   | 50                   | 230  | 1740                             | 8100  | 2250                                              | 10500 | 7030                              | 32800  |
| 8           | 3     | 25                         | 110  | 83                   | 365  | 2900                             | 12700 | 3750                                              | 18500 | 11700                             | 51500  |
| 9           | 5     | 35                         | 150  | 116                  | 500  | 4050                             | 17400 | 5250                                              | 22500 | 16400                             | 70500  |
| 10          | 7 1/2 | 50                         | 210  | 165                  | 700  | 5800                             | 24400 | 7500                                              | 31500 | 23400                             | 98300  |
| 12          | 7 1/2 | 75                         | 320  | 250                  | 1000 | 8700                             | 37000 | 11250                                             | 49000 | 35100                             | 149800 |

NOTE: These ratings are predicated upon specific conditions of draft and furnace volume. It may be permissible, under desirable conditions, to operate at higher rates, or advisable under restricted conditions, to operate at reduced rates. Heating capacities are based upon 150,000 Btu per gal of oil for rotary burners and 140,000 Btu per gal of oil for pressure atomizing burners and upon an overall boiler efficiency of 75 per cent.

\* Steam capacity based on steam F and A 212 F.

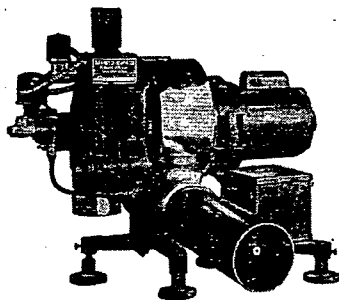
## Rayfield-Staffco Burner Co.

2066 S. Canalport Ave. • Chicago 8, Ill.

DOMESTIC, COMMERCIAL AND INDUSTRIAL OIL BURNERS FOR ALL GRADES OF FUEL OILS, FOR SMALLEST TO LARGEST BUILDINGS.  
DOMESTIC AND SMALL COMMERCIAL AND INDUSTRIAL GAS BURNERS

### RAYFIELD-STAFFCO BURNERS for No. 4 or No. 5 HEAVY OILS

Model JR.—1.00 to 5.00 gph.  
Model D4—3.00 to 12.00 gph.  
Model D5—10.00 to 22.00 gph.  
Maximum 8,800 EDR

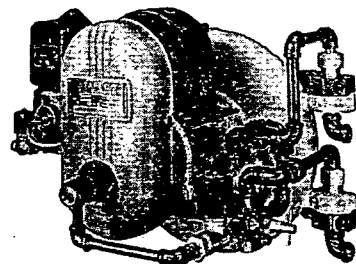


For No. 4 or No. 5 Heavy Oils

These fully automatic burners are designed to provide efficient heating with the cheaper grades of oil. Both models are all-electric operating, self-lubricating and have self-cleaning nozzles for long, trouble-free service. By utilizing the low-priced fuels, these units keep heating costs to a minimum. Ideal for smaller commercial and industrial application.

### RAYFIELD-STAFFCO ROTARY BURNERS FOR No. 5 and No. 6 HEAVIEST FUEL OILS

9 sizes ranging from 10 to 165  
gph firing rates  
Maximum 66,000 EDR



For No. 5 or No. 6 Heaviest Oils

These sturdy burners, known and used all over the world, give excellent results and are built for long life with minimum service. Available with many types of controls including mechanical, electrical and electronic types. All equipped with Regulating valves to maintain constant oil flow regardless of oil viscosity or temperature. Adjustable air vanes to produce any flame shape or size desired.

### SHELL COMBUSTION HEAD OIL BURNERS for No. 2 or No. 3 CATALYTIC OILS

### GUN TYPE GAS BURNERS

1586

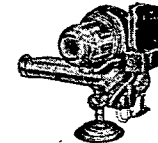
## Siemon Manufacturing Company

Grandview, Mo.  
(Suburb of Kansas City, Mo.)

Representatives in most  
Principal Cities

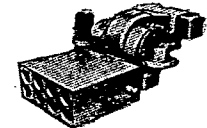
### "POWER-FLAME" Gas Burners

The "POWER FLAME" forced draft burners offer **EXTREME FLEXIBILITY**. "FG" series Gun Type units are ideal where limited space is a factor such as Scotch Marine type boilers, narrow fire-box heaters and the like.



FG Series—Gun Type

Series "BFG" units—Block Type—designed for use where high capacities are required and minimum base heights for installation are available. Both types employ standard items of control equipment, are shipped as a package, factory wired and tested before shipment. Ask for Cat. Nos. FG-1055 and BFG-655 for complete specifications.



BFG Series—  
Spread-block type

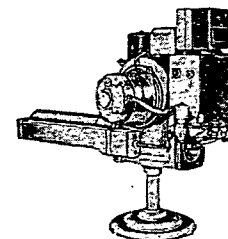
### HOURLY CAPACITIES AND SPECIFICATIONS

| Burner Model | Gas Input<br>MBTU/Hr |      | Gross Boiler<br>Output<br>100% Rating |                | Max BHP | Gas Conn. | Motor Hp | Type Control |
|--------------|----------------------|------|---------------------------------------|----------------|---------|-----------|----------|--------------|
|              | Min.                 | Max. | Sq Ft<br>Steam                        | Sq Ft<br>Water |         |           |          |              |
| *FG175B      | 85                   | 175  | 460                                   | 750            | 3.9     | 3/4"      | 1/20     | Thermo-Relay |
| *FG330B      | 150                  | 330  | 900                                   | 1400           | 7.3     | 1"        | 1/20     | Thermo-Relay |
| FG500B       | 300                  | 500  | 1420                                  | 2300           | 11.1    | 1"        | 1/20     | Thermo-Relay |
| FG500B-E     | 300                  | 500  | 1420                                  | 2300           | 11.1    | 1"        | 1/20     | Electronic   |
| BFG-750E     | 450                  | 750  | 2250                                  | 3600           | 16      | 1"        | 1/2      | Electronic   |
| BFG-1000E    | 650                  | 1000 | 3000                                  | 4800           | 22      | 1 1/4"    | 1/2      | Electronic   |
| BFG-1600E    | 900                  | 1600 | 4800                                  | 7500           | 35      | 1 1/2"    | 1/2      | Electronic   |
| BFG-2200E    | 1500                 | 2200 | 6600                                  | 10400          | 49      | 2"        | 1/2      | Electronic   |
| BFG-3000E    | 2000                 | 3000 | 9000                                  | 14500          | 69      | 2 1/4"    | 1/2      | Electronic   |
| BFG-4500E    | 3000                 | 4500 | 13500                                 | 21000          | 100     | 3"        | 1/2      | Electronic   |
| BFG-6000E    | 4500                 | 6000 | 18000                                 | 29000          | 133     | 3"        | 1/2      | Electronic   |
| BFG-9000E    | 6000                 | 9000 | 27000                                 | 43500          | 200     | 4"        | 1        | Electronic   |

\* A.G.A. Listed 1000 Btu Gas @ 5" W. C. Pressure—Available for Mixed or L. P. Gases  
\*\* Based on 70% Boiler Efficiency

### "COMBI-MATIC" Forced Draft GAS-OIL Burners

Listed as standard by Underwriters' Laboratories. The "FGO" Series units employ a "tube within a tube" principle to fire both fuels (gas and light oils) efficiently. Installation costs are reduced to a minimum since all units are packaged and factory wired and "FIRE TESTED BEFORE SHIPMENT." All units are pressure atomizing type, **SIMPLE TO INSTALL, SERVICE AND MAINTAIN.** Ask for Cat. No. FGO-9154 for complete specifications.



### HOURLY CAPACITIES AND SPECIFICATIONS

| Burner Model | Gas Input<br>MBTU/Hr |      | Oil #1, 2, 3<br>Gals.<br>per hour | Gross Boiler<br>Output<br>100% Rating |                | Max BHP | Gas Conn. | Motor Hp | Type Control |
|--------------|----------------------|------|-----------------------------------|---------------------------------------|----------------|---------|-----------|----------|--------------|
|              | Min.                 | Max. |                                   | Sq Ft<br>Steam                        | Sq Ft<br>Water |         |           |          |              |
| FGO-700A-E   | 400                  | 700  | 3-5                               | 2100                                  | 3875           | 18      | 1 1/4"    | 1/2      | Electronic   |
| FGO-1000A-E  | 700                  | 1000 | 5-7                               | 3000                                  | 4800           | 22      | 1 1/2"    | 1/2      | Electronic   |
| FGO-1400A-E  | 1000                 | 1400 | 7-10                              | 4200                                  | 6750           | 30      | 1 1/2"    | 1/2      | Electronic   |
| FGO-2200A-E  | 1400                 | 2200 | 10-18                             | 6600                                  | 10500          | 48      | 2"        | 1/2      | Electronic   |
| FGO-3000A-E  | 2200                 | 3000 | 16-22                             | 9000                                  | 14000          | 66      | 2 1/4"    | 1/2      | Electronic   |
| FGO-3500A-E  | 2800                 | 3500 | 20-25                             | 10500                                 | 16750          | 77      | 3"        | 1/2      | Electronic   |

1000 Btu Gas @ 5" W. C. Pressure—Available for Mixed or L. P. Gases  
\* Based on 70% Boiler Efficiency

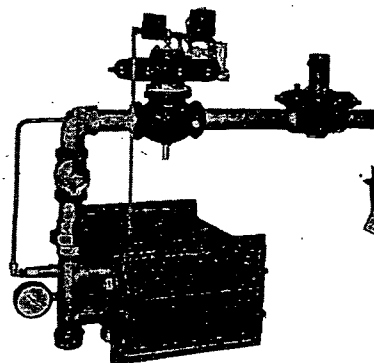
1587



## John Zink Company

4401 S. Peoria — Tulsa, Okla.

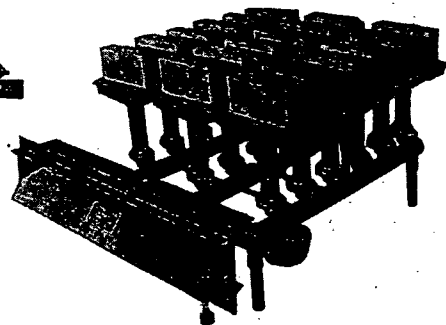
SHREVEPORT • NEW ORLEANS • CORPUS CHRISTI • HOUSTON • SAN ANTONIO • LUBBOCK •  
FORT WORTH • LOS ANGELES  
See other page for additional offices



STV

### SERIES STV GAS BURNER

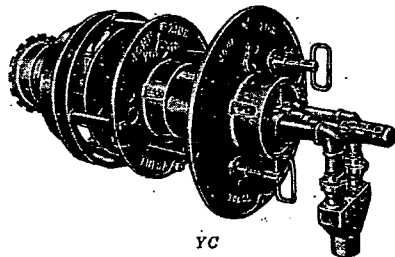
Ideal for heating boiler installations. From one head to fifty heads. Quiet, efficient and economical operation. Write for literature.



VR

### SERIES VR VERTICAL GAS BURNER

This burner is of the "upshot" or vertical radiant type with multiple burner heads so designed as to entrain a certain amount of primary air from the total air entering through the louvre. The "VR" burners are especially designed to operate in boilers having low draft and small combustion space. Write for literature.



YC

### SERIES YC COMBINATION GAS AND OIL BURNER

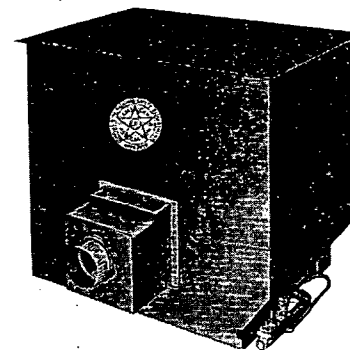
The John Zink Series YC Combination Gas and Oil Burner is recommended for boilers and process furnaces where maximum heat release at low excess air and high heat density is required. Features of the Series YC are Rugged Weather-Proof Construction; Easy to Remove Fuel Guns; Lightweight Fuel Guns; Burn Any Commercial Fuel Oil; Burn Any Gas at Reasonable Pressure; Draft—Natural, Forced or Induced; Center Firing of Both Fuels; Will Operate with Either Fuel as well as in Combination; Can Be Equipped With Any Standard Type Controls.

Also: SMOKELESS FIELD FLARE BURNERS

## John Zink Company

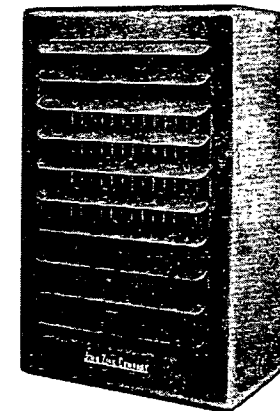
4401 S. Peoria — Tulsa, Okla.

BOSTON • NEW YORK • DETROIT • CHICAGO • OMAHA • DALLAS • LITTLE ROCK  
See other page for additional offices



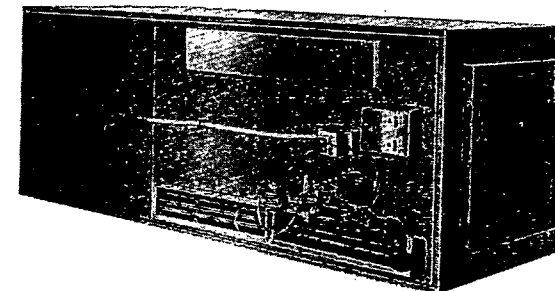
### FLOOR FURNACES

A size for every home heating requirement. Small grille—fool proof—simple to operate—A.G.A. approved—sturdy construction.  
Sizes—35,000; 50,000 and 65,000 Btu input. Write for literature.



### NEW SUSPENDED UNIT HEATER (Series U H S Fan Type)

A.G.A. approved for Natural, Mixed, Manufactured or LP Gas. For clean, safe trouble-free heating of industrial and commercial establishments. A complete packaged unit that is fully automatic. Conserves valuable floor space. Designed for an attractive addition to any store or shop. Write for literature.



### CENTRAL GAS HEATERS (Horizontal-Vertical)

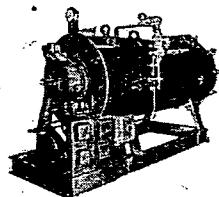
A truly universal, efficient, simple and compact central heating unit. Fully automatic, it is a complete packaged unit ready for installation. May be installed in the basement, attic, service closet or utility room. It is designed as a winter air conditioner with a summer switch to provide air circulation during warm weather. Two models available. Write for literature.

Also: EVAPORATIVE COOLERS, CONVERSION BURNERS,  
ATTIC FANS

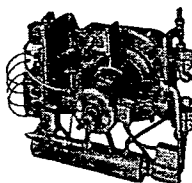
## York-Shipley, Inc.

Main Office and Plants—York 16, Pennsylvania  
OIL AND/OR GAS-FIRED EQUIPMENT FOR INDUSTRY

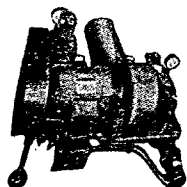
York-Power provides a complete line of economical automatic heating and processing equipment, gas or oil-fired, for every industrial and commercial need.



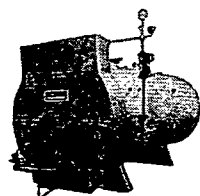
York-Power Steam-Pak (illustrated) and Steam-Pakette Generators are designed for either low-pressure heating loads or high-pressure processing loads, from 15 to 500 hp using Nos. 3, 5, or 6 fuel oil, or gas.



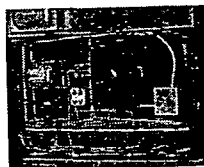
York-Power Horizontal Rotary Burners come in a wide range of sizes, from 45 to 400 boiler hp; oil or combination oil or gas fired. Burners take Nos. 3, 5, or 6 oil.



York-Power Econol Burner, our latest oil-gas combination burner with improved low-cost operating features. Burns Nos. 1, 2, 3, 4 and 5 fuel oil. Available in two sizes: 36 and 75 max boiler rating hp at boiler outlet.



York-Power Scotch Marine (Illustrated) or Firebox Boiler Burners for efficient, low-cost heating. Oil and/or gas fired.



York-Power F/C (Factory Coordinated) Industrial Fuel Burning Systems now provide factory-packaged, industrial fuel burning systems, with all basic components pre-wired and mounted in position. Photo shows details of wiring of main control panel.

For further information write York-Shipley, Inc., or call the York-Shipley Distributor nearest you.

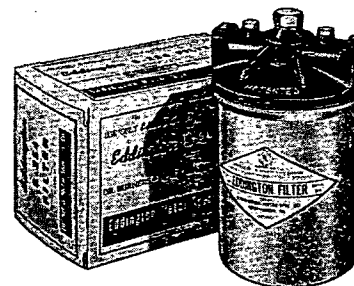
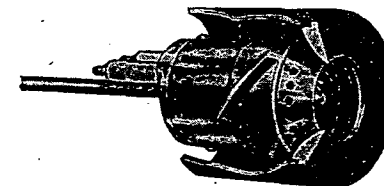
## Eddington Metal Specialty Company

Eddington, Pennsylvania

Filters, Nozzles, Valves, Stabilizers & Air Cones, Strainers, Adaptors, Inspection Mirrors, Servicemens' Nozzle Kits, Combustion Heads

### HIGH PRESSURE COMBUSTION HEAD (HP-53)

Developed especially to provide Air-Oil Mixture of Catalytic Fuel Oils at high CO<sub>2</sub> ratings. Excellent results in field tests with both steel and cast iron furnaces. Ready adaptation to conventional burners in field and by Oil Burner Manufacturers. Also available is a low pressure combustion head (LP-53) which converts high pressure oil burners to low pressure without change in housing design.



### FUEL OIL FILTER

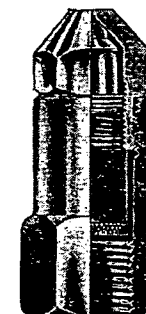
For heating oils in pressure and gravity type oil burners, space heaters, water heaters, stoves and ranges. Light weight, sturdy aluminum construction. Staggered surface of cartridge provides maximum filtering area. Easily replaced by loosening a single bolt and without interrupting pipe connections. Completely interchangeable with other makes.

### DIMENSIONAL SPECIFICATIONS OF FILTERS

| MODEL NO. | HEIGHT                        | DIAMETER         | WEIGHT      | INLET                                         | OUTLET                                        | SURFACE AREA | UNDERWRITERS APPROVED |
|-----------|-------------------------------|------------------|-------------|-----------------------------------------------|-----------------------------------------------|--------------|-----------------------|
| S-252     | 6 $\frac{5}{16}$              | 4 $\frac{1}{16}$ | 1 lb 10 oz. | $\frac{1}{4}$ - $\frac{3}{8}$ - $\frac{1}{2}$ | $\frac{1}{4}$ - $\frac{3}{8}$ - $\frac{1}{2}$ | 98 sq in.    | 25 gph                |
| S-254     | 5 $\frac{1}{2}$ $\frac{1}{2}$ | 3 $\frac{1}{16}$ | 1 lb 5 oz.  | $\frac{3}{8}$                                 | $\frac{3}{8}$                                 | 72 sq in.    | 25 gph                |

### OIL BURNER NOZZLE

Stainless steel throughout with particularly high quality steel and finish of Tip, Disc, and Locknut for maximum wear and heat resistance. Supplied standard with Hollow (H), Semi Hollow (SH), and Solid (S) spray patterns. Custom made if so required for specific Combustion Heads, Boiler Burner Units, or Burners. Factory tested for spray angle, atomization, and actual rated capacity.





**METALBESTOS** DIVISION  
WILLIAM WALLACE COMPANY • BELMONT, CALIF.

## Be Sure of Safe Gas Venting

Use  
**METALBESTOS—**  
the insulated vent

### Right for you . . .

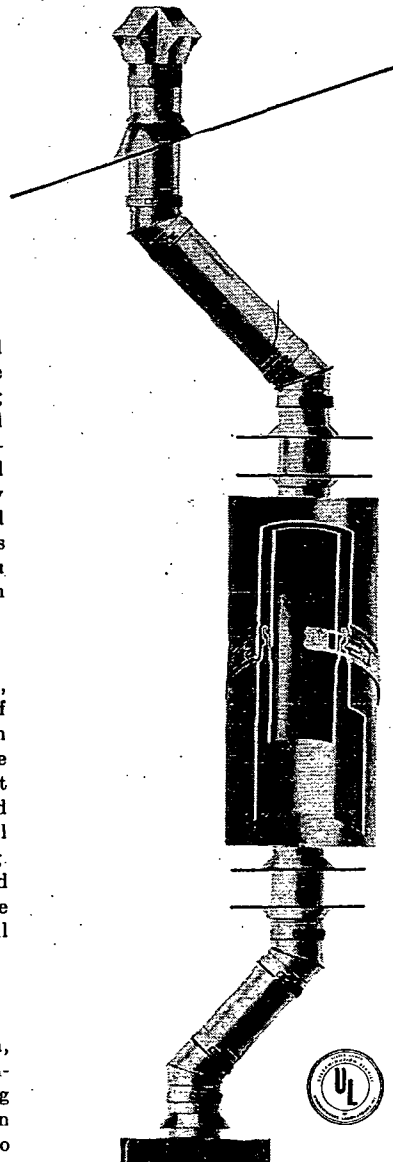
because Metalbestos is easily and quickly installed. Precision made couplers slip together without forcing . . . are tightly and permanently sealed without using mastic or cement. Adjustable lengths, adjustable elbows and other versatile fittings speed assembly and eliminate wasteful cutting and fitting. Your costs are lower, profits higher, because with Metalbestos you can make more installations per man per day.

### Right for your customers . . .

because Metalbestos assures safe, trouble-free venting for the lifetime of the house itself. Double-wall design provides an inner "hot stack" to create a strong venting draft and prevent condensation . . . and an air insulated outer pipe to protect adjacent wall surfaces from dangerous overheating. Joints that stay permanently tight and sturdy damage-resistant construction are further reasons why you can install Metalbestos and then forget it.

### Send for free copy of VENT INSTALLATION HANDBOOK

Based on the latest gas venting research, this pocket-size booklet contains complete, up-to-date information on venting practices plus many helpful installation tips. Write today for your copy. No obligation.



**METALBESTOS** DIVISION  
WILLIAM WALLACE COMPANY • BELMONT, CALIF.

## specify METALBESTOS for all Type B venting needs

RV Metalbestos Round Vent  
—for standard applications.

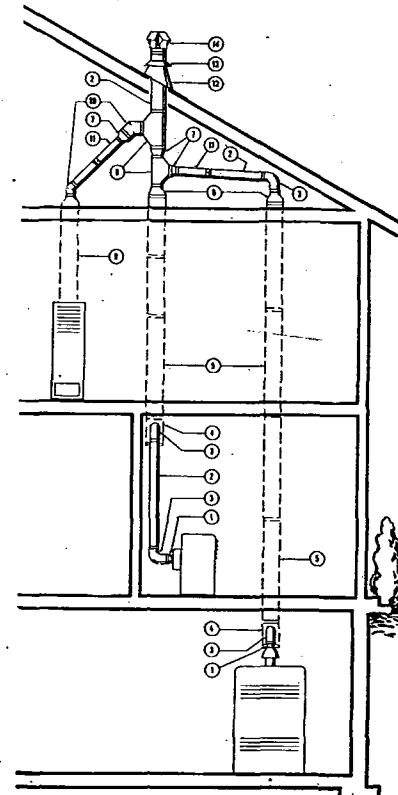
WV Metalbestos Oval Vent  
—for in-the-wall venting

Approved by *Underwriters' Laboratories*  
for use with approved gas appliances.

**DOUBLE-WALL DESIGN . . .** an inner "hot stack" for strong draft, minimum condensation . . . a cooler outer pipe for maximum protection of surrounding wall areas.

**QUICK COUPLERS . . .** and adjustable fittings for fast, low-cost installation.

**DURABLE CONSTRUCTION . . .** all metal, will never crack or break . . . makes a sturdy, tightly sealed venting system that will last the lifetime of the house itself.



Typical Metalbestos gas vent installation for two-story structure. Refer to adjacent list for identification of various fittings.

### SAFE, CORRECT VENTING FOR RECESSED WALL HEATERS

Metalbestos Type B-W Gas Vent is listed by *Underwriters' Laboratories, Inc.* for use with recessed wall heaters. Installation in 2 x 4 stud walls is simple with no furring out or extra insulation required. The narrow double-wall gas vent measuring only 2½ in. x 7¼ in. overall in cross section, when centered in standard stud walls provides a full ½ in. clearance from adjacent material. Furnished in 4 in. size in 3, 4 and 5-ft lengths.

1. Draft Hood Connector
2. RV Round Pipe
3. RV 90° Adjustable Round Elbow
4. RV Round to WV Oval Tee
5. WV Oval Pipe
6. WV Oval to RV Round Adapter
7. RV Round Increaser
8. RV Round Tee
9. Type B-W Wall Heater Vent
10. RV 45° Adjustable Round Elbow
11. RV Round Adjustable Length
12. RV Adjustable Roof Flashing
13. RV Storm Collar
14. RV Belmont Top

NOTE: RV Round pipe and fittings are furnished in sizes of 3 in. to 8 in. diameter. WV Oval Metalbestos and Type B-W Wall Heater Vent are available in standard 4 in. size only.

## AMERICAN DISTRICT STEAM DIVISION

AdSCO INDUSTRIES, INC.

20 MILBURN ST. BUFFALO 12, N. Y.  
PLANTS, BUFFALO, N. Y.—RICHMOND, CALIF.

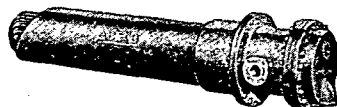
EXPANSION JOINTS—HEATERS  
HEAT EXCHANGERS—STRAINERS  
SEPARATORS



### INSTANTANEOUS HEATERS

AdSCO instantaneous heaters are made in a large variety of types, including the simple U-bend instantaneous shown above, which is used to heat water for showers, dishwashers, laundries, and other purposes. These heaters are also used as Convertors for furnishing hot water to space heating systems.

Many straight-tube, float-head units are used as closed feed-water heaters; boiler blow-down heaters, and for various uses in the process industries.



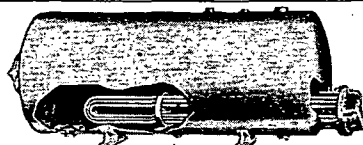
### TANK SUCTION HEATERS

AdSCO tank suction heaters reduce viscosity of heavy oil or other fluids so they can be pumped economically. Instead of employing pipe coils on the bottom of the tank to raise the temperature of all the liquid, only the liquid to be pumped is heated. Steam waste is eliminated. These heaters are furnished with nozzle for welding into storage tanks or with flange for bolting to existing flanged nozzle.



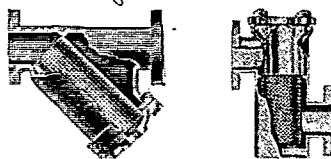
### OIL PRE-HEATERS

AdSCO oil pre-heaters help obtain the highest performance from fuel oil by heating it properly for complete combustion in the burner. In many cases, the work done by oil pre-heaters permits the use of heavier grade, less costly fuel oil. These heaters frequently are used with AdSCO tank suction heaters, the two units making an efficient team.



### STORAGE HEATERS

AdSCO storage heaters are built in accordance with the ASME code for working pressures desired. Tanks are made of flange-quality steel, nickel-clad, or stainless-clad steel, or copper silicon alloy. Where alloy tanks are used, tube sheets are of non-corrosive metal, so that service water does not come in contact with any ferrous parts. Steel tanks can be lined with AdSCO Phenolic 6-2 or Adscote bitumastic to prevent corrosion. All units are equipped with cold-water spreaders. Manholes are heavily reinforced. Copper U-bend heating element is easily removed for cleaning.



### STRAINERS

AdSCO strainers remove dirt, scale and other foreign matter from steam, gas, air, water and oil lines. Their installation ahead of every regulator, pump, valve or trap protects this delicate equipment, reduces maintenance and prevents expensive shut-downs.

Type Y strainers with flanged ends, left, have large screen surfaces and are easily cleaned. Sizes 1½ in. to 14 in., pressures to 600 psig.

Type S strainers, right, are usually installed on suction side of pump. Five cover designs are available: lever and toggle, toggle and bolt, clamp, through bolt, and stud-bolt.

AdSCO separators (not shown here) remove moisture, oil and small solid matter from steam, air and gas lines. Available in vertical up-flow and down-flow as well as horizontal types. Sizes to 10 in. and pressures to 300 psig.

## Aerco Corporation

Paris Avenue, P.O. Box 248  
Northvale, N. J.

AERCO's Controlled "HTR" (Heat Transfer Rate) Heat Exchanger is a Compact Storage Water Heater featuring an Internal Compensator which:

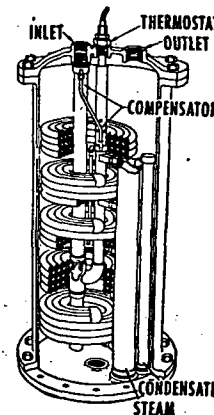


Figure 1—Sectional drawing of Aerco Compact Storage Water Heater.

- Anticipates changes in required steam flow before the actual heat transfer takes place.
- Meters the steam flow accurately in direct proportion with load.
- Prevents surges in steam flow, eliminating need for large storage.
- Maintains ACCURATE control of outlet water temperature.
- Prevents OVERRIDE of outlet temperature on sudden interruption of water flow.

For UNIFORMLY VARYING LOADS (i.e. Hospital General Water Supply), the ability of the above heater to prevent steam flow surges ELIMINATES the need for large STORAGE.

For NON-UNIFORMLY VARYING LOADS or periodic high peak flows and low average demands (i.e. Small Commercial Laundry), the AERCO COMPACT STORAGE WATER HEATER with an Accumulator and Recirculating Pump (as shown in Figure 2) gives a low cost combination which also permits:

- Minimum storage volume for peak demands.
- Minimum steam input for required load.
- Accurate controlled outlet water temperature under all load conditions.

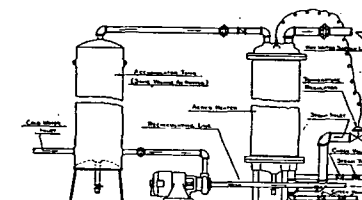


Figure 2—Aerco Compact Storage Water Heater in combination with Accumulator and Recirculating Pump.

### CONSTRUCTION

Shell fabricated to ASME Code Standards, of Flange Quality Steel with plastic or copper lining. Shell ends Cast-iron or Bronze. Internal parts of Copper or Brass. Tested for 125 psig operating pressure. Capacities, 300 to 25,000 gph.

### OPERATION

Cold water enters top, flows down through the Compensator, then up across steam coils to discharge at top. Steam feeds into coils through Steam Riser and leaves through Condensate Return.

Compensator anticipates and controls heat transfer rate by sensing changes in flow or incoming temperature before water passes over the heating coils. It accomplishes this by causing variations of temperature to occur at the Regulator bulb which are definitely related to changes in flow and incoming temperature as well as the final temperature.

Send for booklet: "THE NEW APPROACH To the Design of Hot Water Supply Systems" and Bulletin #22 for capacity data and sizes.





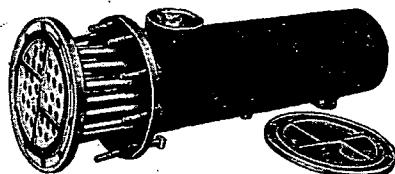
## General Fittings Company



Box 151K, East Greenwich, R.I., U.S.A.

HOT WATER HEATING AND HEAT TRANSFER

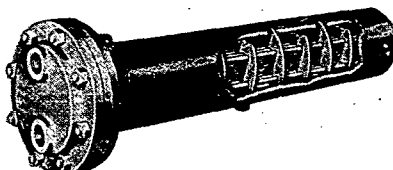
### GENERAL Instantaneous Water Heaters



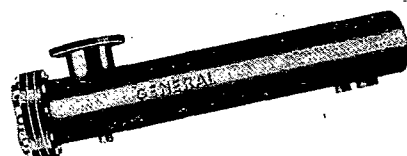
For continuous supply of hot water for industrial service or processes, apartments, hotels, etc. No storage tank. Two types: steam or boiler water through shell instantly heats water drawn through copper coils as needed. Capacities to 300 gpm.

### GENERAL Fuel Oil Heaters

Baffle-type heaters for use with live steam, exhaust steam or boiler water through tubing; fuel oil through heater shell. U-type heaters for water-through shell, oil-through tubing. Capacities to 2,000 gph.



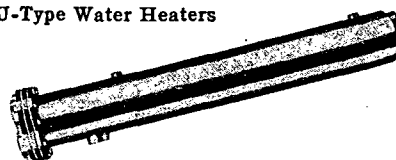
### GENERAL Converters



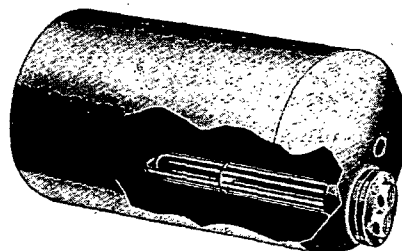
Compact, efficient heaters for supplying forced hot water heating systems. Two types available: for use with constant steam supply, or for mounting below boiler water level. Capacities to 9,000,000 Btu per hr.

### GENERAL Indirect U-Type Water Heaters

Horizontal heaters for use with large-size storage tanks. For use with steam source or below water-line installation on heating boilers.



### GENERAL Coil-Heated Tanks



Black Iron or Galvanized. Boiler water or steam through coils. Heater easily removable for cleaning.

WRITE FOR CATALOG 61 OF FLUID-HEATING SPECIALTIES

1596

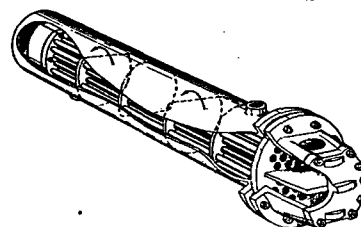
## KILLEBREW

Engineering

Corporation

8640 Pardee Lane, Saint Louis 23, Mo.

### ASME FABRICATION

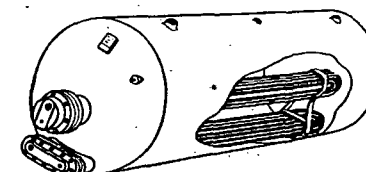


### FRE-FLO INSTANTANEOUS WATER HEATER

Easily cleaned, straight tube with removable cover plate and floating head. Designed for heavy loads and fouling fluids. Standard sizes from 50 gph up.

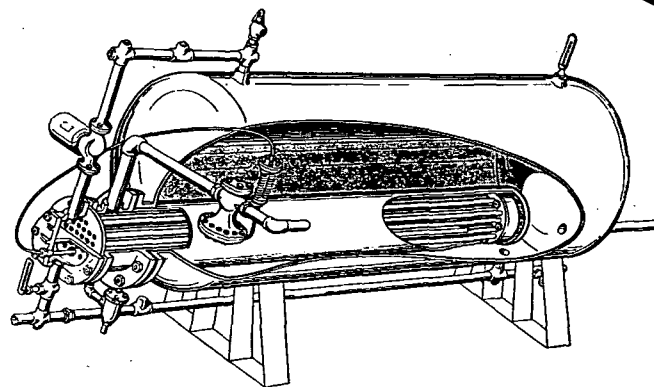
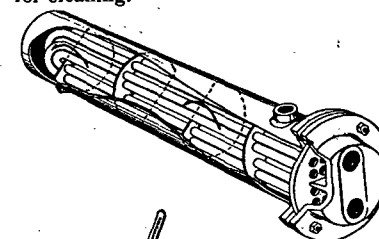
### FRE-FLO RADIATION CONVERTER

Complete range of sizes. Used with steam or boiler water. Cast iron head, steel shell, copper U tubes and bronze tube supports or baffles.



### FRE-FLO STORAGE WATER HEATER

Steel (rust resistant lining optional) or alloys. Copper tubes on square pitch or flat bundles to set low in tank for use as condensate cooler or used where heavy fouling requires complete access for cleaning.



### FRE-FLO LOAD LEVELER

A simple, rugged, packaged water heater designed specifically for handling extreme surge loads, yet levels the steam load on your boiler. Will deliver one or two temperatures of your selection, individually controlled. The Fre-Flo Load Leveler is completely assembled, ready to connect to utilities. Sizes from 450 gph and up.

WRITE US REGARDING YOUR HEAT EXCHANGE PROBLEMS  
FRE-FLO CATALOG AVAILABLE

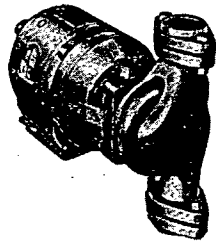
1597

## Bell and Gossett Company

Morton Grove, Illinois

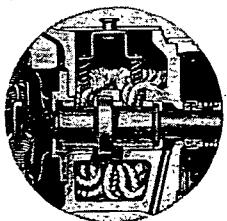
### HYDRO-FLO HOT WATER SYSTEMS AND SPECIALTIES

#### B & G Booster Pumps



The B & G Booster is the basic unit of a B & G *Hydro-Flo* Forced Hot Water Heating System. It is built as a horizontally driven unit for sound engineering reasons which have demonstrated their practical value in thousands of installations. This construction makes possible many desirable, exclusive features. For example, the patented water-tight Seal eliminates need for a stuffing box.

This Seal positively prevents entry of water into bearings. Shaft is of highly polished, hardened machine steel. The close-fitted Impeller makes every revolution count by holding water slippage to a minimum.

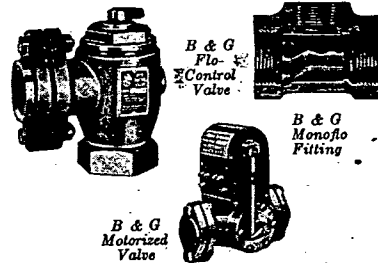


Oil Lubricated Bearings

B & G Boosters have a genuine oil-circulating lubrication system—one of the greatest reasons for quiet, dependable, economical operation. Oil is drawn up from the oil well by wool fibre wicking and dropped on the horizontal bearing surfaces. Medium grade motor oil is used and only a few drops at infrequent intervals are required.

SEE THE B & G HANDBOOK FOR COMPLETE DESIGNING DATA

1598



#### B & G Flo-Control Valves

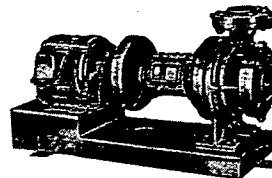
This valve, installed in the main, shuts off circulation to radiators when heat is not needed, permitting summer operation of a B & G Indirect Water Heater. It also helps maintain a uniform room temperature during the heating season.

#### B & G Monoflo Fittings

B & G Monoflo Fittings permit the use of a *single* pipe main instead of the conventional flow and return lines. They are installed at the junction of the radiator risers to the single main and assure the diversion of the proper amount of heated water into each radiator. Savings in space, labor and materials are obviously effected. Available in cast-iron and copper.

#### B & G Motorized Valves

Thermostatically operated valves used to control boiler water flow through individual circuits of zoned heating systems.



#### B & G Universal Pumps

Designed for forced hot water heating systems in apartment and office buildings, factories, schools, etc. The Universal is not an ordinary centrifugal pump, but is specially designed to assure quiet operation, so essential in heating system applications.

### HOT WATER SYSTEMS AND SPECIALTIES

#### B & G Relief Valves

Designed and built to ASME requirements. Tested by National Board—labelled with ASME symbol.

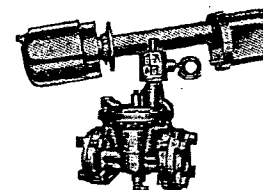
For relieving excess boiler pressures in hot water heating systems, and in the lines of service water systems. B & G Relief Valves have the design features which assure dependable service.



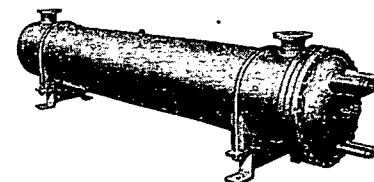
#### B & G Reducing Valves

All working parts brass, with built-in strainer. Easily adjusted to meet varying building heights. Also high pressure reducing valves for protection of plumbing fixtures.

#### B & G Comfort Control System



Outdoor type, *wind-compensating* temperature control. The Regulator projects through the building wall, with the indoor end warmed by water in the radiation circuit. A small amount of this heat is conducted to the outside end, where it is dissipated at a rate dependent upon temperature and wind velocity. This heat dissipation governs the Control Valve, which permits hot boiler water to enter the system in required amounts.



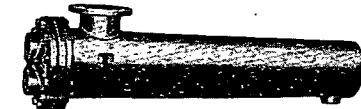
#### B & G Type "WU" Heat Exchangers



A shell and tube heat exchanger with hot boiler water pumped through the shell by a B & G Booster, making possible big capacity in a small unit.

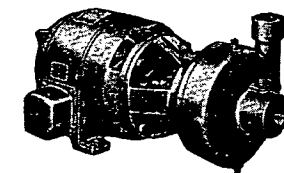
Pumping boiler water through the heater also affords excellent temperature control and permits use of much smaller pipe and fittings.

#### B & G Type "SU" Heat Exchangers



For heating water with steam. Ideal for industrial plants or wherever large volumes of hot water are required continuously for service water supply or process work. No storage tank required—the large heat transfer surface in these units heats water instantly as needed. Available in a wide range of capacities.

#### B & G Centrifugal Pumps



Design and construction based on years of experience in the industrial field. Rugged, compact units—built to withstand strain of continuous operation. Semi-open or enclosed impellers—motors flexible coupled or integral with pump. Series 1522 illustrated.

#### B & G Refrigeration Components

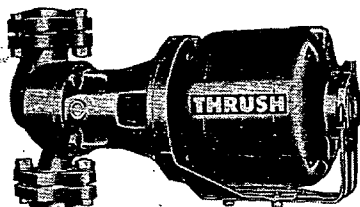
A very complete line of direct expansion evaporators, condensers, liquid receivers, combination liquid receivers and subcoolers for refrigeration and air conditioning. Special alloys may be incorporated in the units for those critical heat transfer applications.

1599

# H. A. Thrush & Company

Peru, Indiana  
Representatives in Principal Cities

## FORCED CIRCULATING THRUSH FLOW CONTROL SYSTEM OF HOT WATER HEATING AND HEATING SPECIALTIES

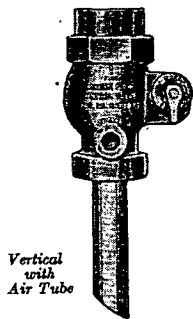


Horizontal Water Circulator

Thrush Flow Control System of Hot Water Heat assures continuous radiant heat whether used with radiant panels, convectors, radiant baseboards or radiators. Circulation is forced and operation is entirely automatic. It automatically compensates for outdoor weather changes. Hot water for kitchen, laundry and bath, both summer and winter is provided by the heating plant boiler. Piping plans and engineering assistance are available to the trade.

### THRUSH WATER CIRCULATORS

Forced circulating pumps for Hot Water Heating and Domestic Water Systems. Insure uniform heating. Quiet and efficient, long lived and vibration-free. Sealed-in lubrication. Made in 7 sizes,  $\frac{3}{4}$  in., 1 in.,  $1\frac{1}{4}$  in.,  $1\frac{1}{2}$  in., 2 in.,  $2\frac{1}{2}$  in., and 3 in. Hi-Head Horizontal Thrush Water Circulators, designed for use with radiant baseboards, convectors, radiant panels, etc., which require higher heads, are also available in 1 in.,  $1\frac{1}{4}$  in., and  $1\frac{1}{2}$  in. sizes.



Vertical with Air Tube

### THRUSH FLOW CONTROL VALVES

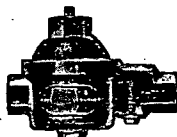
Special check valves for use on automatically fired boilers, automatically control circulation when installed with a Thrush Circulator. Close tight when circulator is not running, prevent gravity circulation when heat is not needed in the radiators. Available with Air Tube which vents air from boiler into pressure tank, greatly improving heating efficiency by eliminating air from the system. 1 in. through  $1\frac{1}{2}$  in. valves also available with solder type outlet unions. Also made in angle type with or without air tube and in horizontal type for zoning. Made in six sizes, 1 in.,  $1\frac{1}{4}$  in.,  $1\frac{1}{2}$  in., 2 in.,  $2\frac{1}{2}$  in. and 3 in.



Thrush Pressure Tank With Vacuum Breaker

### THRUSH PRESSURE TANKS NOW HAVE VACUUM BREAKER

Genuine Thrush Pressure Tanks are air tight... tested under pressure... and equipped with the convenient Thrush Vacuum Breaker at no extra cost. Easy to drain if waterlogged.



No. 18— $\frac{3}{4}$  in. Automatic Filling Valve



No. 4 Bronze or Iron  $\frac{1}{2}$  in.  $\frac{3}{4}$  in. and 1 in.

### THRUSH AUTOMATIC FILLING VALVES AND LOW PRESSURE RELIEF VALVES

Whenever system pressure drops below 12 lbs. city water pressure will automatically open the Thrush Automatic Filling Valve and admit water until the system is filled.

Thrush Relief Valves protect heating boilers from excess pressures. Large metal diaphragm assures positive closing and opening.



### ASME APPROVED NO. 46 THRUSH SAFETY RELIEF VALVE FOR HOT WATER HEATING SYSTEMS

Rated output of 283,500 Btu based on steam capacity discharge. Primarily a water relief valve designed to serve double duty of relieving water, as well as steam should critically high temperatures occur. Testing lever. 30 lbs pressure.  $\frac{3}{4}$  in. inlet, 1 in. outlet.



No. 75



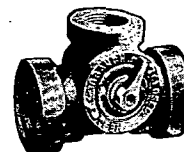
No. 76

### NO. 75 THRUSH HIGH PRESSURE WATER RELIEF VALVES

To protect hot water heaters, range boilers and automatic water heaters from excess pressure. Factory setting 85 lb. Adjustable at factory to 150 lb maximum.

### NO. 76 HIGH PRESSURE AND TEMPERATURE RELIEF VALVES

The valve illustrated above at right has an added safety feature. It not only guards against excessive pressures, but also relieves if excessive temperatures develop. A fusible element melts at 210 F. Both types are designed for use in the hot water outlet line.



C. I. Patent No. 2,404,998 —Bronze Patent No. 2598148

### ADJUSTABLE THRUSH SUPPLY TEES FOR ONE PIPE SYSTEMS

Provide exact balancing of forced circulating one-pipe hot water heating systems. Easily adjusted. When branch flow is cut down main flow is increased, not retarded. Available in bronze with solder connections for use with copper pipe and in threaded cast iron for steel pipe. Non-adjustable tees also available.

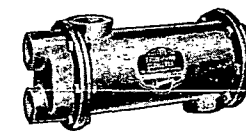
### NO. 5 HOT WATER AIR VALVE

An inexpensive, dependable, automatic air vent for Hot Water coils, convectors, radiators, unit heaters, and high points of mains. Tapping  $\frac{1}{8}$  in., I.P.T.

### THRUSH TANK DRAIN

Combines Drain Valve and Vacuum Breaker in one handy, inexpensive fitting. Removing plug admits air to permit quick draining of waterlogged tank.

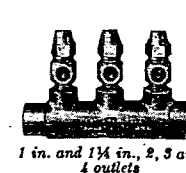
### WRITE FOR NEW CONDENSED CATALOG



Patent No. 2,180,620

### THRUSH WATER HEATERS

Highly efficient heat exchangers or converters. Fifteen sizes, for Hot Water or Steam. Pressure up to 150 lb water, 50 lb steam. Straight tubes readily cleanable. Provide Domestic Hot Water at low cost. Also used industrially for heating or cooling liquids.



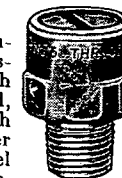
1 in. and  $1\frac{1}{4}$  in., 2, 3 and 4 outlets



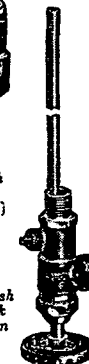
$\frac{3}{8}$  in. or  $\frac{1}{2}$  in.

### THRUSH MANIFOLDS AND BALANCING VALVES

Thrush Manifolds save time, space and labor installing Radiant Heating. Available in 1 in. and  $1\frac{1}{4}$  in. sizes, each with two, three or four  $\frac{3}{8}$  in. or  $\frac{1}{2}$  in. threaded branch outlets. Also available in  $1\frac{1}{4}$  in. and  $1\frac{1}{2}$  in. sizes with three or five  $\frac{3}{4}$  in. solder branch connections. Ends have solder connections. Manifold with Balancing Valves as shown above is used in return lines only. Used in supply lines without valves. Balancing Valves permit individual filling of each coil, eliminate air quickly and save time. Two types, three sizes,  $\frac{3}{8}$  in.,  $\frac{1}{2}$  in. or  $\frac{3}{4}$  in. Flared fittings for  $\frac{3}{8}$  in. and  $\frac{1}{2}$  in. tubing.



No. 5 Thrush Air Valve (2 in Box)



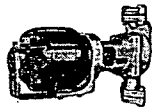
Thrush Tank Drain

## Taco Heaters, Incorporated

1160 Cranston Street, Cranston 9, R. I.  
TACO HEATERS OF CANADA, LTD., 4 Gilead Place, Toronto



### TACO CIRCULATORS



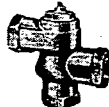
Easy to service in the field. Available in a full line— $\frac{3}{4}$  in. to 3 in. Motors are especially selected for quiet performance and low cost operation.

### TACO UNIVERSAL FLOW CHECK



An accurately weighted automatic valve. Opens when circulator is running. Closes when thermostat stops circulator to prevent hot boiler water entering system. For angle or horizontal application.

### TACO PANELTROL



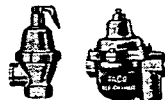
Adjustable to deliver water to radiant heating panels for any temperature between 110 F and 150 F even though boiler water is kept at higher temperature for summer-winter hot water.

### TACO AUTOMATIC AIR VALVES



Taco-Vent is leak-proofed. A porous bronze plug limits the flow of water through valve. The Steam Vent eliminates pinging, clicking or hissing.

### TACO RELIEF AND REDUCING VALVES



Automatically maintains sufficient water and pressure in system. The new Taco ASME Relief Valve ( $\frac{3}{4}$  in.) handles 80 per cent of all hot water heating jobs, and is set to relieve at 29 lbs. Reducing Valve is factory set at 12 lbs.

Send for Catalog I-99 for complete information and engineering data.



### TACO VENTURI FITTINGS

Only one required per radiator on return ... use ordinary tee for supply. Powerful suction action draws water through radiator for positive circulation. May be used for above or below main radiation.



### TACO-MATIC VALVE

Designed primarily to protect the performance of a tankless hot water heater on a forced circulation hot water heating system. Also performs function of a reverse acting control, eliminating added cost.



### TACO AIR-SCOOP

Scoops air from hot water system by a series of baffles. Air is then vented to either atmosphere or expansion tank. When system is first filled ... vent radiators and high points once ... no return to job.



### TACO TEMPERING VALVE

Guards against excessively hot domestic hot water. Mixes cold water with hot water from Taco Tankless or storage heater to provide tempered water at fixtures.



### TACO WATER HEATERS, CONVERTORS AND CHILLERS

Taco Convertors and Water Heaters provide hot water and radiation for commercial and institutional heating purposes. Chillers are designed for chilling water in the air conditioning and refrigeration fields.

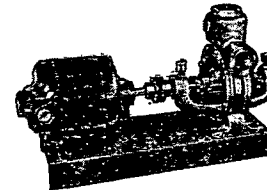


## AURORA® PUMP DIVISION

THE NEW YORK AIR BRAKE COMPANY  
40 LOUCKS STREET • AURORA • ILLINOIS

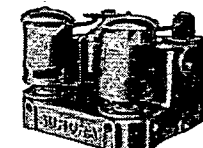


Manufacturers of  
Turbine-Type, Vertical and Horizontal Centrifugal and Special Design Pumps  
Distributors in Principal Cities



APCO Single Stage Turbine-Type Pumps. Also available in Two Stage.

Barring Unusual Conditions We MAINTAIN A COMPLETE STOCK FOR IMMEDIATE SHIPMENT



Packaged Duplex Apco-Matic Condensation Return Unit designed for smaller jobs. LARGER UNITS up to 150 gpm capacity, horizontal and vertical also available.

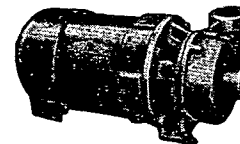
APCO PUMPS are IDEALLY SUITED to MANY HEATING and AIR CONDITIONING DUTIES—CAPACITIES UP TO 150 GPM—HEADS TO 600 FT.

FEATURES—APCO pumps are distinguished for their ability to deliver small capacities against high heads; their ability to deliver with but slight change in capacity or efficiency against drastic head variations. They possess these advanced features — SIMPLE — WEAR-FREE — COMPACT — HIGH EFFICIENCY — WILL NOT VAPOR BIND — HYDRAULICALLY BALANCED — ACCESSIBILITY — HIGH SUCTION LIFT

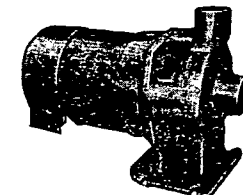
LOW HEAD

SMALL CAPACITY—SIDE SUCTION PUMPS

MEDIUM HEAD



At Left  
TYPE—SAC—Close Coupled, Caps 5 to 85 gpm. Heads to 45 ft. Sizes Available  $\frac{3}{4}$ ", 1 $\frac{1}{4}$ ", 2"



At Right  
TYPE—JMC—Close Coupled Caps, 5 to 150 gpm. Heads to 100 ft. Sizes Available 1", 1 $\frac{1}{4}$ ", 1 $\frac{3}{4}$ ", 2"

The SAC and JMC Close-Coupled Pumps are available in a PACKAGED Arrangement for IMMEDIATE DELIVERY. APPLICATIONS

Well suited as integral part of manufacturer's product such as air conditioning units, cooling towers, evaporator coolers, hot water circulators etc., also for general service.

CONSTRUCTION SPECIFICATIONS Made in bronze fitted, all iron or all bronze construction.

CASINGS, vertically split—end suction. High grade material as specified. Casting wearing ring is standard on Type JMC.

MECHANICAL SEAL is standard on all sizes and is located in packing cover—easily replaceable.

IMPELLER is balanced, enclosed type of high grade bronze material.

SHAFTS—Stainless steel on Types JMC, SAC and JA. Can be furnished on Type SA at additional cost.

MOTOR Built to NEMA specifications and equipped with STAINLESS STEEL shaft.

BALL BEARINGS—Permanently sealed against dust and moisture—No lubrication required.

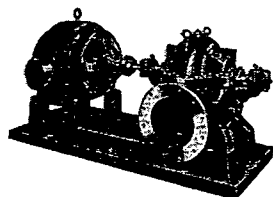
AURORA CENTRIFUGAL PUMPS are available in many types and sizes—all noted for their streamline co-ordination between impellers and shells.

Write for  
CONDENSED CATALOG "V"

## Buffalo Pumps

Division of Buffalo Forge Co.  
450 Broadway, Buffalo, N. Y.

A complete line of Centrifugal Pumps, Single and Double Suction, Single and Multi-stage, for all types of heating and air conditioning installations. Write for Engineering Bulletins mentioned below, or consult the Buffalo Engineering Representative in any principal City.



### DOUBLE SUCTION SINGLE STAGE PUMPS

Extensively used for handling chilled water and other air conditioning and clear water applications including air washers, these pumps are available in capacities from 10 to 14,000 U.S. gallons per minute, against heads up to 350 ft. Highly efficient operation is provided by their simply formed water passages and their hydraulically balanced impellers (water enters each side of impeller, with equal pressure and volume). All parts are

ample for durability under hard service. Top half of the casing is readily removable for servicing without disturbing piping. Write for *BULLETIN 965-Q*.

### CLOSE-COUPLED SINGLE SUCTION PUMPS

These pumps offer the advantages of compactness, high performance and simple installation without need for shaft alignment. (A 4 in. pump, delivering 600 gpm at 60-ft head, requires less than 2 cu ft of space). Available in 1 in. to 6 in. discharge sizes. Design permits vertical or horizontal installation, with discharge adjustable to desired angle. These pumps are suited to handling hot water with low submergence. Write for *BULLETIN 975-D*.



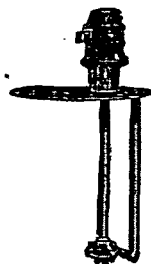
### SINGLE SUCTION MULTISTAGE PUMPS

Used for boiler-feed and other clear water service, these heavy-duty pumps are especially suited to delivering at high pressures and temperatures. Available in two and four stage models for capacities from 20 to 900 gpm at heads up to 1500 ft. Shaft is extra-heavy and oversize bearings support the shaft on

each end. Top-half of pump casing is removable for servicing without disturbing piping. Write for *BULLETIN 980-D*.

### AUTOMATIC SUMP PUMPS

These are shipped as preassembled units ready to put into the sump pit, wire and start pumping. No priming is necessary, since there is no suction lift. Thrust load is carried by ball bearings, and the shaft is fully enclosed to prevent fouling with waste or stringy matter from the sump. All parts are readily accessible. Write for *BULLETIN 963-H*.



DOMESTIC PUMP & MANUFACTURING CORP.  
SHIPPENSBURG • PENNSYLVANIA

INDUSTRIAL  
PUMPS

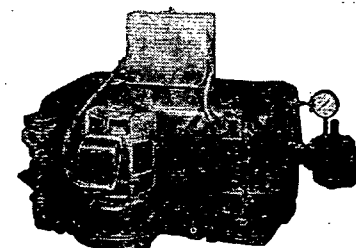
**"DOMESTIC"**  
FOUNDED 1903

COMMERCIAL  
PUMPS

Products: Return Line Vacuum Heating Pumps; Condensate Return Pumps; Vertical, Horizontal and Flange Mounted Centrifugal Circulating Pumps.

### THREE COMPLETE LINES OF VACUUM HEATING PUMPS

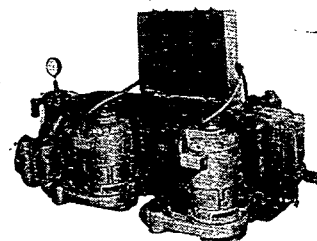
Type VLR Single and Duplex Units for Standard and Special capacities up to 20,000 sq ft EDR. *Bulletin S110*. Type VLS Single and VLD Duplex for Standard and Special capacities from 25,000 to 150,000 sq ft EDR. *Bulletin S130*. Type VCA with individually sized and separately controlled vacuum and condensate pumps. Air capacities up to 95 cfm at 20 in. Hg and condensate capacities up to 300 gpm at 75 psi. *Bulletin S150*.



Vacuum Pump Type VLR1

The heart of all Domestic-Ames Vacuum Pumps is the multi-orifice vacuum producer. Average air evacuating rate is twice its rating, reducing operating time and power cost. Removes up to 300 per cent of rated air capacity at start of heating cycle to shorten warm-up period. It is simple, efficient and capable of producing a near perfect vacuum. It will retain its original effectiveness year after year.

All types vacuum-tight accumulators (condensate receivers) available.



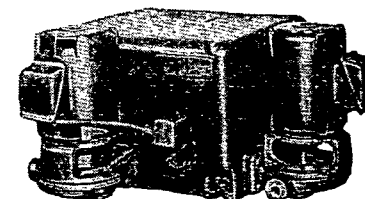
Vacuum Pump Type VCA4

### CONDENSATION AND BOILER FEED PUMPS

Single and Duplex Units for systems up to 150,000 sq ft EDR and 60 psi. Each motor of the Type CC Unit is controlled by its own float switch. *Bulletin S200*.

The BOILER FEED type CM Unit provides automatic water make-up to replace water lost from the system and to maintain the most efficient boiler steaming level. *Bulletin S200*.

UNDERGROUND CONDENSATE PUMPS are available for use where returns are either too low for a standard pump or below floor level. *Bulletin S240*

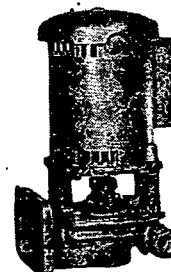


Condensation Pump Type CC2

All Domestic-Ames Vacuum Heating and Condensation Pumps have life-time cast iron receivers with low inlets. Vertical pump mountings put motors above dirt and water and contribute to unit's compact design. Pumps are close coupled for precision alignment and smooth, quiet operation.

### GENERAL PURPOSE CENTRIFUGAL PUMPS

New Domestic "Centriflo" for hot and cold liquids. Quiet, efficient and compact. Head to 200 ft capacities to 400 gpm. Bronze fitted, all iron or bronze. Mechanical seal or packing. Motors 1750 or 3500 rpm, 1 or 3 phase, open, totally closed or explosion proof. Flange mounted, vertical or horizontal close coupled. *Bulletin S680*



## Chicago Pump Company

622 W. Diversey Parkway Eastgate 7-1020

Chicago 14

**PRODUCTS**—Return Line Vacuum Heating and Boiler Feed Pumps, Condensation, House, Booster, Fire Pumps, Circulating, Brine, Sewage, Bilge, Sludge, Pneumatic and Tankless Water Supply Systems and Automatic Alternator for Duplex Sets of Pumps.

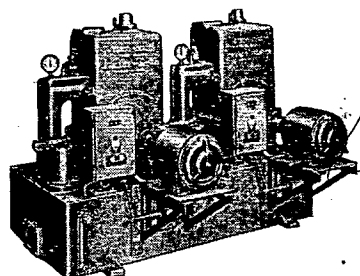


Fig. D-9900—Duplex "Condo-Vacs" with Duplex Double Automatic Control

### "CONDO-VAC"

Return Line Vacuum and Boiler Feed Pump for Heating Systems

No vacuum on stuffing boxes, ample clearance in rotating member. It costs less to operate a "Condo-Vac." "Condo-Vac" reduces corrosion in piping and boiler to minimum—because pump does not take in air from atmosphere and entirely eliminates all air coming back from system. "Condo-Vac" is quiet, has a low inlet, entirely automatic, fool-proof, easy to maintain. Ask for Bulletin 270.

For every heating system get the pump that is specifically designed for the particular job. For below floor returns, for low vacuum systems, for small capacity

high pressure requirements, for any standard heating system, or any unusual condition, there is a CHICAGO Heating Pump that will do the job better.

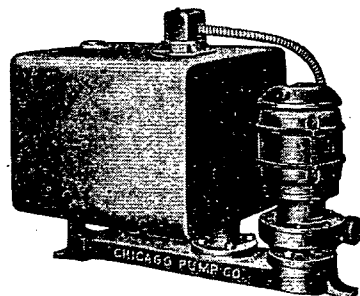


Fig. D-9800

### "SURE-RETURN" CONDENSATION PUMPS

for Low and Medium Pressure, and Systems up to 75,000 Sq Ft Radiation

"Sure-Return" Condensation Pumps and Receivers are built for systems up to 75,000 sq ft of direct radiation and for low and medium pressures. Built in either single or duplex units. Duplex units are alternated in their operation by the Automatic Alternator. Complete data in Bulletin 250.

### VERTICAL CONDENSATION PUMPS

for Low and Medium Pressure for Systems from 500 to 100,000 Sq Ft Radiation

The vertical condensation pump is designed to receive returns from lowest radiation. The receiver is placed underground—an ordinary hole sufficing if necessary—and requires very little floor space. Unit is shipped complete, easy to install, assembled so as to prevent steam leaks. Special bearings will stand up under hot water for several years. A special float mechanism is guaranteed not to leak or stick in stuffing box. Complete data and description in Bulletins 245, 253 and 255.

Fig. V-9800 Vertical Condensation Pump



## Chicago Pump Company

622 W. Diversey Parkway

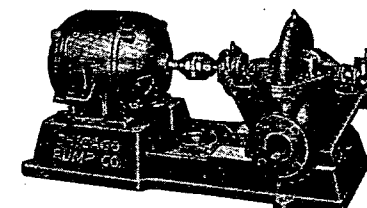
Eastgate 7-1020

Chicago 14

**PRODUCTS**—Return Line Vacuum Heating and Boiler Feed Pumps, Condensation, House, Booster, Fire Pumps, Circulating, Brine, Sewage, Bilge, Sludge, Pneumatic and Tankless Water Supply Systems and Automatic Alternator for Duplex Sets of Pumps.

### TYPE D, DOUBLE SUCTION, HORIZONTALLY SPLIT CASE PUMP

For house pump, fire and booster service. A ruggedly built, heavy duty pump for long trouble-free service. The rotating assembly may be inspected without disconnecting the piping. Capacities up to 1900 gpm—heads to 530 ft. Described in Bulletin 101.



Type D, Double Suction, Horizontally Split Case Pump

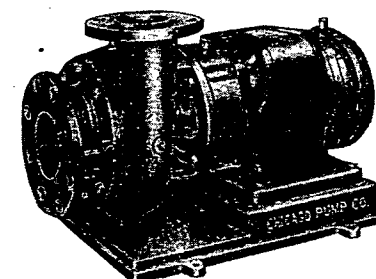
For circulating service, heating, bilge, or sewage pumping, CHICAGO equipment is among the best available. Each pump is specifically designed to do the particular job and do it right. Over 40 years ex-

perience with pumps for every application is built into every unit.

For "worry proof" pumping at all times—specify CHICAGO Industrial Pumps.

### TYPE C-C, CLOSE COUPLED BOOSTER PUMP

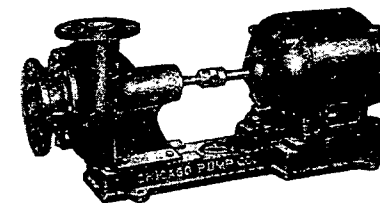
Designed to handle the toughest pumping jobs efficiently and in the least possible space. May be mounted in any position as long as the motor is not lower than the pump. Provided with leak-proof mechanical seal. Capacities up to 500 gpm—heads to 215 ft. Described in Bulletin 108.



Type C-C, Close Coupled Booster Pump

### TYPE F-C, PEDESTAL MOUNTED, SIDE SUCTION PUMP

Built to the same exacting engineering standards as the Type C-C Pump and with the same capacity and head. The flexible coupling drive permits easy field servicing and the use of customer's choice of motor manufacture. Described in Bulletin 107.



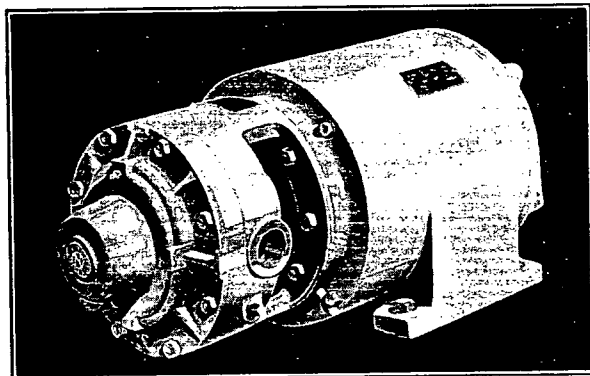
Type F-C, Pedestal Mounted, Side Suction Pump

## The Nash Engineering Company

234 Wilson Road

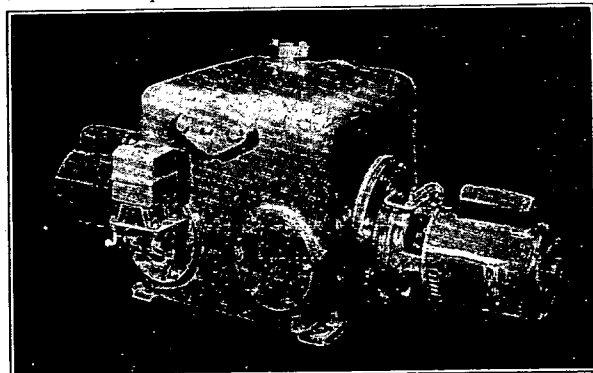
South Norwalk, Conn., U. S. A.

Sales and Service Offices in all Principal Cities



**NASH HOSPITAL PUMPS**

For vacuum and pressure systems in hospitals to provide vacuum or pressure to operating rooms, laboratories and wards. Nash pumps possess particular characteristics adapting them to this exacting service. Silent service is assured, because the pumps and equipment are installed in a mechanical equipment room. Automatic control assures constant maintenance of the correct vacuum or pressure. No pulsation is present in either vacuum or pressure produced by Nash Pumps. Air delivered by Nash Compressors is entirely free from dust, heat or oil. Even dust entering the pump inlet is effectively removed. No oil or dust filters are required. No expert attendance is required. *Bulletin on request.*



**CONDENSATION PUMP TYPE CS**

Following the advanced design of our CSM Heating Pumps, the CS Condensation Pump has features representing long life, dependable operation and low maintenance and installation cost.

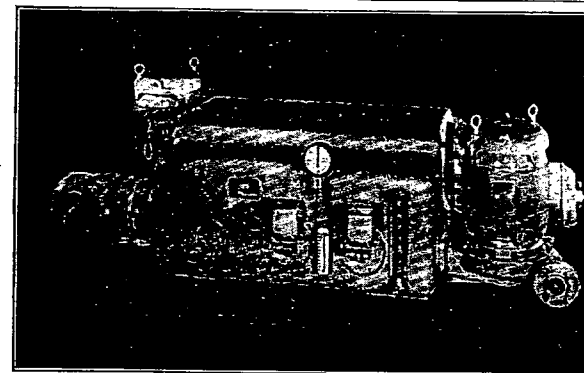
Pump is single suction centrifugal in bronze fitted construction with renewable bronze sealing rings. Balanced impeller is designed for high efficiency handling hot condensate. Pump and motor form a compact unit. Simple mechanical seal replaces conventional stuffing box, eliminating maintenance. Strainer area nearly three times that in previous pumps. Easily removed for cleaning. Inlet connection is only 12, 14 or 15 inches, depending upon size of unit, permitting easy and low cost installation. *Bulletin on request.*

## The Nash Engineering Company

234 Wilson Road

South Norwalk, Conn., U. S. A.

Sales and Service Offices in all Principal Cities

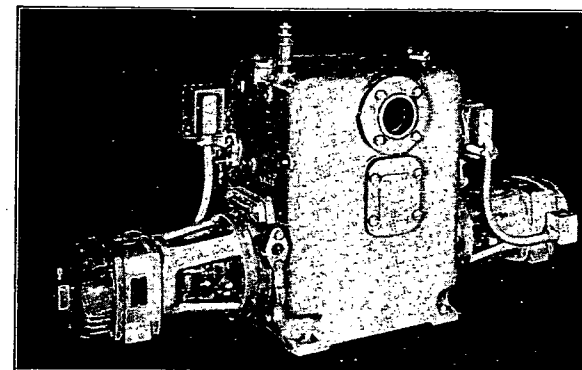


**RETURN LINE VACUUM HEATING PUMP  
TYPE CSM**

The new CSM Heating Pump achieves a high level of performance and efficiency. Complete flexibility is secured in this design, since each pumping element is driven by its own motor, actuated by its own control.

This makes possible a wide range of air and water capacities that can be selected to meet the exact requirements of each particular job.

These pumps are now available in a full range of air and water capacity combinations, for operation up to 20 inches Hg vacuum, and for pressures from 10 lbs to 70 lbs. *Bulletin on request.*



**RETURN LINE VACUUM HEATING PUMP  
UNIT TYPE**

Removes air and condensation from return lines of vacuum heating systems. Separation of liquid and gas is made under vacuum. Independent air and water units, combined in single casing and rotating on single shaft, handle returns with high efficiency. Air unit delivers to atmosphere without back pressure. Water unit delivers directly to boiler. Bronze fitted throughout. No internal wearing parts. No internal lubrication. Supplied direct connected to electric motor, or for belt drive, for continuous operation or with automatic control. Standard capacities up to 40,000 sq ft equivalent direct radiation. Larger units special. *Bulletin on request.*





**KRAISSL** CO.  
INC.

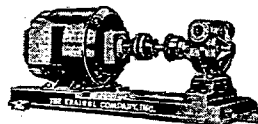
297 Williams Ave. Hackensack, N.J.

Sales representatives in principal cities.

Pumps and separators for fuel oil burner and heating service; circulators for water service; filters and strainers for oil, water, liquids, air and steam applications.

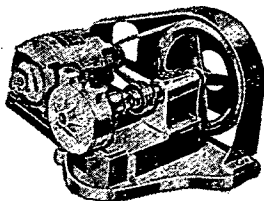
### Class 50 Light Oil Pumps

Direct drive for No. 1 to No. 4 oils inclusive. High suction lift; pressures up to 100 psi. Ask for *bulletin A-1330*. Particularly adapted to dirty oil conditions where extraneous matter would cause seizure in more closely fitted mechanisms. Capacity 1 to 10 gpm. Class 60 M Pumps provide capacities from 2 to 212 gpm; special bearings available for solvent service.



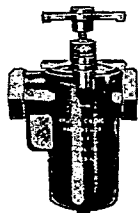
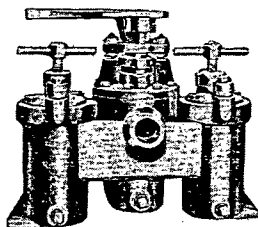
### Class 60 Heavy Oil Pumps

Reduction drive for heavy oils including No. 6 and blended No. 5—for direct burner operation or booster pump application. Internal gear type, machined to close tolerances for max. vacuum characteristics. Ball bearing, V-belt reduction drive—connected to pump by loose coupling—eliminate side deflection from pump shaft. Suction and discharge  $\frac{1}{2}$  in. to 2 in.; capacities 75 to 2100 gph; pressures to 100 psi. Write for *bulletin A-1193*



### Class 72 Separators

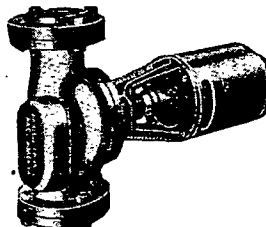
Strainers or filters for both suction and discharge service on every burner installation. Single and duplex units for both standard and high pressure service. Design features ease of cleaning and interchangeability of separator baskets. Available with *Underwriters Labels* from  $\frac{1}{4}$  in. to 4 in.; larger sizes up to 6 in. Ask for *bulletin A-1430*



UL listed single strainers for installation as integral part of pump type burners. Any practical degree of separation; sizes  $\frac{1}{4}$  in. to 4 in. inclusive. Ask for *bulletin A-1214*

### Class 34 Water Circulators

Enclosed-impeller type centrifugal pump for both vertical and horizontal mountings—particularly suitable for high head applications. Ball bearing construction, replaceable wear plate, simplified dismounting and remounting without complete disassembly. Capacities up to 140 gpm. Ask for *bulletin A-1531*



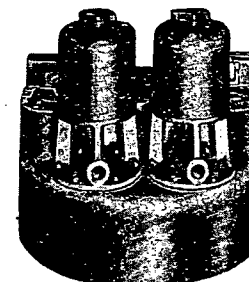
## Skidmore Corporation

St. Joseph, Michigan

Quality Heating Pumps for over a quarter of a century



Write for  
*Bulletin No. 19-A*  
on Type UV Pump  
*Bulletin No. 21-B*  
on Type CV Pump

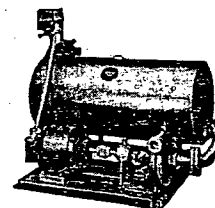


### SKIDMORE TYPE UV PUMP

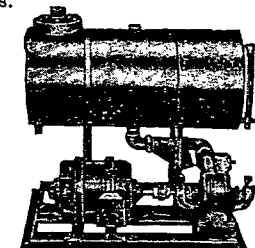
The Skidmore Type UV Condensation Pump, single or duplex unit, is designed for use where returns are too low to permit the operation of horizontal type pumps. Type UV Pump operates very satisfactorily where condensate is to be returned to the boiler or other points, from all types of steam heating systems or process equipment. Type UV Pump consists of vertical pump and motor unit with float and float switch mechanism mounted on cover plate which is bolted to sump type receiver. Capacities 2000 to 40,000 sq ft EDR and discharge pressures from 10 to 75 lbs.

### SKIDMORE TYPE CVS PUMP

The Skidmore Type CVS Condensate Pump is built for maximum efficiency, requires a minimum of space. Designed in both single and duplex units. Shown above is the duplex pump with two float switches. This model also furnished with automatic alternator on all sizes. Integral pump casing and motor stand of cast iron construction, bolted to top of receiver. Pump bronze fitted throughout, with enclosed centrifugal impeller of special design for hot water. Capacities 500 to 10,000 sq ft EDR, pressures from 10 to 40 lbs.



Write for  
*Bulletin No. 14-A*  
on Type HS Pump  
*Bulletin No. 17*  
on Type TM Pump



### SKIDMORE TYPE HS PUMP

The model HS Condensation pump is economically designed to offer maximum efficiency with lower operating cost. The Type HS will operate at high temperature encountered in condensation pump service. The pump can be disassembled without disturbing piping connections. Furnished in either single or duplex type. Pump casing is constructed of heavy close grain cast iron, vertically split, bronze fitted throughout. Capacities 1,000 to 65,000 sq ft EDR, pressures 10 to 75 lbs.

### SKIDMORE TYPE TM PUMP

Type TM pump consists of motor, steel receiver, automatic make-up valve mounted on receiver, water level gage glass mounted on receiver, self-cleaning strainer between pump and receiver, assembled and mounted on steel base. Cast iron base furnished if required. Electric boiler water level controller furnished for mounting on boiler. The Type TM Condensate and makeup water pump is of turbine type designed for boilers up to 250 hp and pressures up to 150 lbs.

Write for Complete Engineering Data  
Bulletins on Skidmore Condensate and Vacuum Pumps will be sent on request.

# The V. D. Anderson Company

Div. of International Basic Economy Corp.,  
1935 West 96th Street, Cleveland, Ohio

Quality Steam Specialties Since 1886

Representatives  
in all  
principal  
cities

## SUPER-SILVERTOP STEAM TRAPS

Inverted bucket steam traps of an improved, thoroughly tested design. For use on steam-using equipment where it is desired to remove condensate and air automatically in order to produce maximum heating efficiency.

### FEATURES

**Simplified Piping**—Hooks up as an elbow or straight-in-line—only one nipple needed since the U-tube is inside the trap. Saves 3 elbows, 3 nipples and 60 minutes of time, compared to conventional inverted bucket steam traps.

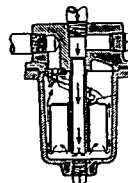
**Precision Parts Alignment**—The bucket does not swing free. It is controlled in true engineering fashion, guided on a hexagonal tube. This makes a knife-edge contact, eliminating almost all friction. The unusual guide arrangement keeps all parts in proper alignment and prevents the bucket from hitting the sidewalls of the case. Positive closing of the valve is insured.

**Self-Cleaning**—The reversing of the condensate flow on entering the trap produces a scrubbing action. This stirs up any sediment and dirt which is carried away in the discharging condensate.

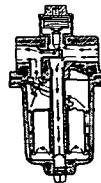
**No Restricting Passages**—Even in the smallest sizes there are no narrow cored passages to become clogged with scale.

**Cannot Air-Bind**—As the air is automatically discharged ahead of the condensate in each cycle of operation.

**Vacuum or Pressure**—These traps do not leak steam. No danger of vacuum being destroyed—trap is recommended for vacuum operation.



Standard



Heat-Kwik

## THREE TYPES OF STEAM TRAPS

**Standard Inverted Bucket**—Use where normal heat-up periods are satisfactory.

**Thermal Air Eliminator**—This trap should always be used where instant heat is necessary.

**Heat-Kwik Traps**—Designed for extremely fast air elimination at pressures up to 150 psi. Recommended for all production units such as steam jacketed kettles, autoclaves, dryers, sterilizers, etc.

### SIZES, LIST PRICES, AND CAPACITIES (Standard Steam Traps)

| Size No. Trap     | 110     | 118     | 119     | 120       | 121       | 122     | 23        | 24      | 25        |
|-------------------|---------|---------|---------|-----------|-----------|---------|-----------|---------|-----------|
| Size Connections  | 1/2"    | 3/4"    | 1"      | 1 1/4"    | 1 1/2"    | 2"      | 2 1/2"    | 3"      | 3 1/2"    |
| (See Note)        | only    | or 3/4" | or 1"   | or 1 1/4" | or 1 1/2" | or 2"   | or 2 1/2" | or 3"   | or 3 1/2" |
| Max. Ga. Pressure | 100     | 150     | 200     | 250       | 300       | 350     | 400       | 450     | 500       |
| List Price        | \$10.00 | \$9.00  | \$10.00 | \$12.00   | \$16.00   | \$25.00 | \$32.00   | \$45.00 | \$70.00   |

### WITH THERMAL AIR ELIMINATOR

| List Price | \$11.60 | \$10.60 | \$11.60 | \$13.60 | \$17.60 | \$28.20 | \$35.20 | \$49.80 | \$76.40 |
|------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
|------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

### CAPACITY IN POUNDS OF WATER PER HOUR

| Differential Pressure | 1    | 5    | 10    | 20   | 50   | 100   | 125   | 150   | 200 | 250 |
|-----------------------|------|------|-------|------|------|-------|-------|-------|-----|-----|
| 137                   | 161  | 225  | 390   | 790  | 1220 | 1500  | 2400  | 9200  |     |     |
| 305                   | 360  | 510  | 970   | 1790 | 2720 | 3200  | 5274  | 21000 |     |     |
| 435                   | 505  | 705  | 1190  | 2480 | 3850 | 4600  | 7500  | 29650 |     |     |
| 300                   | 700  | 980  | 1850  | 3450 | 5380 | 6000  | 11100 | 40300 |     |     |
| 455                   | 650  | 900  | 1400  | 2490 | 4180 | 4500  | 7500  | 26000 |     |     |
| 440                   | 675  | 1200 | 2380  | 3740 | 4200 | 10000 | 25300 |       |     |     |
| 500                   | 740  | 1310 | 2060  | 4090 | 3400 | 8000  | 19100 |       |     |     |
| 450                   | 580  | 1000 | 2220  | 4400 | 3700 | 8600  | 20500 |       |     |     |
| 500                   | 655  | 1100 | 1920  | 3700 | 4150 | 8900  | 16800 |       |     |     |
| 3600                  | 4500 | 9600 | 13750 |      |      |       |       |       |     |     |

\* Capacities based on continuous flow. When ordering be sure to specify maximum steam pressure. Note: Pipe sizes shown in heavy type are standard and traps will be shipped tapped standard unless otherwise specified. Pipe sizes shown in light type furnished at no additional cost but only from Cleveland stock.

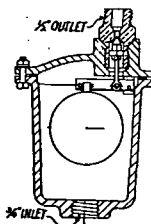
## HEAT-KWIK SUPER SILVERTOP TRAPS

| Size No. Trap    | 119BL   | 119BH | 120BL | 120BH | 121BL | 121BH | 122BL | 122BH | 23BL  | 23BH  | 24BL   | 24BH   |
|------------------|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|
| Size Conn.       | 3/4"    | 3/4"  | 3/4"  | 3/4"  | 3/4"  | 3/4"  | 1"    | 1"    | 1"    | 1"    | 1 1/4" | 1 1/4" |
| Max. Gage Press. | 50      | 150   | 50    | 150   | 50    | 150   | 50    | 150   | 50    | 150   | 50     | 150    |
| List Price       | \$16.00 | 22.00 | 18.00 | 24.00 | 22.00 | 28.00 | 31.00 | 37.00 | 38.00 | 44.00 | 54.00  | 60.00  |

| DIFF. PRESS. | CAPACITY IN POUNDS OF WATER PER HOUR |      |      |      |      |      |      |      |      |      |       |       |
|--------------|--------------------------------------|------|------|------|------|------|------|------|------|------|-------|-------|
| 1            | 487                                  | 487  | 652  | 652  | 1052 | 1052 | 1482 | 1482 | 1762 | 1762 | 2662  | 2662  |
| 3            | 880                                  | 880  | 1158 | 1158 | 1868 | 1868 | 2598 | 2598 | 2988 | 2988 | 4588  | 4588  |
| 5            | 1136                                 | 1136 | 1596 | 1596 | 2416 | 2416 | 3346 | 3346 | 3826 | 3826 | 5900  | 5900  |
| 10           | 1584                                 | 1584 | 2069 | 2069 | 3359 | 3359 | 4729 | 4729 | 5479 | 5479 | 8379  | 8379  |
| 15           | 1890                                 | 1890 | 2458 | 2458 | 3988 | 3988 | 5158 | 5158 | 6458 | 6458 | 11058 | 11058 |
| 20           | 2108                                 | 2108 | 2858 | 2858 | 4658 | 4658 | 5188 | 5188 | 7208 | 7208 | 12308 | 12308 |
| 30           | 2166                                 | 2166 | 2856 | 2856 | 4026 | 4026 | 6256 | 6256 | 5956 | 5956 | 7656  | 7656  |
| 50           | 2731                                 | 2731 | 3231 | 3231 | 4321 | 4321 | 6011 | 6011 | 6331 | 6331 | 9331  | 9331  |
| 80           |                                      | 3109 |      | 3569 |      | 4419 |      | 6549 |      | 6849 |       | 10849 |
| 100          |                                      | 3143 |      | 3668 |      | 4848 |      | 6208 |      | 6668 |       | 12468 |
| 125          |                                      | 3447 |      | 4017 |      | 4767 |      | 6107 |      | 6107 |       | 10707 |
| 150          |                                      | 3484 |      | 3904 |      | 5124 |      | 7304 |      | 6604 |       | 11504 |

\* Capacities based on continuous flow. When ordering be sure to specify maximum steam pressure.



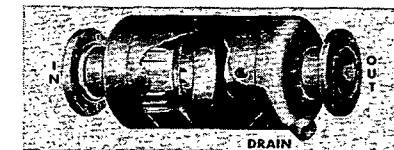
Anderson Air Release Valve No 171

## Anderson Air Release Valves

Anderson air release valves are automatic air vents used for venting air from hot water service and heating systems. Eliminates the annoying venting of air through faucets when water is first turned on. The air release valve consists of an extremely durable valve and seat, a fool-proof lever and ball float which opens or closes the valve, depending upon the presence of water or air. Write for Bulletin No. 454.

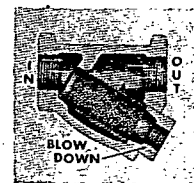
Anderson Hi-eF Purifiers are used on steam lines and in boilers to produce clean, dry steam. Type L shown here should always be used ahead of steam engines and turbines to protect this valuable equipment against slugs, line scale, moisture, salts and dirt. Internal type Hi-eF Purifiers should be installed in boilers to assure the delivery of clean, dry steam devoid of carryover, entrainment and condensate. Also for use in cleaning and drying air and other gases. Write for Bulletin No. 700.

## Hi-eF Purifiers



Anderson Hi-eF Purifier Type L

## Anderson Strainers



Anderson Self-Cleaning Strainers remove scale, grit, and sediment from the line ahead of steam traps, reducing valves, air tools, pumps, temperature regulators, etc. Stainless steel strainer screens (brass available on 2 1/2 in. and 3 in.) are standard equipment and have an extremely large free area. Standard screen for steam and other gases has 1/4 in. openings for liquids 1/2 in. openings. Other sizes of openings furnished when specified, prices on application.

### SPECIFICATIONS AND PRICES

| Pipe Size                     | 1/2"   | 3/4"   | 1"     | 1 1/4" | 1 1/2" | 2"     | 2 1/2"  | 3"      |
|-------------------------------|--------|--------|--------|--------|--------|--------|---------|---------|
| Overall Length                | 3 1/4" | 3 1/4" | 3 3/4" | 3 3/4" | 4 3/4" | 5 1/4" | 6"      | 7 3/4"  |
| Blowdown Connection Pipe Size | 1/2"   | 1/2"   | 1/2"   | 1/2"   | 3/4"   | 1"     | 1 1/4"  | 1 1/2"  |
| Shipping Weight (lbs.)        | 1      | 1      | 1 1/4  | 2 1/4  | 3 3/4  | 5 1/4  | 9 1/4   | 16 1/4  |
| List Price                    | \$2.00 | \$2.50 | \$2.75 | \$3.25 | \$4.00 | \$5.00 | \$7.25  | \$11.00 |
| (Stainless Steel Screen)      |        |        |        |        |        |        |         |         |
| List Price                    |        |        |        |        |        |        |         |         |
| (Brass Screen)                |        |        |        |        |        |        |         |         |
| List Price                    |        |        |        |        |        |        | \$22.00 | \$27.00 |



## ARMSTRONG MACHINE WORKS

851 Maple Street, Three Rivers, Mich.

Guaranteed: Satisfaction or Your Money Back

Traps Available From Local Stocks of 39 Factory Representatives and 135 Jobbers or Through the Supplier of Your Choice or Direct from the Factory—Representatives Listed in Major Industrial and Classified Phone Directories

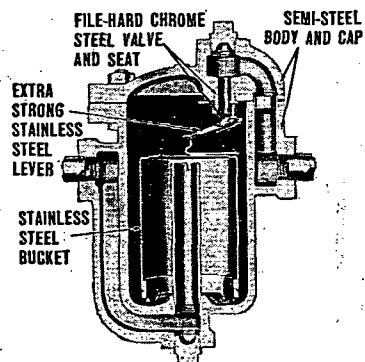
### ARMSTRONG INVERTED BUCKET STEAM TRAPS

**FOR LOW PRESSURE HEATING**—for draining mains, risers, coils, convectors, radiators and unit heaters at pressure differentials from 1 lb up—vacuum, gravity or closed return systems. For EDR ratings and selection data, ask for Catalog J.

**FOR UNIT HEATERS.** Bulletin No. 2312 gives complete trap selection and installation data and lists Btu ratings for all sizes of 30 makes of heaters—free on request.

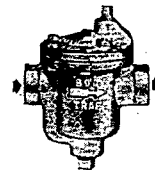
**FOR STEAM HEATED EQUIPMENT**—for draining all types of institutional and industrial units including hot water heaters and kitchen, hospital and laundry equipment. Ask for selection data.

**FEATURES.** High Quality Mechanisms in Armstrong traps for low and medium pressures are identical in design, workmanship and materials to those used in traps for 900 psig. 900F—see illustration.

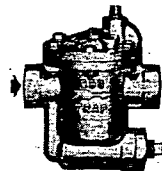


Open float (inverted bucket) cannot collapse. Nothing to stick, bind or clog. Only two moving parts, heavily reinforced for wear. Corrosion-resistant materials. Non air-binding. Quick-acting. High capacity for size. No cooling legs required.

| Side Inlet Traps                                                                                                                                                  |     | No. 800      | No. 811      | No. 812      | No. 813    | No. 814            | Choice of side inlet or bottom inlet body styles for lowest cost installation |       |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------------|--------------|--------------|------------|--------------------|-------------------------------------------------------------------------------|-------|
| Pipe Connections                                                                                                                                                  |     | 1/2" or 3/4" | 1/2" or 3/4" | 1/2" or 3/4" | 3/4" or 1" | 1" or 1 1/4"       |                                                                               |       |
| List Price (Regular)                                                                                                                                              |     | \$10.00      | \$14.00      | \$23.00      | \$31.00    | \$46.00            |                                                                               |       |
| List Price (Blast Trap)                                                                                                                                           |     | \$12.00      | \$16.00      | \$26.00      | \$34.00    | \$49.50            |                                                                               |       |
| Height                                                                                                                                                            |     | 5 1/4"       | 6 1/4"       | 8 1/4"       | 11 3/4"    | 13 3/4"            |                                                                               |       |
| Diameter                                                                                                                                                          |     | 5"           | 5"           | 6 1/2"       | 7 3/4"     | 9"                 |                                                                               |       |
| Weight                                                                                                                                                            |     | 5 lbs.       | 6 lbs.       | 15 lbs.      | 27 lbs.    | 45 lbs.            |                                                                               |       |
| Maximum Pressure, lbs.                                                                                                                                            |     | 150          | 250          | 250          | 250        | 250                |                                                                               |       |
| Continuous discharge capacity in lbs. of water per hour at pressure indicated. For more complete information see the Capacity Chart in Armstrong Steam Trap Book. | 5   | 450          | 830          | 1600         | 2900       | 4800               | 7500                                                                          | 14500 |
|                                                                                                                                                                   | 10  | 560          | 950          | 1900         | 3500       | 5800               | 9000                                                                          | 17300 |
|                                                                                                                                                                   | 15  | 640          | 1060         | 2100         | 3900       | 6500               | 10000                                                                         | 19200 |
|                                                                                                                                                                   | 20  | 690          | 1100         | 2200         | 4000       | 6600               | 10200                                                                         | 19500 |
|                                                                                                                                                                   | 30  | 800          | 1200         | 2300         | 4100       | 6700               | 10300                                                                         | 19600 |
|                                                                                                                                                                   | 40  | 840          | 1250         | 2350         | 4150       | 6750               | 10350                                                                         | 19700 |
|                                                                                                                                                                   | 50  | 860          | 1270         | 2370         | 4170       | 6770               | 10370                                                                         | 19750 |
|                                                                                                                                                                   | 70  | 880          | 1290         | 2390         | 4190       | 6790               | 10390                                                                         | 19800 |
|                                                                                                                                                                   | 100 | 890          | 1300         | 2400         | 4200       | 6800               | 10400                                                                         | 19850 |
|                                                                                                                                                                   | 125 | 900          | 1310         | 2410         | 4210       | 6810               | 10410                                                                         | 19900 |
| Bottom Inlet Traps                                                                                                                                                |     | No. 211      | No. 212      | No. 213      | No. 214    | No. 215            | No. 216                                                                       |       |
| Pipe Connections                                                                                                                                                  |     | 1/2" or 3/4" | 1/2" or 3/4" | 1/2" or 3/4" | 1"         | 1", 1 1/4", 1 1/2" | 1 1/2" or 2"                                                                  |       |
| List Price (Regular)                                                                                                                                              |     | —            | \$13.00      | \$21.00      | \$29.00    | \$55.00            | \$78.00                                                                       |       |
| List Price (Blast Trap)                                                                                                                                           |     | —            | \$15.00      | \$24.00      | \$32.00    | \$60.00            | \$85.00                                                                       |       |
| Height                                                                                                                                                            |     | —            | 6 3/4"       | 8"           | 10 3/4"    | 12 1/4"            | 17"                                                                           |       |
| Diameter                                                                                                                                                          |     | —            | 4 1/4"       | 5 1/4"       | 6 3/4"     | 7 3/4"             | 10 3/4"                                                                       |       |
| Weight                                                                                                                                                            |     | —            | 6 lbs.       | 12 lbs.      | 21 lbs.    | 35 lbs.            | 78 lbs.                                                                       |       |
| Maximum Pressure, lbs.                                                                                                                                            |     | —            | 250          | 250          | 250        | 250                | 250                                                                           |       |



No. 800-814



No. 880-883



No. 801



No. 21



**OPEN FLOAT AND THERMOSTATIC**—for fast heat-up when steam is turned on to pipe coils, small on-and-off unit heaters. When trap is cold, large thermic vent discharges 500 to 1500 cu ft free air/hr. Thermic closes at 210 F and regular bucket vent handles normal air load. Specify "blast trap"—see table.

**INTEGRAL STRAINER TRAPS.** No. 880, 881, 882 and 883 have strainers in trap body, otherwise identical to 800, 811, 812 and 813 listed in table. No. 880 lists at \$11.50, 881 at \$16.00, 882 at \$25.50, 883 at \$34.00. Each costs less to buy and install than standard trap plus separate strainer.

**RIGHT ANGLE TRAP NO. 801.** Capacity and price same as No. 800 listed in table. For replacing old radiator traps or wherever angle connections are simplest.

**BOTTOM INLET TRAPS**—No. 211 through 214 have same mechanisms and capacities as No. 811 through 814 side inlet traps. No. 215 and 216 are larger. See table.

**AIR RELIEF TRAPS** (ball float) for venting air from high points in hot water systems and similar applications. Stainless steel mechanisms. No. 21 is 6 1/4 in. diameter, lists at \$16.00. No. 21-G fits in wall having 2 x 4 studs, lists at \$18.00. Ask for Bulletins 2062 and 450.

**Y-TYPE STRAINERS**—250 psig semi-steel bodies, stainless perforated or wire mesh screens. Blowout-proof stainless-clad asbestos gasket locked in place by bushing. Square bushing threads assure easy removal. List prices: 1/4 in., 3/8 in., 1/2 in.—\$2.75; 3/4 in.—\$3.25; 1 in.—\$4.00; 1 1/4 in.—\$5.00; 1 1/2 in.—\$6.50; 2 in.—\$10.00. Details in Bulletin 602.

**STEAM HUMIDIFIERS** for Stores, Offices, Hospitals, Factories, Churches, Laboratories, etc. Automatic, closely controlled humidification is provided by introduction of steam directly into the room. Installation is comparable to that of steam unit heaters. A room humidistat controls the solenoid steam admission valve and fan. The smallest unit, for up to 40,000 cu ft, lists at \$170.00. Large models available for installation in central air ducts. Air-operated models available for explosive atmospheres. Capacities range from 31 to 630 lbs/hr steam. Bulletin No. 500 gives complete information.

# Barnes & Jones

New York Office: 101 Park Avenue

34 Crafts Street

Newtonville 60, Mass.

Barnes & Jones Vapor and Vacuum Systems of Steam Heating; Modulation Valves; Adjustable-Orifice Radiator Valves; Packless Quick-Opening Radiator Valves; Thermostatic Radiator Traps; Thermostatic Trap Replacement Units; Condensators (Boiler Return Traps); Float and Thermostatic Traps; Strainers; Gages; Systems of Zone Control for Steam Heating. Complete Catalog on Request

## Vapor and Vacuum

Series K—The Series K Valve is of the modulating type equipped with dial and pointer to indicate whether the valve is open or shut or in an intermediate position. Lever or wheel handle.

Series F—The Series F Valve has no dial or pointer and is therefore furnished only with wheel handle or lock shield. Of same quality as Series K, but lower priced. Both Series K and Series F Valves are quick opening, have non-rising stems, renewable disc seats, of packless design. Made angle pattern in  $\frac{1}{2}$ ,  $\frac{3}{4}$ , 1, and  $1\frac{1}{4}$  in. sizes; straightway (globe) pattern in  $\frac{3}{4}$  and 1 in. sizes. For use in vapor or vacuum systems.

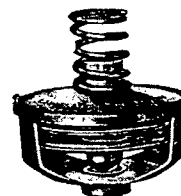
Type H—The Type H Valve is of the adjustable orifice type so arranged that the dial indicates at all times the size of the radiator for which the valve is adjusted. May be adjusted with steam on the system. Noiseless in operation. Lever or wheel handle, unauthorized tampering virtually impossible. Made for pressure differentials of 1, 2, 3, 4 and 5 pounds,  $\frac{3}{4}$  in. valve up to 100 sq ft. 1 in. valve over 100 sq ft.

Thermostatic Radiator Traps—The B & J precision made thermostatic trap contains the unique, patented cage unit which is a complete operating unit in itself. The cage assembly contains the double thermostatic element calibrated in the factory, and locked in correct adjustment with the trap seat, which is also an integral part of the cage unit. Suitable for pressures up to 15 lb  $\frac{1}{2}$  to 1 in. Medium and high pressure traps suitable for pressures between 15 lb and 100 lb can be furnished.

Float and Thermostatic Traps—Barnes & Jones F&T traps respond instantly to sudden loads and pass condensate, regardless of temperature, through water sealed float operated valve. Thermostatic element gives rapid air venting. Made in Low and Medium pressure ratings. All working parts are readily accessible. No special wrenches needed. No disconnecting of pipe lines.  $\frac{3}{4}$  to 2 in.

Cage Units—Most maintenance engineers believe in a regular check-up of their heating systems. Barnes and Jones make this check-up easy by providing a means for testing all steam traps, and for replacing the actuating units of any make trap. The B & J cage unit replaces all working parts. The double diaphragm unit is correctly and permanently adjusted before leaving the factory. Made for all sizes, pressures and makes of vapor and vacuum traps up to 65 lbs. It's a complete one-piece replacement containing thermostatic element, valve piece and seat locked in unalterable adjustment. No field calibration is necessary. Ask for *Bulletins C-34 and R-44*.

**PUMPS—CONDENSATE & VACUUM HEATING.** Condensate Pumps up to 65,000 sq ft EDR. Vacuum Pumps up to 100,000 sq ft EDR. 10 psi to 150 Psi Discharge Pressure. Steel or Cast Iron Receivers. Single & Duplex Units. 1750 rpm & 3500 rpm Units. Ask for *pump catalog*.



# A. W. CASH COMPANY

P. O. Box 551 • Decatur, Illinois



**CASH  
STANDARD**



## AUTOMATIC

PRESSURE, HYDRAULIC, TEMPERATURE,  
PROCESS AND COMBUSTION CONTROLS

The A. W. CASH COMPANY under trade mark CASH STANDARD manufactures a complete line of automatic valves, regulators, controllers, governors, hydraulic valves, refrigeration back pressure valves and complete process and combustion control systems. Typical examples.

**PRESSURE REDUCING AND REGULATING VALVES**  
Streamlined Reducing Valve, Type 1000. Three principles assure high capacity and close pressure control: streamlined inner valve eliminates turbulence; straight-line flow through valve housing; aspirating effect controls valve opening, amplifies slight pressure changes into large valve operating forces. High and low pressure models in eight sizes,  $\frac{1}{4}$  in. to 2 in. x  $2\frac{1}{2}$  in. (expanded outlet if desired).

Self Contained Pressure Reducing Valve, Type 1260. For steam, air, oils, water, gases, other fluids. Spherical self-cleaning inner valve rotates freely, seats in different positions at each closure. Built-in strainer protects seat. Screwed ends,  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in. and 1 in.

Single Seat, Diaphragm Type Reducing Valve, Type D. For steam, hot or cold water, air, oils, many chemicals and gases. Free circulation around moving parts assures even expansion and contraction, prevents seizing. A simple, inexpensive valve. Screwed ends,  $\frac{1}{4}$  in. to 2 in.

## PILOT OPERATED VALVE

Pilot Operated Pressure Reducing Valve. Type 30-AP. For steam, air, most fluids. Pilot normally operated by independent fluid. Manner of connecting control lines to pilot and installing reversible inner valve makes it a pressure reducing and regulating valve or a relief or back pressure valve; determines whether main valve opens or closes with failure of operating fluid delivered to pilot. Screwed ends,  $\frac{1}{2}$  in. to 3 in.; flanged ends, 1 in. to 12 in.

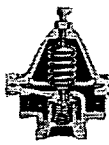
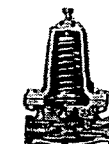
## AUTOMATIC COMBUSTION CONTROL SYSTEMS

Cash Standard Systems are for use on all kinds of boilers (forced or natural draft), stokers and burners, and for coal, powdered coal, gas, oil, other fuels. All elements of efficient combustion controlled automatically; combustion rate regulated to keep pace with changes in steam demand.

Furnace Draft Controller, Type 90. Operates remotely installed hydraulic cylinder, normally regulating damper on forced draft jobs; either alone or as part of a system. Extremely sensitive; fully automatic; no packing or gasometer.

Air-Flow Controller, Type 95. Works with Type 100 to maintain proper flow of air to combustion chamber with respect to rate of combustion, automatically compensating for variables: fuel bed resistance, fan speed variation, number of boilers or fans in service.

Super Sensitive Automatic Controller, Type 100. Double-acting, with four-way valves. Operates balanced valves, chronometer valves, butterfly valves all sizes; controls fans and other motor driven apparatus. For vacuum and pressures to 600 lb gauge. Reduces and regulates pressure, relieves pressure, controls back pressure, maintains constant differential pressure or liquid level, controls rate of flow. For steam, water, air, salt brine, various gases, chemicals. Six sizes of power cylinder employed in many different models for wide variety of uses.



## C. A. Dunham Company

400 W. Madison St., Chicago • Toronto • London

**DUNHAM**

### HEATING & COOLING EQUIPMENT

Radiation • Unit Heaters • Pumps • Specialties • Heating Systems

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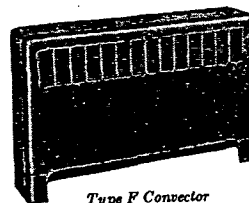
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SAN FRANCISCO, CALIF.  
SCHENECTADY, N. Y.  
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WASHINGTON, D. C.  
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**CONVECTORS**—Attractive, easy-to-install. Use with hot water or steam. Eight models, capacities with steam 1 lb entering air 65F: 9 to 139 EDR. Dimensions: 4, 6, 8 and 10 in. wide; 18 to 112 in. long; 12 in. window convactor, 20, 24, 26, 32, and 38 in. high. Picture window, extra long, plaster front and institutional types also available.

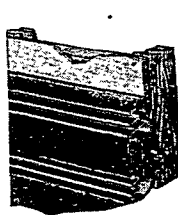
**BASEBOARD**—Snap-on front baseboard for forced hot water, steam or vapor heating. Fits flush with floor. 10 in. high. Shipped in 10-ft lengths for easy, on-the-job cutting. Steel or copper elements shipped in 1- to 6-ft lengths. Semi-recessed and flush-back enclosures. 12 in. baseboard also available for commercial applications.

**FIN-VECTOR®**—Can be installed at any level above 4 in. from floor. Three style covers: sloping top, flat top, expanded metal. Adjustable hook-and-link hanger or new ball bearing bracket supports elements. One, two, or three tiers high. Two tube sizes, 1½ and 2 in. steel or copper tube. Self-spacing fins.

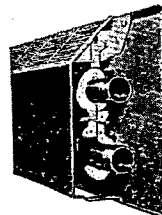
**THERMO VECTOR® RADIATION**  
For along-the-wall heating of educational, commercial or institutional buildings with steam or hot water. Flush-type model, one, two or three tiers high. Two tube sizes: 1½ in. and 2 in. Lever-operated damper.



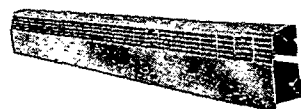
Type F Convactor



Baseboard Radiation

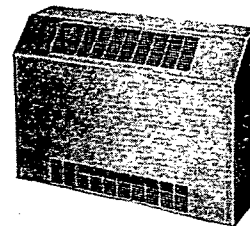


FIN-VECTOR Radiation

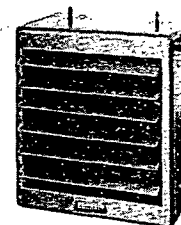


THERMO VECTOR Radiation

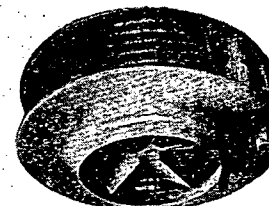
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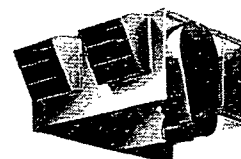
VARI-TEMP® Heating-Cooling Unit



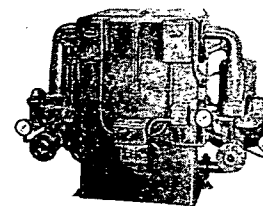
Horizontal Unit Heater



Vertical Unit Heater



Blower Type Unit Heater



Model C2 Vacuum Pump

**HEATING-COOLING UNITS**—For individual room heating with steam or forced hot water; cooling with chilled water; ventilating; heating and ventilating; or cooling and ventilating. Three different sizes can be floor, wall, ceiling or inverted mounted. Can be recessed or completely concealed. Capacities at 2 lb steam, 60 F ent. air: 21,000 to 84,000 Btu.

**UNIT HEATERS**—Type M, Model H and HM, not shown. Cabinet type. Seven styles, 3 sizes. Blower fans directly mounted on double end shaft motor. Capacities at 2 lb steam, 60 F ent. air: 18,000 to 108,000 Btu.

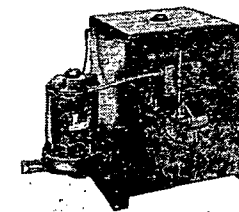
**UNIT HEATERS**—Type V. Horizontal discharge. 11 sizes, 2 models. Capacities at 2 lb steam, 60 F ent. air: 15,600 to 360,000 Btu per hour.

**UNIT HEATERS**—Type C. Vertical discharge. Four types of diffusers available. Ten sizes, 2 models. Capacities at 2 lb steam, 60 F ent. air: 42,000 to 576,000 Btu.

**UNIT HEATERS**—Blower, Type R. New, redesigned line. 5 types of mountings for floor, wall, ceiling, inverted or platform. Mixing dampers, by-pass dampers, filter sections available. Capacities at 2 lb steam, 60 F ent. air: 86,000 to 1,500,000 Btu per hour.

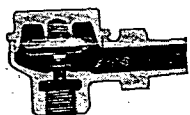
**VACUUM PUMPS**—Pull and maintain, at low amperage, up to 26 in. vacuum without dependence on close clearances. Only ONE principal moving part. Single motor easily handles BOTH air and condensate removal. Low 9¼-in. return line connections. Capacities: 2,500 to 65,000 EDR. Single or duplex units.

**CONDENSATION PUMPS**—Pumps feature mechanical seal that eliminates stuffing box worries. Capacities: 2,000 to 50,000 EDR. Single and duplex units.

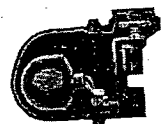
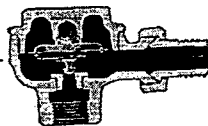
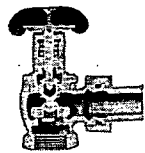


Type CHV Condensation Pump

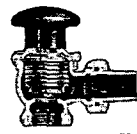
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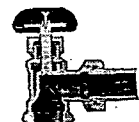
No. 1E Radiator Trap

Type TH1-A Thermo-  
static TrapSeries 30 Float and  
Thermostatic TrapsTypes OB and OBS  
Bucket Traps

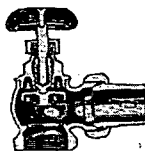
No. 740 Radiator Valve



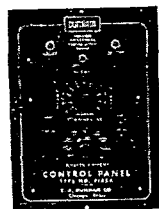
Type 1140 Radiator Valve



No. 400 Radiator Valve



No. 600 Radiator Valve

Electronic Control  
Panel

**RADIATOR TRAPS**—For all types of low pressure steam heating systems. Body and cover of cast bronze, disc of Monel metal. Available in 6 patterns. Capacities from 200 to 700 EDR.

**THERMOSTATIC TRAPS**—Trap has cast brass body and cover; replaceable stainless steel valve and seat; disc of Monel metal. For 5 to 100 lb working pressures. Capacities from 125 to 4,500 lb of condensate per hour.

**FLOAT AND THERMOSTATIC TRAPS**—Use as drip trap for steam mains, unit heaters, heat exchangers. Float, copper; float valve and seat, Monel metal. Up to 15 psi gauge working pressure. Sizes:  $\frac{3}{4}$ , 1,  $1\frac{1}{4}$ ,  $1\frac{1}{2}$  and 2 in. with capacities from 100 to 5,750 lb of condensate per hour.

**INVERTED BUCKET TRAP**—Body and cover of high tensile iron castings. Valve and seat (renewable and interchangeable) are specially hardened, corrosion-resistant steel. Operating pressures 20 to 150 lb gauge. Sizes  $\frac{1}{2}$ ,  $\frac{3}{4}$ , 1 and  $1\frac{1}{4}$  in. Capacities from 220 to 5,600 lb of condensate per hour.

**SPRING PACKED VALVES**—For low-pressure systems up to 15 lb. Heavy coil spring keeps packing tight around valve stem. Body and bonnet, cast brass. Sizes:  $\frac{1}{2}$  to 2 in. in 4 body patterns.

**PACKLESS VALVES**—Packless construction (no packing spring or stuffing box) provides tight permanent seal. Sizes:  $\frac{1}{2}$  to  $1\frac{1}{2}$  in. in 4 body patterns.

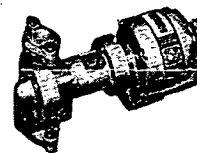
**HOT WATER VALVES**—For hot water heating systems with pressure to 60 lb. Cast brass body. Packing nut, one-piece asbestos ring provides tight stem seal. Sizes:  $\frac{1}{2}$  to 2 in.

**PACKED STEM VALVES**—For low-pressure steam systems and hot water systems up to 60 lb. Cast brass body and bonnet. Sizes:  $\frac{1}{2}$  to 2 in.

## DUNHAM HEATING SYSTEMS

**VARI-VAC® DIFFERENTIAL VARI-VAC HEATING** saves up to 40 per cent on fuel because VARI-VAC automatically provides the exact amount of heat needed by using a continuous flow of sub-atmospheric steam at temperatures that vary with the weather.

**METRO®** single-riser method of piping, costs less to install and maintain. Provides continuous path for flow of steam from top to bottom of building. Continuous pipe runs down through overlying rooms and is offset into each room into convectors or baseboard radiation.



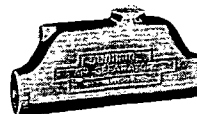
## DUNHAM CIRCULATORS

Standard and high head capacity models for all water heating or cooling systems. Single spring motor coupling. Special brand name motor with built-in overload protection. Extra-large oil reservoir. Field replaceable seals.



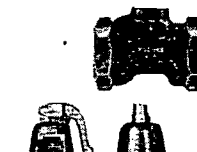
## FLOW CONTROL VALVES

Completely automatic. No adjustment for winter-summer operation. Easy to clean without breaking pipe connections or removing valve mechanism. Angle pattern: 1 to  $2\frac{1}{2}$  in. incl. Horizontal pattern: 1 to 3 in. incl.



## AIR SEPARATORS

Automatically remove air from forced hot water heating system. One-piece construction. Positively prevents re-entry of air into system. 30 psi working pressure. Sizes:  $\frac{3}{4}$  to  $2\frac{1}{2}$  in. incl.



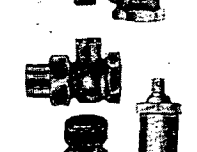
## FLOW DIVERTOR FITTINGS

Assure proper water flow through all radiation. Only one fitting normally needed (on return) for each unit of radiation. Size (thread to thread): 1 in. x  $\frac{1}{2}$  in. to 2 in. x 1 in. incl.; (sweat to sweat):  $\frac{3}{4}$  in. x  $\frac{1}{2}$  in. to 1 in. x  $\frac{3}{4}$  in. incl.



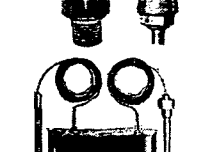
## RELIEF AND REDUCING VALVES

Pressure Relief Valves have extra-large diaphragm area, non-stick design. Factory set at 30 lb. Pressure Reducing Valves have built-in strainer. Factory set 12 lb. Adjustable. Combination Relief and Reducing Valves available.



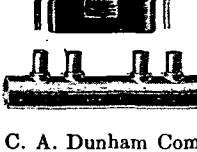
## CIRCULATOR VALVES

Extra-large flow area reduces water resistance and circulator load. T-type handle operates in only  $\frac{1}{4}$  turn. Straightway and angle patterns; thread or sweat; full range of sizes; 60 psi working pressure.



## BALANCING ELBOWS AND FITTINGS

Extra-large flow area. Unique sloping seat provides V-shaped opening for accurate balancing from full open to any degree of closure. Thread or sweat. Complete line includes vent tees, union elbows, connectors.



## AUTOMATIC AIR VENTS

Expansion Type Vents need no adjustment. Manual venting for rapid air removal when system is first filled. 50 lb. working pressure. Float Type Vent has built-in siphon to prevent water-logging. 35 lb. working pressure.

## VARI-FLOW® CONTROLS

Fully automatic indoor-outdoor temperature controls for all types of hot water heating systems. No seasonal adjustment needed. Immersion bulb and capillary "wrap-around" types.

## DISTRIBUTOR HEADS

For radiant panel and "spaghetti" type hot water heating. Same  $1\frac{1}{4}$  in. copper head usable for supply or return, both  $\frac{1}{2}$  and  $\frac{3}{8}$  in. tube connections. Each length has 14 pairs of connections.

C. A. Dunham Company manufactures a complete line of quality heating equipment. For catalogs and literature write: Dept. HVAC-56 C. A. Dunham Company, 400 W. Madison Street, Chicago 6, Ill., or see your local Dunham Sales Engineer.



# Hoffman Specialty Mfg. Corp.

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Indianapolis, Ind.

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## ENGINEERED VENT VALVES for STEAM and HOT WATER SYSTEMS

### UNIT HEATER STEAM VENT



No. 74 For steam unit heaters with working pressure up to 35 lbs. Vents air at any time with rising, dropping or steady pressure. Effectively eliminates air from the unit heater to keep it "Piping Hot" at all times. Capacity 300 C.I.M. at 1 lb press., and 800 C.I.M. at 10 lbs and over. Max. oper. press: 35 psi.

### MAIN VENTS FOR WATER SYSTEMS

No. 79 Valve tapped at top for 1/4 in. waste pipe conn. Gives continuous venting under all conditions. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 75 psi.

No. 791 Can be easily taken apart for cleaning. Tapped at top for 1/8 in. drain conn. Size conn: 1/4 in. Max. oper. press: 35 psi.



No. 79 and No. 791

### CONVECTOR VENTS—Steam

No. 1-B Adjustable port. Non-vacuum. Size conn: 1/4 in. Max. oper. press: 10 psi.

No. 71-A Single port, non-vacuum. Size conn: 1/8 in. Max. oper. press: 15 psi.

No. 71-B Single port, non-vacuum. Size conn: 1/4 in. Max. oper. press: 15 psi.

No. 71-C Single port, non-vacuum. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 15 psi.

No. 41 & 43 No. 41 single port, non-vacuum. Size conn: 1/8 in. Max. oper. press: 10 psi. No. 43 same as No. 41 except size conn: 1/4 in.

No. 45 Single port, non-vacuum. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 10 psi.

### MAIN VENTS—Steam

No. 4 Small non-vacuum steam mains. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 25 psi.

No. 4-A For one-pipe or two-pipe non-vacuum systems. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 10 psi.

No. 16-A Small one-pipe vacuum systems. Non-adjustable port. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 10 psi.

No. 75 Medium size non-vacuum systems. Single port. Float. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 10 psi.

No. 75-A Similar to No. 75 except for larger systems. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 10 psi.

No. 76 For one-pipe medium size vacuum systems. Single port. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 10 psi.

No. 76-A Similar to No. 76, except larger venting capacity. Size conn: 3/4 in. male, 1/2 in. female. Max. oper. press: 10 psi.

### RADIATOR VENTS

No. 1-A Adjustable vent ports, non-vacuum. Size conn: 1/8 in. Max. oper. press: 10 psi.

No. 2-A Adjustable port vacuum valve. Size conn: 1/8 in. Max. oper. press: 10 psi.

No. 70-A Single port, non-vacuum. Meets Federal spec. W W—V-151 for Type 1 valves. Size conn: 1/8 in. Max. oper. press: 15 psi.

No. 1000 Large single port, non-vacuum. Size conn: 1/8 in. Max. oper. press: 10 psi.

No. 40 Single port, non-vacuum. Size conn: 1/8 in. Max. oper. press: 10 psi.

No. 500 Vents all systems automatically. Size conn: 1/8 in. Max. water press: 50 lbs Max. steam press: 15 psi.



No. 71-A, B and C



No. 75, 75A

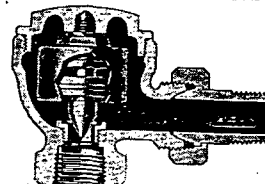


No. 1A, 2A

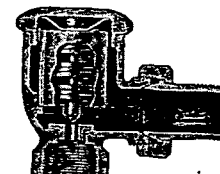


No. 500

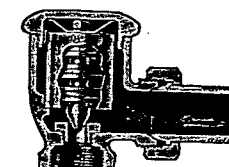
## LOW, MEDIUM AND HIGH PRESSURE THERMOSTATIC TRAPS



Low Pressure Thermostatic Trap



Medium Pressure



High Pressure

Low pressure traps have brass bodies, caps and union nut and tailpiece. 17C is made in Angle, Swivel and Vertical patterns. 8C is made in Angle and Straightway patterns. 9C is made in Angle pattern only. Thermostat and seat both renewable.

No. 17C Capacity 200 sq ft EDR 25 lb pressure 1/2 in. connection

No. 8C Capacity 400 sq ft EDR 25 lb pressure 3/4 in. connection

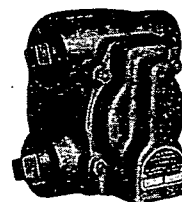
No. 9C Capacity 700 sq ft EDR 25 lb pressure 1 in. connection

Medium Pressure Nos. 8 & 9 and High Pressure Nos. 8H & 9H have all bronze bodies and caps with union nut and tailpiece. Thermostats are 6 diaphragms of special non-corrosive metal. Thermostats and seats are renewable. 1/2 in. sizes are furnished in Angle, R.H., L.H. and Straightway patterns, others in Angle only. Medium Press. 50 lb limit. High Press. 125 lb.

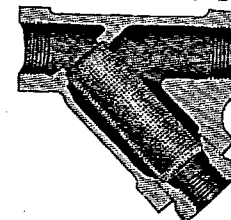
Capacities—Lb Condensate per Hour—Working Pressure—Lb per Sq In. Gage

| Traps | 5   | 15  | 25  | 50  | Traps | 25  | 50  | 100  | 125  |
|-------|-----|-----|-----|-----|-------|-----|-----|------|------|
| 8     | 100 | 180 | 235 | 400 | 8H    | 235 | 400 | 550  | 590  |
| 8     | 125 | 225 | 300 | 490 | 8H    | 300 | 490 | 650  | 720  |
| 9     | 225 | 350 | 450 | 650 | 9H    | 450 | 650 | 875  | 950  |
| 9     | 325 | 500 | 625 | 850 | 9H    | 625 | 850 | 1125 | 1250 |

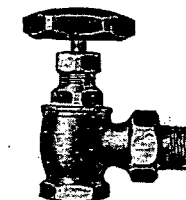
## F & T TRAPS, DIRT STRAINERS AND SUPPLY VALVES



F & T Trap



Dirt Strainer



Supply Valve

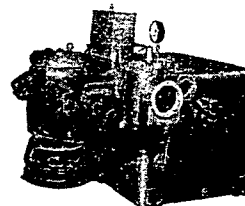
50 Series Float and Therm. Traps are available in pressure ranges to 125 lbs. Used for venting and draining risers, steam mains, unit heaters, blast coils, etc. 50 Series Traps are made for easy servicing with all working parts mounted on cover. Remove four bolts to expose all parts. Pipe sizes are from 3/4 in. to 2 in. cap. from 70 to 12,000 lbs. condensate per hour.

Radiator Supply Valves are made in sizes from 1/2 to 2 in. in Angle, R.H., L.H., and Straightway patterns. Brass bodies, union nut and tailpiece. Nos. 180 and 185 have non-rising handles. Both are packless. No. 186 is especially suited to vacuum systems.

Hoffman Dirt Strainers are self-cleaning Y type. Brass strainer cylinders and cast iron body. Sizes 1/2 to 2 in. for 125 lb pressure. Should be used in line ahead of all float and thermostatic traps. Also available with monel metal strainers.

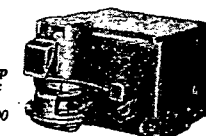
## CONDENSATION AND VACUUM PUMPS

Hoffman pumps are available in varying capacities, a-c and d-c current, single, two, or three phase, and in pressures up to 60 lbs.

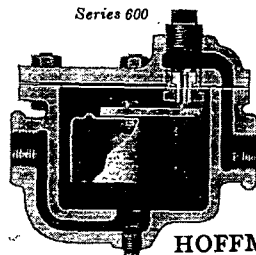


Vacuum Pumps  
Single and Duplex  
Units Capacities  
from 8,500 to 100,000  
sq ft EDR

Condensation Pump  
Single and Duplex  
Units Capacities  
from 1,000 to 160,000  
sq ft EDR



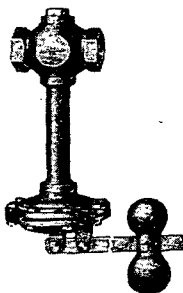




## HOFFMAN INVERTED BUCKET TRAPS

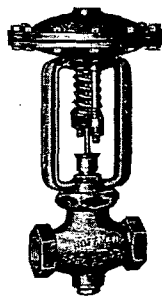
### Working Pressures to 250 lbs

Simple mechanism assures high operating efficiency. Features include—straight-through pipe connection; simple seat adjustment; all working parts connected to bonnet and easily removed with it; stainless steel seat and pin.



## HOFFMAN PRESS. REDUCING VALVES

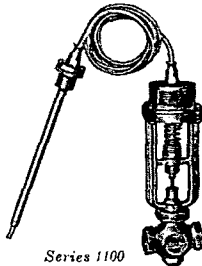
Series 700 Max. Press. 200 psi., Low  
Press. 1 to 25 psi.  
Series 710 Max. Press. 250 psi., Low  
Press. 5 to 80 psi.  
Series 715 Max. Press. 250 psi., Low  
Press. 2½ to 125 psi.  
Series 720-S & 720-W Max. Press. 250 psi.,  
Low Press. 2 to 125 psi.  
Series 750 Max. Press. 250 psi., Low  
Press. 2½ to 25 psi.



Choice of types specifically engineered for your needs—continuous service, or, for tight sealing against low pressure side when there is no demand—and with typical Hoffman features of design.

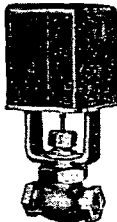
## HOFFMAN TEMPERATURE REGULATORS

**Series 1100**—for steam pressure to 150 lb per sq in. Standard temperature range—80 F to 250 F. Other ranges available on special order. Self-motivated. Hydraulically formed bellows of selected material. Rugged construction. For water heaters, convectors, fuel oil preheaters and other similar applications.



## HOFFMAN "ZONET" ZONE CONTROL

**Series 1200**—Zonet systems or packages for Steam and Hot Water consist of heat anticipating Room Thermostat, motor operated Globe Type Valve, Transformer, Fuse Block and fuse, and in the case of steam zoning, a Vacuum Breaker. The motor operated, two position, single seated, packed globe type Valve (illustrated) is available in sizes from ½ in. to 6 in. Maximum service pressure: steam 100 lbs per sq in., water 150 lbs per sq in.



## WALL AND BASEBOARD RADIATION

Series "S" Wall Radiation made of 18 gauge steel in 1, 2 and 3 tier heights for either 3¼ in. or 4¼ in. steel or aluminum fin element.

Series "F" Wall Radiation made of 20 gauge steel in 1, 2 and 3 tier heights for  $3\frac{1}{4}$  in. or  $4\frac{1}{4}$  in. steel or aluminum fin element.

Series "A" Baseboard. Copper and aluminum heating elements. Furnished in 1 in. nominal size only with 48—2 in. x 4 in. aluminum fins per ft.

Series "B" Baseboard. Pre-assembled unit, ready to install. 10 ft lengths only. Can be cut on job to suit.

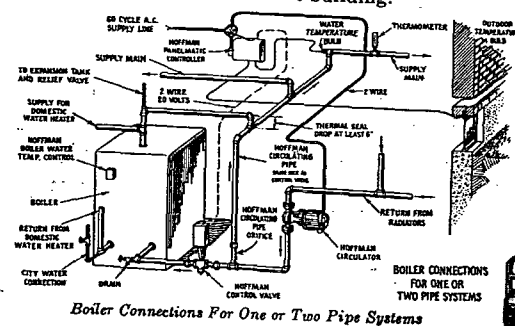


## HOFFMAN "PANELMATIC" HOT WATER SYSTEM CONTROLS

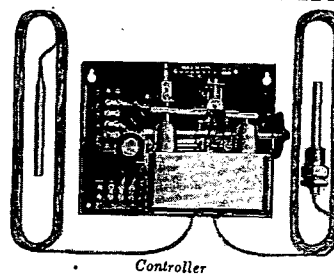
**Designed for all Types of Radiant Heating**  
The Hoffman method vastly improves the ordinary forced hot water system by the application of *Continuous Circulation*. This method permits a smoothly modulated regulation of the heat supply. The Control Valve closes and the circulating stream by-passes the boiler as long as the heat requirements are satisfied.  
When the circulating water begins to cool, the Control Valve opens and the water

When the circulating water begins to lose heat, the Control Valve is slowly opened by the Controller, permitting hot boiler water to enter the system. Thus, the delicate precision of the Hoffman Controller smoothly varies the temperature of the *continuously circulating* water so that the heat supply is always equalized with the heat loss and room temperature remains constant throughout all changes in the weather. There is no type of building to which Hoffman Hot Water Control is not applicable.

There is no type of building to which Hoffman Hot Water Controlled Heat cannot be applied. The system permits zoning of apartments, institutions, large residences and factories, thereby assuring a distribution of heat in direct relation to either personal temperature preference or to the functional activities of the building.



HEATING COMFORT IS ACHIEVED BY  
THESE SIX HOFFMAN SPECIALTIES



**The Panelmatic Controller**  
The brain of the Hoffman system. It automatically maintains a constant comfort condition regardless of the outdoor temperature. Its accurate balancing mechanism electrically opens or closes the Hoffman Hot Water Control Valve as required.

**Outdoor Temperature Anticipating Bulb**  
This Bulb transmits changes in the outdoor temperature to the balancing mechanism of the Panelmatic Controller.

**Hot Water Temperature Bulb**  
Accurately relays temperature changes of the supply main water to the balancing mechanism of the Hoffman Comfort Controller.

**Circulating Pipe Orifice**  
A calibrated orifice used to balance the circuits through the boiler and through the Hoffman circulating pipe.

**Hot Water Control Valve**  
Opens only sufficiently to supply the correct amount of water to maintain the proper water temperature being circulated through the system.

**Thermometer.** Should be installed about 6 in. from submerged Water Temp. Bulb.

**Hoffman Hot Water Circulator**  
A centrifugal pump of prescribed capacity and low in power consumption. Usually installed in the return main and continuously circulates the water through the system. Can be installed in horizontal or vertical position.

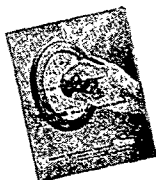


## ILLINOIS ENGINEERING COMPANY

2059 SOUTH RACINE AVENUE • CHICAGO 8, ILLINOIS

DIVISION OF AMERICAN AIR FILTER COMPANY, INC.

STEAM HEATING SYSTEMS • CONTROLS • STEAM AND POWER SPECIALTIES



**ILLINOIS HEATING SYSTEMS**, with or without control, are offered in five types and cover the complete range of vacuum and vapor heating requirements.

**ILLINOIS SELECTOTHERM CONTROL SYSTEM**—A high vacuum steam heating system with single dial control that provides comfort, economy and convenience. For buildings of any size where boilers are mechanically fired and used for low pressure steam heating only.

**CONTINUOUS FLOW CONTROL SYSTEMS**—Type A—For zoned installations or where steam is used for other than heating and domestic hot water service, or where steam is supplied by Central Station Service. Furnished for pneumatic or manual operation.

**CYCLING FLOW CONTROL SYSTEMS**—Type R—For automatic or manual control of steam flow and pressures in vacuum systems and one-pipe or two-pipe gravity installations.

**VACUUM SYSTEMS**—A two-pipe steam circulating system in which a standard vacuum pump is used. For any type of building, industrial plants, or for groups of buildings heated from a central plant.

**VAPOR SYSTEMS**—A two-pipe system circulating steam at low positive pressures without pump or mechanical vacuum producer. Recommended for Residence, Small Apartment, and similar service.

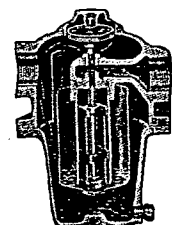
### ILLINOIS STEAM SPECIALTIES

Heaters, Hot Water Generators, Drips of Mains and Risers. Series G operating ranges from 25 inches vacuum to 15 lbs pressure.

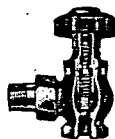
**Illinois Radiator Supply Valves** Quick Opening, Spring Loaded, Packless. For any two-pipe steam, vapor or vacuum heating system. Extremely smooth and easy to operate with a cool, break-proof plastic handle for finger tip control.

**Illinois Thermostatic Trap Series G**

For Vacuum and Vapor Heating Systems—  
For Working Pressures Up to 15 Pounds Positive acting and responsive to the slightest temperature changes, it discharges condensate quickly and freely without loss of live steam.



Series G



**Float and Thermostatic Traps Series G** For Low Pressure Service. Compact, simple, accessible, durable, dirt-proof. Positive valve action. Wire drawing impossible. Low discharge temperatures. Efficient air venting. Trap not damaged by freezing.

#### Recommended Applications

For draining Low Pressure Heating Systems, Ventilating Units, Unit Heaters, Pre-Heaters, Re-Heaters, and other Fan System Heat Surface, Process



## ILLINOIS ENGINEERING COMPANY

2059 SOUTH RACINE AVENUE • CHICAGO 8, ILLINOIS

DIVISION OF AMERICAN AIR FILTER COMPANY, INC.

STEAM HEATING SYSTEMS • CONTROLS • STEAM AND POWER SPECIALTIES

**STEAM TRAPS**—A special feature is the impact operated valve with snap action. The valve is either open or shut. It cannot remain in an intermediate position. Wire drawing, scoring or cutting of valve and valve seat are positively eliminated. The valve cannot chatter on the seat under any operating condition. Sizes from  $\frac{1}{2}$  in. to 2 in. Pressures from 5 psi to 250 psi and heavy duty to 600 psi.

**ILLINOIS MOTORIZED VALVES** (on and off)—Type R5—For automatic control of steam temperatures and pressures to prevent overheating and conserve steam. May be operated by any automatic contact device or by manual switches.

**ILLINOIS THERMOSTATIC TRAPS FOR HIGH PRESSURES**—Series HG—Maximum working pressure 150 pounds. Used where neat appearance and compactness are desirable, as for trapping sterilizers or water stills in hospitals; steam jacketed kettles, coffee urns, warming tables and for process work.

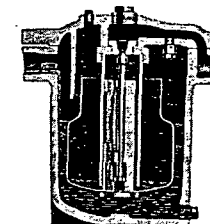
These traps are also furnished for medium pressures.

**ILLINOIS CONDENSATION PUMPS**—The complete line includes both horizontal and vertical, Single and Duplex Units. *Illinois Type "ECR" Pump*. Capacities, 2,000 to 65,000 sq ft edr. Discharge pressures to 50 psi. Bronze fitted throughout. Dependable mechanical seal eliminates leakage around shaft. Heavy duty float control with seamless copper float. Float switch adjustable for various levels. No sub-base required. Cast iron receiver.

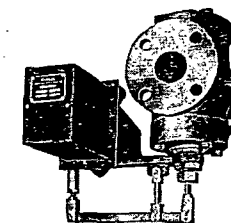
**ILLINOIS ASU HEAT EXCHANGERS**—For heating water with steam. Complete range of sizes and capacities.

#### Other Illinois Products

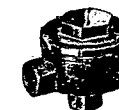
Air Vent Traps  
Boiler Return Traps  
Strainers  
Control Valves: Non-Return, Back Pressure, Stop and Check  
Exhaust Heads  
Suction Strainers  
Separators—Oil and Steam  
Pressure Regulating Valves



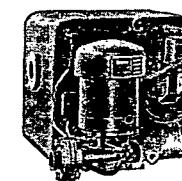
Series 35 Steam Trap



Type R Valve



Series HG Trap



Type "ECR" Close Coupled Pump



ASU Heat Exchanger

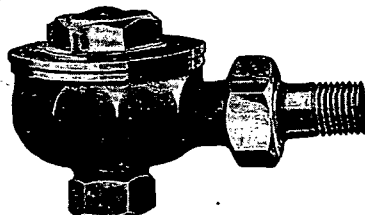
## Jas. P. Marsh Corporation

Dept. 5, Skokie, Illinois

Branches in Principal Cities

Marsh products include: Pressure, Vacuum and Compound Gauges; Dial Thermometers; Steam Traps; Vents; Packless Radiator Valves and other heating specialties; Tri-trol Regulators; Electrimatic Refrigeration Water Regulators and Solenoid Valves.

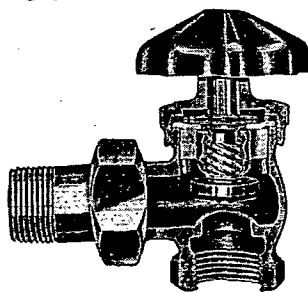
**Radiator Traps**—These highly efficient radiator traps are equipped with a phosphor bronze diaphragm charged with a



Thermostatic Diaphragm Radiator Trap

volatile fluid making them equally efficient for use on pressures below atmospheric up to 15 lbs pressure. Also other traps available up to 125 lbs pressure.

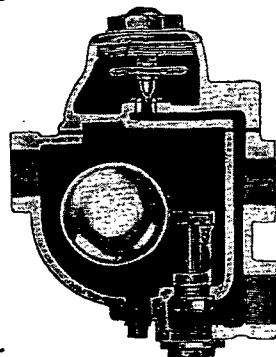
**Packless Radiator Valves**—The metal-to-metal seal of Marsh Radiator valves makes them truly packless. They contain no packing of any kind to wear, crack and deteriorate. Proved by many years of service. Easy to operate. Close on less than one turn. Individually tested. Adaptable for hot water as well as steam heating systems.



Packless Radiator Valve

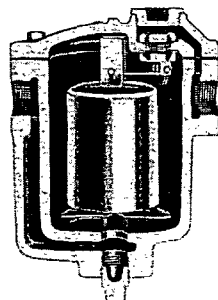
**Marsh Float and Thermostatic Traps**—One of the many types of Marsh Heavy Duty Float and Thermostatic Traps is illustrated. These traps are designed for removal of air and condensate from steam mains, branches, or risers, unit heaters, steam coils, etc. The size and weight of the trap permits installation in the piping without any other means of

support. Condensation is discharged through a float-operated valve located at the lowest point inside the trap body. Air vent is located in a by-pass in the cap or cover of the trap. Air passes through a passageway and out through the trap outlet. Construction permits removal of mechanism without disturbing the piping.



Float and Thermostatic Trap

**Marsh Inverted Bucket Traps** are ideal for all types of hospital and kitchen equipment or similar service where a

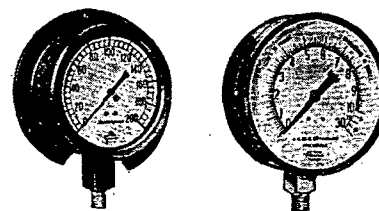


Inverted Bucket Trap

considerable volume of condensate is handled. Traps are self-venting and have large water capacity thus assuring unusually high efficiency in removing condensate, air and gases.

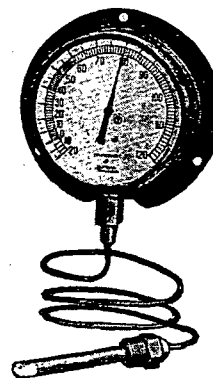
## Jas. P. Marsh Corporation

**Marsh Pressure Gauges**—The Marsh standard, low pressure gauge will contribute to the economy and improve the operation of any type of steam boiler. It is finely built throughout and is available with the Marsh "Recalibrator" for quickly and easily resetting the hand to zero when the gauge is knocked out of adjustment.



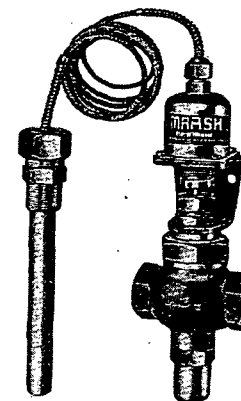
Marsh Gauges include vacuum and compound types in a wide range of designs covering all services and pressures. Over 90 years of gauge manufacturing has reached its highest achievement in the Marsh "Mastergauge" for use where high pressures and temperatures are present and where maximum stamina and accuracy are essential.

**Marsh Dial Thermometers**—The same basic refinements found in Marsh Gauges are found in Marsh Dial Thermometers. Bourdon tube types are available in self-



contained and distant reading instruments, vapor-tension or gas filled. All ranges up to 400 F are covered. "Recalibrator" is standard in all bourdon tube types. Ask for catalog information.

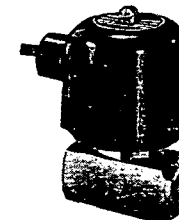
**Marsh Electrimatic Refrigeration Valves**—The Marsh Electrimatic line of refrigeration valves includes condenser water regulators for ammonia, Freon or methyl chloride service; temperature actuated valves, packless solenoid valves, and other related products.



Type HT  
Water  
Regulator

The Electrimatic Type HT Temperature Actuated Regulating Valve is illustrated. It is used to control the flow of hot water or low pressure steam in heating or other industrial processes. The valve opens with rise in temperature and closes with fall in temperature. Main application is in heating, but may also be used as a by-pass control in cooling and process service. Regulator is quick opening and tight closing on either high or low pressures. Five standard temperature ranges cover most conditions. Cartridge construction of working parts eliminates need for removal of valve from line for cleaning or servicing.

**Marsh Electrimatic Solenoid Valves** are made in both direct-acting and pilot-operated types in  $\frac{3}{16}$ ,  $\frac{3}{8}$  in. and  $\frac{1}{2}$  in. or-



Packless  
Solenoid  
Stop  
Valve

ifice sizes respectively. They are of packless, tight seating construction with impregnated coils to withstand frost and moisture.



## Maid-O'-Mist, Inc.

3217 No. Pulaski Road  
Chicago 41, Ill.

Manufacturers of  
Heating and Air  
Conditioning Specialties

**Products:** Automatic air valves for hot water heating and cooling systems; automatic humidifiers for steam or hot water; automatic humidifiers for warm air furnaces; steam boiler water line controls; water line float control valves; liquid gas and air strainers.

### AUTO-VENT

#### Air Eliminators



No. 7 Auto-Vent

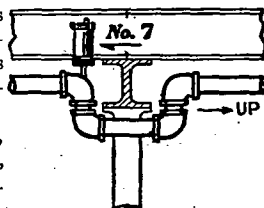
Maid-O'-Mist Auto-Vents permit automatic venting of the air which causes circulation trouble in heating and cooling systems. More and more, contractors who value satisfied customers are installing these trouble stoppers.

**No. 7 Auto-Vent.** For mains, pipe lines, unit heaters, chillers, convectors, coils, etc. Designed for vertical mounting only. Size 4 3/8 in. x 2 1/4 in. with 1/2 in. I.P. female connection. Made of brass and equipped with a self-closing, float operated valve. All working parts, including

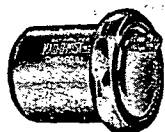
valve and copper float, mounted on a removable bonnet for quick servicing or replacement. Valve is equipped with a Monel metal spring and a Neoprene valve seat which is unaffected by high temperatures, oil, anti-freeze, etc. For pressure not exceeding 75 lbs.

**No. 77 Auto-Vent.** Identical to No. 7 Auto-Vent, except for an additional 1/8 in., I.P. side opening to permit its use on overhead pipe lines, coils, etc., where head room is factor. Ideally suited for Diesel engine and cooling manifold use, where vibration demands secure mounting. No air chamber required.

**Auxiliary Equipment:** No. 7X—bonnet assembly for No. 7 and 77; No. 777—self-closing valve core; No. 7A—connector for safe waste.

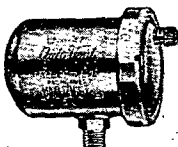


Venting trapped mains and circulating lines



No. 27 Auto-Vent For Horizontal Mounting Only with 3/8 in. I.P. female side connection—Size 3 in. x 2 1/2 in.

No. 27 and 37  
Auto-Vents



No. 37 Auto-Vent For Horizontal Mounting Only with 3/8 in. I.P. vertical male bottom connection—Size 3 in. x 2 1/2 in.

For convectors and free standing radiation. Construction and internal working parts are same as in No. 7 Auto-Vent. Made of non-ferrous metals and designed for pressure not over 50 lbs. No air chamber required. **Auxiliary Equipment:** No. 27X—bonnet assembly for Nos. 27 and 37; No. 7A—connector for safe waste. No. 666 valve core.

Write for price sheet and descriptive literature.

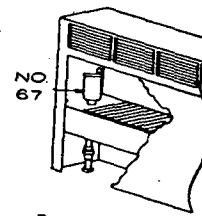
## Maid-O'-Mist, Inc.

### No. 67 Auto-Vent



No. 67 Auto-Vent

For convectors and baseboard radiators. Designed for vertical mounting only. Size 3 3/8 in. x 1 1/2 in. with a 1/2 I.P. male connection. Designed for limited space, small, self-closing, float operated valve may be installed in trouble spots previously neglected or improperly vented. Valve is equipped with a Monel metal spring and Neoprene valve seat, which is unaffected by high temperature, oil, etc. No air chamber required. For pressures up to 30 lbs. Where a Safe Waste is needed, specify No. 7A connector fitting.



For venting convector radiators

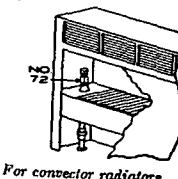
### No. 72 Auto-Vent



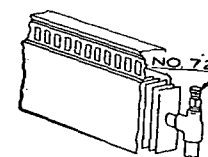
No. 72 Auto-Vent

For convectors, baseboard and free-standing radiation. Designed for both vertical and horizontal mounting. Size 1 1/2 in. x 1/2 in. with 1/2 in. I.P. male connection. No. 72 Auto-Vent is a fast venting self flushing valve of the expansion type. All expansion and contraction of the single, non-porous, composition disk is confined to four port vents. Internal siphon tube prevents water logging when installed in either vertical or horizontal position. Immediate drainage means fast disk drying, quick venting cycle which is continuous and no air chamber is needed.

Manual venting features plus tight shut off are all controlled by valve cap adjustment. Valve cap is tamper-proof and can be removed and replaced without damage or special tools for cleaning or flushing, if needed.



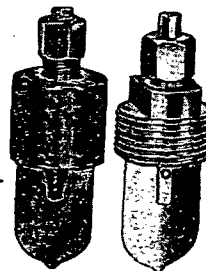
For convector radiators



For baseboard radiation

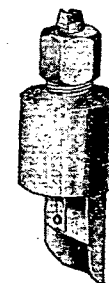
### No. 14, No. 15 and No. 16 Balancing Valve Adapter Units

for Hot Water  
Heating and Cooling Systems



No. 14  
No. 14 for copper and bronze tees. Nominal pipe sizes 3/8 in., 1/2 in., 3/4 in., 1 in.  
No. 15 for tees. Sizes 1/2 in., 3/4 in., 1 in., 1 1/4 in., 1 1/2 in.

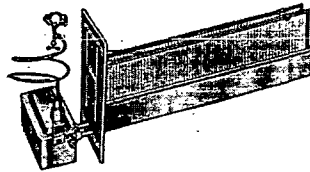
Maid-O'-Mist Valve Adapter Units make any copper, bronze, or cast brass or iron tee a balancing valve. These units, quickly soldered or sweat fitted into copper, brass, and bronze tees or threaded into cast iron tees, regulate hot water flow through radiators, convectors, baseboard panels, radiant coils, return mains, and branches. Can be inserted in side outlet or run of tee of same pipe-size to complete either a straightway or angle balancing valve. Full, free flow of water through the tee is possible. Since there is no inside reduction of pipe diameter, there is no water restriction except for the balancing required. This permits the use of additional balancing in a heating or cooling system without preliminary planning. Precision made of non-ferrous metals. Simple balancing requires only a screw driver.



No. 16 unit for 3/4 in. and 1 in. cast brass tees to complete angle balancing valves.

## CONVECTOR HUMIDIFIER

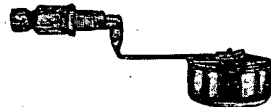
Maid-O'-Mist Convector Humidifier has no flat bottom to block the flow of warm air. Their individual  $\frac{3}{8}$  in. copper water troughs are spaced 1 in. apart to allow unrestricted air flow between the evaporator pads. Maid-O'-Mist Convector Humidifiers are designed for use with radiators and cabinet convectors in hot water heating systems and for all types of warm air furnaces.



2 Trough Convector Humidifier, also available in 1 and 4 trough sizes

## NO. 50 SERIES FLOAT CONTROL VALVES

The No. 50 Series Float Control Valves are precision designed to fill requirements for humidifying units, pan fillers, air conditioning equipment, evaporative coolers, air washers and other applications where dependable water level control is essential in limited space to meet various operating conditions.



(No. 51 float control valve)



(No. 52 float control valve)

\*No. 51 Float Control Valve. Only  $5\frac{1}{4}$  in. long overall, including copper float which is  $2\frac{1}{8}$  in. diameter by  $1\frac{1}{4}$  in. deep. Valve body is made of hex-brass rod with removable, raised, hard nylon valve seat. Valve stem is brass with an incased heat and oil resistant, special Neoprene washer. Valve seat is protected with a 100 mesh Monel Metal screen. Valve body is fitted with two  $\frac{1}{4}$  in. I.P. locknuts for horizontal mounting securely in  $\frac{3}{16}$  in. hole—or valve may be screwed directly into tapped opening. Supply is equipped with union coupling for  $\frac{1}{4}$  in. O.D. copper tubing. Working pressures up to 85 lbs. with capacity of  $\frac{1}{2}$  gal per minute at 50 lbs pressure.

\*No. 52 High Duty Float Control Valve. Same general construction as No. 51 but designed for use where a larger volume of water is required. Capacity 1 gal per minute at 50 lbs pressure, with working pressures to 125 lbs. Overall length 8 in. with oversized float  $1\frac{1}{2}$  in. diameter by  $4\frac{1}{8}$  in. long.

\*No. 53 High Duty Float Control Valve. Same general construction as No. 52 except valve is vertically mounted with special bracket as integral part for mounting on reservoir or pan, well above water line. Only  $6\frac{1}{2}$  in. long. Non-back-siphoning when installed according to instructions.

\*No. 59 Float Control Valve. Same general construction as No. 51 valve, except valve is vertically mounted with special bracket as integral part for mounting on reservoir or pan, well above water line. Non-back-siphoning when installed according to instructions. Only 5 in. long.

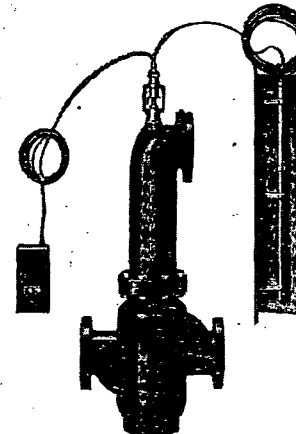
\*NOTE: Nos. 51, 52, 53 and 59 can be furnished with a  $\frac{3}{8}$  in. I.P. male connection at additional cost, when specified on order.

Series 6900—Water Line Float Control Diaphragm Valves. The No. 6900 Series float control valves are heavy duty large capacity water level controls. Rugged, strong and precision made, the cast brass body is fitted with a removable chromium valve seat. Controlled water level is accomplished through the action of the oversized copper float, linkage and special Neoprene diaphragm. Valve can be furnished to discharge water in an upward or downward position as specified. Inlet and outlet tapping  $\frac{3}{8}$  in. I.P. Capacities from  $1\frac{1}{4}$  gal to 6 gal per min. The No. 6927 Brass Mounting Plate (3 in. diameter) with gasket and screws is used where special mounting of the No. 6900 Series Valves is necessary. Write for prices and descriptive literature.

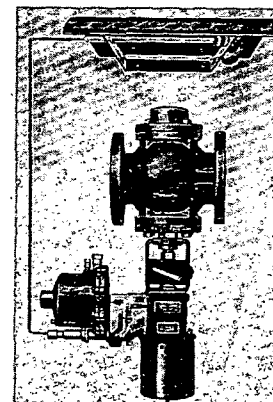
## Sarcotherm Controls Inc.

Empire State Bldg., New York 1, N. Y.

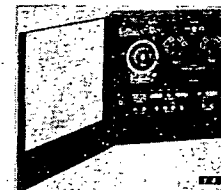
REPRESENTATIVES IN PRINCIPAL CITIES, FACTORY AT BETHLEHEM, PA.



Type STA-1 for Hot Water and Radiant Heating Systems



Type W for Steam Heating Systems



Automatic Control Panel

Fully automatic weather modulated control systems for all types of heating, and all necessary accessories.

## Hot Water and Radiant Heating

Sarcotherm provides a carefully engineered control system for radiant or panel heating which is fully modulating, and allows continuous circulation. The customary lag of conventional room thermostats is eliminated with the comfort control "Thermoray" sensitive to both convection and radiation.

For forced hot water heating system for garden apartments, housing developments, hospitals, and institutional buildings, Sarcotherm provides a completely zoned control system, including automatic night set-back and automatic morning pick-up.

## Steam Heating Systems

The Type "W" Sarcotherm Control system automatically proportions the amount of heat supplied to the actual need for any given weather condition. The control is fully modulating, and complete program control panels are provided to meet any control cycle required.

## Control Panels

Adjustments can be made through a manual control panel or through a completely automatic program panel that provides round-the-clock control of heating systems. For special applications control panels with indicating gages can be provided. All panels are electrically operated and can be remotely positioned in any desired location.

## Engineering Service

Consulting Engineers and Contractors are invited to consult with our Engineering Staff on any proposed control system. There is no obligation.

## Sarco Company, Inc.

Empire State Bldg., New York 1, N. Y.

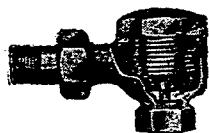
Branches in Principal Cities

Affiliate Company: SARCO THERM CONTROLS, INC.

PRODUCTS in addition to those listed below:

Room thermostats, lift traps, balancing fittings, dial thermometers, motor valves, cooling controls. Also Sarcotherm weather-compensated control systems for hot water and radiant heating. (See page 1633)

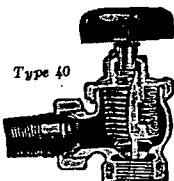
### SARCO RADIATOR TRAPS



Radiator Trap, Type H

Type H for VACUUM, vapor or gravity steam systems: Self-adjusting bronze bellows for highest vacuum to 25 psi. Discharges condensate, air and air-steam mixture. Body and cap of brass. Self-aligning head and removable seat of hard bronze or stainless steel. Angle, straightway, offset, vertical.  $\frac{1}{2}$  to 1 in. Cat. N 150.

### SARCO RADIATOR VALVES

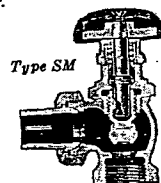


Type 40

Type 40—Packless—for VACUUM and all other steam systems. Valve stem sealed by packless bronze bellows, balanced pressure type. Angle or globe,  $\frac{1}{2}$  to  $1\frac{1}{4}$  in.

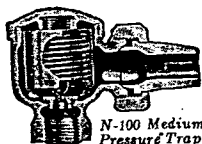
Details: Brass body, reversible discs, bakelite handle. Available with modulating devices. Lever, wheel or extension handles; lockshield tops. Cat. N150 & N221.

Type SM—Spring-packless or gland packed for all steam and hot water systems. Angle, globe, offset,  $\frac{1}{2}$  to 2 in. Same details as for above type 40. Cat. N150 & N221.



Type SM

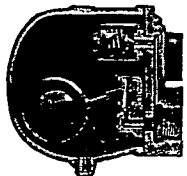
### SARCO N-100 TRAPS



N-100 Medium Pressure Trap

Similar in style to above Sarco Radiator Trap, the N-100 Thermostatic Trap is suitable for operation at pressures up to 125 psi. Shield protects bronze bellows from condensate thrust, prevents over-expansion if removed while hot. Stainless steel renewable valve head and seat. Angle, straightway and vertical. Sizes  $\frac{3}{8}$  in. to 1 in. Bulletin 190.

### SARCO FLOAT-THERMOSTATIC STEAM TRAPS

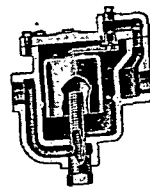


Float-Thermostatic Trap

Discharge condensate at steam temperature, continuously and without shock. Automatically vent air and gases by built-in thermostatic by-pass. Immediately responsive to varying loads and pressures. Sizes  $\frac{3}{4}$  in. to  $2\frac{1}{2}$  in. for pressures to 200 psi. Catalog No. N-450.

### SARCO INVERTED BUCKET TRAPS

Sarco Camlift valve mechanism provides rapid and free discharge of the condensate. Special design to prevent prime loss on light loads. Sizes  $\frac{1}{2}$  in. to 2 in., for pressures to 900 psi. Catalog N-360.



Inverted Bucket Trap

### SARCO THERMODYNAMIC STEAM TRAPS

These new type traps virtually eliminate maintenance. Stainless steel throughout . . . immune to both internal and external corrosion. Safe in fire-hazard locations. Not affected by corrosive condensate, superheat, water-hammer. Only moving part is solid stainless steel disc. No valve-closing mechanism to wear or stick. No critical clearances to choke. No gaskets to leak. Same trap for pressures 10-600 psi. Sizes  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in., 1 in. Bulletin No. N-257.

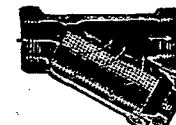


Thermodynamic Trap

### SARCO PIPE LINE STRAINERS

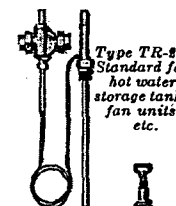
(Also Scraper Strainers)

Furnished in brass, semi-steel or cast steel for all commercial pressures. They are also furnished with hand or motor operated rotary scrapers, which clean the screen without flow interruption. Catalogs No. N-1200 and N-1225.



### SARCO SELF-CONTAINED TEMPERATURE REGULATORS

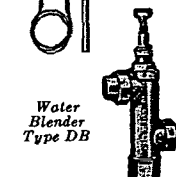
Sarco Temperature Regulators are simple, self-operated valves—the self-contained units that use the uniform force of liquid expansion. No stuffing boxes to leak, no auxiliary “power” required. All moving parts are inside the regulator. For steam, gas, oil, water or brine for temperatures to 300 F. Bulletin N-600.



Type TR-21. Standard for hot water storage tanks, fan units, etc.

### SARCO WATER BLENDERS AND TEMPERING VALVES

For mixing hot and cold water to deliver automatically water at any desired temperatures. Type MB for showers, wash basins, etc. Type DB, a tempering valve for use with submerged heating coils or tankless heaters. Bulletin N-800.



Water Blender Type DB

### SARCO AIR ELIMINATORS

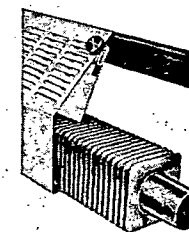
For convector and radiant hot water heating systems. Also for chilled water lines in air conditioning systems. Semi-steel or cast brass body. Copper floats, stainless steel valve parts.  $\frac{3}{4}$  in. and 1 in. Bulletin N-190.



Type 6 Air Eliminator

### SARCOFIN FINNED-TUBE AND BASEBOARD RADIATION

A complete line with approved ratings as established by Institute of Boiler and Radiator Manufacturers. Guaranteed for 1-year against defects in materials and workmanship. Heating elements guaranteed for maximum working pressures. Bulletins No. N-1650 and No. N-1625.



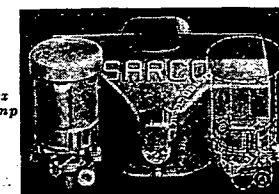
Fined Tube Radiation

### SARCO CONDENSATE AND VACUUM PUMPS

Complete line of condensate and vacuum pumps for all capacity ranges. New Sarco Type S Condensate Pump shown combines all these advantages and others:

1. Low inlet height— $7\frac{1}{2}$  in. above floor;
2. Enclosed bronze impellers with replaceable bronze wearing rings;
3. Quick, easy disassembly for inspection and maintenance, without disturbing any piping;
4. Single unit converted to duplex by simply removing a flange and adding a pump and motor assembly with mechanical alternator. Bulletin on request.

Type S Duplex Condensate Pump



# International Heating & Air-Conditioning Exposition

Permanent Address—480 Lexington Ave., New York 17, N. Y.

## EXPOSITIONS HELD

Philadelphia, 1955; Chicago, 1953; Philadelphia, 1951; Chicago, 1949; New York, 1948; Cleveland, 1947-1940; New York, 1938; Chicago, 1936; New York, 1934; Cleveland, 1932; Philadelphia, 1930.

## FUTURE SCHEDULE

No exposition scheduled for 1956. In 1957, the Exposition will return to Chicago at International Amphitheatre, February 25 to March 1.

## UNDER AUSPICES OF A.S.H.A.E.

These Expositions have been and will be held co-incident with the annual meetings of American Society of Heating and Air-Conditioning Engineers, Inc., and under their auspices. Management is by International Exposition Company with permanent headquarters at 480 Lexington Ave., New York 17, N. Y.

## EXHIBITORS

Comprise leading firms in each phase of the industry; number has varied from 150 to more than 400 exhibitors.

## EXHIBITS

These range from and comprise all the types of articles discussed or advertised in this copy of THE ASHAE GUIDE.

1. **The COMBUSTION Group:** Furnaces, burners (coal, oil and gas), grates, stokers, boilers, radiators (various types), refractories and auxiliaries.

2. **The OIL BURNER Group:**

3. **The HYDRAULIC Group:** Water feeders, water heaters, pumps, traps, valves, piping, fittings, expansion joints, pipe hangers, etc.

4. **The STEAM HEATING Group:** Vapor heating, steam specialties.

5. **The HOT WATER HEATING Group:**

6. **The AIR Group:** Warm Air furnaces and stoves, registers and grilles, cooling towers, air filters, motors, fans, blowers, conditioning equipment, ventilators (room and industrial types), unit heaters, etc.

7. **The AIR CONDITIONING Group:** Equipment which circulates and filters the air, in summer dehumidifies and cools; in winter heats and humidifies, and does all these in proper season for complete, all year-round air conditioning.

## 8. The CONTROL Group:

Instruments of precision for indicating, controlling or recording temperature, pressure, volume, time, flow, draft or any other function to be measured.

## 9. The REFRIGERATING Group:

Compressors, condensers, cooling apparatus, contingent apparatus and refrigerants.

## 10. The CENTRAL HEATING Group:

Apparatus and materials especially designed or adapted to the uses of central heating and central heating station supplies.

## 11. The INSULATING Group:

Structural insulators (refractory and cellulose materials), asbestos, magnesia clays and combinations thereof, pipe and conduit covering, etc., weather-strip-ping, etc.

## 12. The MISCELLANEOUS Group:

Electric Heaters, boiler and pipe repair alloys, liquids and compounds, tools of all kinds, and equipment not specifically included in the above groups, but related thereto.

## 13. The MACHINERY AND GENERAL EQUIPMENT Group.

## 14. BOOKS AND PUBLICATIONS.

## VISITOR ATTENDANCE

Attendance is by invitation and registration only, thereby presenting a selected audience. Included are contractors, dealers, jobbers, supply houses, home owners, industrial users, professional and service organizations, public utilities, real estate management concerns, etc. A detailed analysis of registered attendance is available on request.

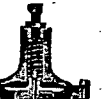
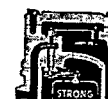
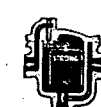
Industrial Expositions in America lead the expositions of the world in style, business effectiveness, industrial influence and educational value. This Exposition stands among the leaders in Industrial Expositions in America. It is an educational institution which brings together the research developments and improvements in equipment and materials for use in heating, ventilating and air conditioning all types of buildings.



# Strong, Carlisle & Hammond Company

1392 West 3rd St., Cleveland 13, Ohio

"STRONG" The Complete Steam Specialties Line



1. **Standard In-Line Traps (Semi-Steel).** Inverted bucket type. Hi-Cap design. Parts on cover for easy removal without breaking pipe connections. All stainless parts.

| Trap No. | Pipe Size (inches) | Continuous Capacity at psi | Weight lbs | List Price   |
|----------|--------------------|----------------------------|------------|--------------|
| 070      | 1/4, 3/4           | 125                        | 490        | 3 3/4 \$7.00 |
| 170      | 1/4, 3/4           | 125                        | 955        | 7 9.00       |
| 271      | 3/4, 1             | 125                        | 1230       | 7 1/2 13.50  |

2. **"Y" Type Strainers (Semi-Steel).** Features perforated Monel screen and new V-shaped gripping lugs. 250 psi 450 deg steam. 400 psi cold, non-shock.

| Pipe Size (inches) | Weight lbs | List Price |
|--------------------|------------|------------|
| 1/4, 3/4           | 1          | \$1.90     |
| 1/2                | 2 1/4      | 2.25       |
| 3/4                | 3 3/4      | 2.70       |
| 1                  | 5 1/4      | 3.25       |
| 1 1/4              | 8 1/4      | 4.10       |
| 1 1/2              | 11 1/2     | 5.25       |
| 2                  | 17         | 7.75       |
| 2 1/2              | 22         | 18.00      |
| 3                  | 32         | 21.00      |

3. **In-Line Blast Traps (Semi-Steel).** Inverted bucket (open-float) and thermostatic type. Hi-Cap design. Integral bi-metal thermal operated vent. For rapid heating on unit heaters, cookers, etc. Anum-Metl seat, stainless bucket and working parts.

| Trap No. | Pipe Size (inches) | Continuous Capacity at psi | Weight lbs | List Price   |
|----------|--------------------|----------------------------|------------|--------------|
| 070-T    | 1/4, 3/4           | 30                         | 660        | 3 3/4 \$8.50 |
| 170-T    | 1/4, 3/4           | 30                         | 1290       | 8 12.00      |
| 271-T    | 3/4, 1             | 30                         | 1760       | 9 17.50      |

4. **Bottom Inlet Traps (Semi-Steel).** Rugged, heavy duty inverted bucket type. "Lever-lift" action and dual fulcrum give high discharge capacity, dependable operation on light loads. All stainless working parts. Anum-Metl valve and seat. Lowest maintenance.

| Trap No. | Pipe Size (inches) | Continuous Capacity at 125 psi-lbs/hr | Weight lbs | List Price |
|----------|--------------------|---------------------------------------|------------|------------|
| 43       | 1/4                | 3,700                                 | 1334       | \$22.00    |
| 44       | 3/4                | 7,180                                 | 26         | 31.00      |
| 45       | 1 1/4              | 15,000                                | 45         | 48.00      |
| 46       | 1 1/2              | 35,280                                | 84         | 80.00      |

5. **F & T Traps (Gray Iron).** For rapid air and condensate removal in low pressure steam systems. Ball-float mechanism controls condensate flow; expanding thermal element controls removal of air. Stainless steel valve and seat, copped hided float. For pressures to 15 psi.

| Trap No. | Pipe Size (inches) | Continuous Capacity at psi | Weight lbs | List Price |
|----------|--------------------|----------------------------|------------|------------|
| 11-T     | 3/4                | 15                         | 230        | 7 \$17.45  |
| 12-T     | 1                  | 15                         | 575        | 7 21.40    |
| 13-T     | 1 1/4              | 15                         | 1,380      | 12 28.80   |
| 14-T     | 1 1/2              | 15                         | 2,760      | 19 55.55   |
| 15-T     | 2                  | 15                         | 5,750      | 33 80.65   |

6. **Type O & K Pressure Regulators (Semi-Steel).** For steam, air and gas. Direct operated. Rugged construction. Fitted with special laminated, phosphor-bronze diaphragms and stainless valve and seat.

| No.                  | Pipe Size (inches)                                                        | Weight lbs | List Price |
|----------------------|---------------------------------------------------------------------------|------------|------------|
| Type O               | 3/4, 1, Initial pressure to 225 psi, 400 F, reduced ranges 0-200.         | 8          | \$15.00    |
| Type K (illustrated) | 1/4, Initial pressure to 225 psi, 400 F, reduced ranges from 0 to 85 psi. | 15         | 19.00      |
| 1                    | 3/4, Type K has an integral strainer.                                     | 15         | 20.00      |
| 1 1/4                |                                                                           | 18         | 27.00      |
| 1 1/2                |                                                                           | 40         | 38.00      |
| 2                    |                                                                           | 40         | 42.00      |

7. **Type C Pressure Regulators (Semi-Steel).** For installations requiring accurate and dependable regulation. Stainless trim, single-seated, piston-operated, pilot controlled spring-loaded.

| No.    | Pipe Size (inches)                                                                          | Weight lbs | List Price |
|--------|---------------------------------------------------------------------------------------------|------------|------------|
| Type C | 1/4, From initial pressure to 2:0 psi, 450 F. For reduced pressure from 0 to 200 psi        | 17         | \$36.00    |
| 1      |                                                                                             | 17         | 39.00      |
| 1 1/4  |                                                                                             | 17         | 43.00      |
| 1 1/2  |                                                                                             | 40         | 46.00      |
| 2      |                                                                                             | 40         | 48.50      |
| 2 1/2  | Available in cast steel series, 30, 40 or 60 flanges; pressure 600 psi; temperature 750 deg | 48         | 60.00      |
| 3      |                                                                                             | 74         | 79.00      |
| 4      |                                                                                             | 98         | 95.00      |
|        |                                                                                             | 150        | 160.00     |

Complete Catalog Available on Request.



## Warren Webster & Company

The Vacuum System of Steam Heating : Since 1888

Main Office and Factory: 1731 Federal St., Camden 5, New Jersey

### WEBSTER HEATING AND AIR CONDITIONING EQUIPMENT

#### Webster Radiation:

Webster Walvector for Steam and Hot Water  
Convectors for Steam and Hot Water  
Tru-Perimeter Webster Baseboard Heating, for Forced Hot Water  
Webster Unit Heaters for Gas, Steam or Hot Water; Series 45 Unit Heater Controls.

#### Webster Hydro-Heat Hot Water Heating Specialties:

Continuous Flow Controls  
Hydro-Heat Water Accumulators  
Tru-Perimeter Expansion Joints  
Pressure Regulating Valves  
Pressure Reducing Valves  
Flow Control Valves  
Purge Headers  
Balance Valves  
Webster Blendor Controls

#### Webster Steam Heating Equipment: Radiator Valves

Thermostatic Traps  
Float-and-Thermostatic Traps  
Dirt Strainers  
Double Service Valves  
Boiler Return Traps and Vent Traps  
Boiler Protectors  
Lift Fittings  
Expansion Joints  
Vacuum Breakers  
Hylo Vacuum Controllers

#### Webster Process Steam Traps:

Thermostatic Traps  
Float-and-Thermostatic Traps

#### Webster Steam Heating Controls:

Webster Moderator Systems  
Main Steam Control Valves  
Motorized Shut-Off Valves  
Metering Orifices  
Pressure Difference Controllers  
Time Switches

#### Air Conditioning

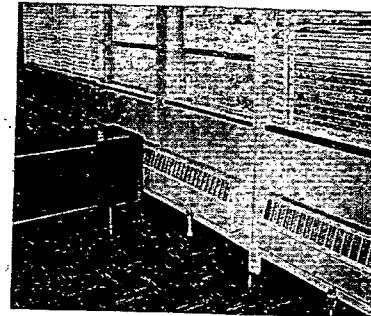
Webster Heating-Cooling Conditioner  
Warren Webster Cool Air System

### WEBSTER TRU-PERIMETER HEATING

Webster Tru-Perimeter Heating uses Webster Baseboard, Webster Walvector, or a combination of both, to replace the heat at the perimeter where heat loss occurs. Heating elements are mounted close to the floor along outside walls, spreading the heat the entire length of the exposed walls.

Webster Tru-Perimeter Heating warms the air within a room, warms the floors,

and warms the inside surface of outside walls where a normal coolness occurs during the winter months. Gently moving warmed air is drawn to floor level and across the floor into the inlet opening of the radiation. Radiant heat rays strike the floor along the full length of the exposed walls. Floors are warm and comfortable even with slab floor construction.



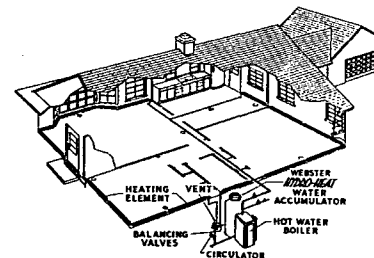
Wall-to-wall application of Webster Walvector.

#### Webster Walvector

Webster Walvector for steam or forced hot water heating is an elongated convector designed for mounting along the wall, close to the floor line and under windows. For new buildings or modernization. Combines an attractive steel enclosure, newly styled and improved, and a highly efficient heating element of copper tubing and aluminum fins in 3 in. and 4 in. fin sizes.

Custom Webster Walvector employs 3 in. or 4 in. fin size heating elements, single or double row. Front or top outlet enclosures for wall mounting or with integral sill.

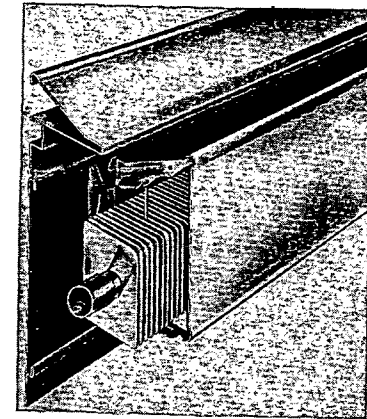
For details on standard Walvector, send for *Bulletin B-1551*; for Custom Walvector, get *Bulletin B-1553*.



Isometric view of Tru-Perimeter Forced Hot Water Webster Baseboard Heating with new Hydro-Heat features, installed in typical modern ranch house. Note simplicity. Kitchen can be heated by Webster Walvector or Webster Convector (not shown). Hydro-Heat Water Accumulator replaces expansion tank, eliminates contact between air and system water.

#### Webster Baseboard Heating

Webster Baseboard Heating is a forced hot water system in which a convector heating element is concealed within a specially built metal baseboard. It is run in a continuous loop around the exposed walls of the house, with a separate loop for each floor or zone. Heating element is copper tubing with aluminum fins. Send for *Bulletin B-1602*.



Cut-away view showing design simplicity of Webster Tru-Perimeter Forced Hot Water Baseboard Heating.

#### Webster Moderator System

The new Type IB Electronic Webster Moderator System provides continuous but automatically graduated or throttled steam flow to orificed radiators—without use of mercury. An outdoor thermostat automatically varies the rate of steam delivery to radiators with changes in outdoor temperature. A Variator, manually operated, modifies the action of the outdoor thermostat for such requirements as quick heating-up, changes in occupancy. For details, ask for *Bulletin B-900-4B*.

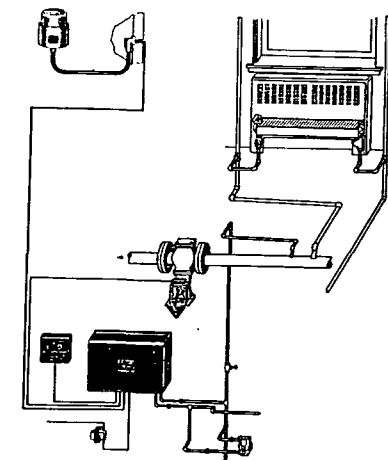


Diagram of Type IB Electronic Webster Moderator System using a single Main Steam Control Valve.

## The Dole Valve Company

Plumbing and Heating Division 1933 Carroll Avenue, Chicago 12, Ill.

Control with

WATER MIXERS

AUTOMATIC REGISTERS

**Dole**

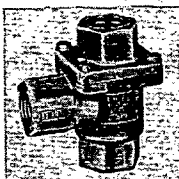
THE ALL STAR LINE

AIR AND VACUUM  
VALVES



Dole 20 Sr. Vent

This high-quality hot water air valve is designed to provide an automatic air eliminator, a manual shutoff and a manual air vent. A Dole design developed on the hygroscopic principle by The Dole Valve Company. A selector dial permits various settings and provides for faster venting. One of a complete line of Dole Hot Water Air Valves.

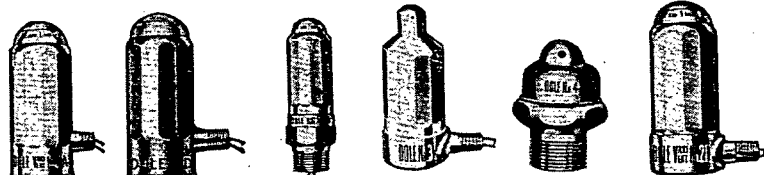


Dole No. 100 Water Mixer

Here is a new water mixing valve utilizing the famous Dole element which gives extra power. It is noncorrosive and trouble-free. The No. 100 is made of a brass forging and yet despite its high quality is low in cost, making it a top value. Nonadjustable. 140 deg setting.

Designed for installation at the water heater or storage tank.

Dole Air Valves



The complete Dole line includes air valves for every type of heating system. Below are six typical valves from the line.

**DOLE NO. 1 A VARI-VENT**—adjustable valve that provides an infinite number of venting speeds.

**DOLE NO. 1 D**—a very fast venting, fixed-orifice, nonadjustable air valve. Factory-set to vent two or three times as fast as regular type air valves.

**DOLE NO. 1 B VARI-VENT**—provides better control of heat on convector type

radiation where faster venting is essential.

**DOLE NO. 3**—designed to assure utmost heating performance on hand-fired steam heating systems. Complete venting is assured at any pressure up to 10 lbs.

**DOLE NO. 4 QUICK VENT VALVE**—for quick venting steam mains and returns up to 25 lbs pressure.

**DOLE 2 B VARI-VENT VACUUM VALVE**—for use on hand-fired gravity one-pipe steam heating systems. Has the Dole patented bellows that locks air out once it has been expelled.

Dole Water Mixers

Dole Water Mixers provide safer tempered domestic hot water on all tankless heaters and storage tank installations. Available in three sizes:  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in. and 1 in.; adjustable range—125 to 175 deg F.

Dole Automatic Register

Provides individual room temperature control. Operates thermostatically from room air temperature. Completely self-contained. Dial permits setting for the heat desired. Made in sizes to fit practically any stack-head opening.

## The Fairbanks Company



393 Lafayette Street

New York 3, N. Y.

Boston; Pittsburgh; Binghamton, N. Y.; Rome, Georgia

Dependable Service GUARANTEED From This Complete Line Of Bronze And Iron Body Valves Available From Your Local Distributor

### BRONZE GLOBE AND ANGLE VALVES

Pressures—125 through 300 lbs S.W.P.

Ends—Screwed, Flanged, Solder, Brazed and Hose.

Discs—Bronze: Renewable Composition; Nickel Alloy Semi-Plug Disc and Seat; Stainless Steel Semi- and Full Plug Disc and Seat.

Needle Valves

Radiator Valves

LP—Gas and Oxygen Valves

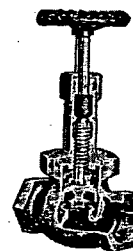


Fig. U-01  
150 lb SWP



Fig. U-0258  
125 lb SWP



Fig. 0405  
125 lb SWP

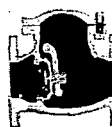


Fig. 10702  
125 lb SWP

### BRONZE GATE VALVES

Pressures—125 through 300 lbs S.W.P.

Ends—Screwed, Flanged, Solder, Brazed and Hose.

Stem Action—Rising with Solid or Split Wedges, Non-Rising with Solid Wedges.

Bonnets—Screwed, Union, Bolted and O. S. & Y.

Radiator Valves

LP—Gas Valves

### BRONZE CHECK VALVES

Horizontal, Angle and Vertical

Types—Swing and Lift

Pressures—125 through 300 lbs S.W.P.

Ends—Screwed, Flanged, Solder and Brazed.

Discs—Bronze, Renewable Composition, Rubber Faced.

LP—Gas Valves

### IRON BODY GLOBE & ANGLE VALVES

Bronze Mounted

Pressures—125 through 250 lbs S.W.P.

Ends—Screwed and Flanged

Discs—Bronze, Renewable Composition, Nickel Alloy Semi-Plug Disc and Seat

Bonnets—O. S. & Y. and Union

Automatic Stop and Check Valves

### IRON BODY GATE VALVES

Bronze Mounted and All Iron

Pressures—125 through 250 lbs S.W.P.

Ends—Screwed, Flanged and Hub

Stem Action—Rising, Non-Rising and Quick Opening

Bonnets—Screwed, U-Bolt, Bolted & O. S. & Y.

Underwriters' and AWWA Approved Valves

### IRON BODY SWING CHECK VALVES

Horizontal—Bronze Mounted

Pressures—125 through 250 lbs S.W.P.

Ends—Screwed, Flanged and Hub

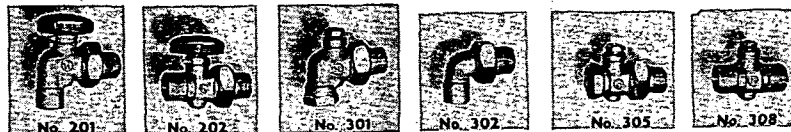
Discs—Bronze, Bronze Faced and Rubber or Leather Faced

Underwriters' Approved Valves.

## HAMMOND BRASS WORKS HAMMOND, INDIANA

Complete line of packed type radiator valves, circulator valves, balancing elbows, convactor valves and gate valves for iron pipe and copper tubing, for use in steam, gravity and forced hot water heating systems; including baseboard, convectors, floor, ceiling, and wall radiant panel heating.

Circulator valves, balancing elbows, and fittings for forced hot water systems.



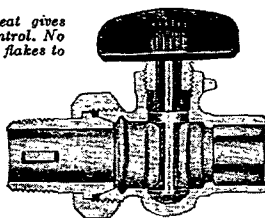
Service recommendations: These circulator valves provide a "nearly tight" shut off when closed and full flow when open. A quarter turn of the handle gives a smooth, easy, full opening.

Valves can be furnished in any combination of copper to iron, copper to copper, iron to copper, etc. Construction of balancing elbows same as circulator valves.

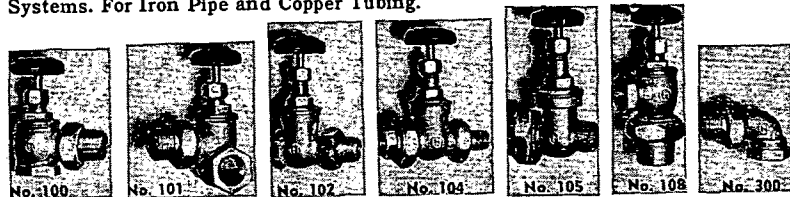
The external adjustment allows for adjusting and re-adjusting while system is in operation and eliminates necessity of draining. Caps can be furnished to prevent tampering.

These valves are engineered and designed to fit into small enclosures of the concealed or convactor type radiators.

Tapered ball seat gives positive flow control. No chance for rust flakes to collect.



Hammond Radiator Valves and Elbows for Steam and Gravity Hot Water Heating Systems. For Iron Pipe and Copper Tubing.



No. 101—Steam Corner. Same as No. 100. Specify whether right or left hand wanted. Valve illustrated is left hand.  
No. 102—Gate Union. For hot water installations and steam or vapor heating systems. Especially suitable for use with unit heaters; ideal for general shut-off valve service at other points throughout heating systems including boilers and hot water heaters. Specify when ordering for hot water system, as such valves are furnished with a small hole drilled through the disc to provide for slow circulation when valve is closed.  
No. 105—Convactor Single Union Gate. Same as No. 102, but single union does

not permit removal of radiator while system is in operation.  
No. 108—Convactor Female Union Steam Angle. Same as No. 100, but should only be used for convactor radiators equipped with inside leg tapplings. The female union eliminates the necessity for exact roughing in measurements to tapping. Variation of the nipple inside leg will allow for adjustment. Shipped with bonnet loose to facilitate installation.  
No. 300—Union Elbow—For gravity hot water heating installations.  
No. 104—Double union gate for convactor radiators only.

See Hammond Catalog for complete line of valves.

Stocked by all leading wholesalers, also 29 factory warehouse stocks located in 29 cities throughout the United States.

## Jenkins Bros.

100 Park Avenue, New York 17, N. Y.

BRIDGEPORT, CONN.; BOSTON, PHILADELPHIA; CHICAGO, SAN FRANCISCO, ATLANTA

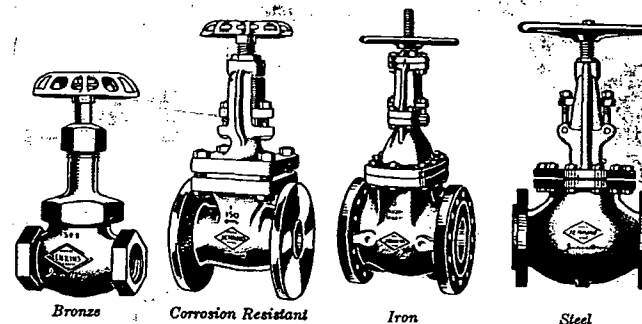
LOOK FOR THE JENKINS DIAMOND



Jenkins Bros.

Leading Supply Houses Everywhere Stock Jenkins Valves

### JENKINS VALVES for LASTING ECONOMY



### PATTERNS AND PRESSURES FOR ANY SERVICE IN JENKINS COMPLETE LINE

Consult Jenkins Catalog for complete details on more than 500 different valves that cover practically all industrial plumbing and heating, and engineering requirements. Below is a brief list.

All-Iron Valves,—globe, angle, gate; Angle Valves,—bronze, steel, and iron body with bronze mounting or trimming.

Blow-Off or Y Valves,—bronze and iron.

Electrically Operated Valves, Gates, Globes, Angles, Fire Line Valves; Floor Stands; Foot Valves for gasoline service.

Gate Valves,—bronze, iron, steel; with solid wedge or double disc parallel seats; with removable bonnet and renewable bushing.

Globe Valves,—bronze, iron and steel; one piece and union bonnets; renewable and integral seats; rubber composition or metal discs and plugs.

Horizontal Check Valves,—bronze, iron and steel; Hose Valves; Indicator Posts; Lock Shield Valves.

Needle Valves; Non-Return Valves; Quick-Opening; Self-Closing Valves.

Radiator Valves; Rapid Action Valves; Regrinding Valves; bronze and iron body with bronze trimming; renewable plug seats and bevel seats of a special nickel alloy in globe, angle, check and swing check patterns.

Stop and Check Valves,—non-return; Swing Check Valves,—bronze, iron and steel.

Stainless Steel Valves,—globe, angle, gate and check.

Underwriters' Pattern Valves,—check and gate; Whistle Valves; Waterworks Valves.

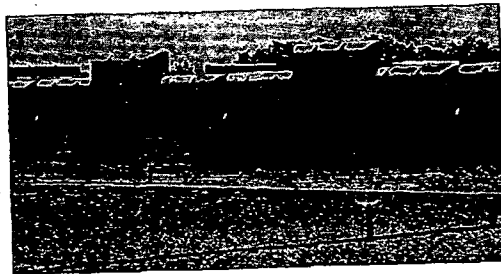
**April Showers Company, Inc.**  
4126 Eighth Street, N.W. Washington 11, D. C.



(Trade Mark Reg. U. S. Pat. Off.)

**AUTOMATIC EVAPORATIVE ROOF COOLING**

Distributors and Dealers in Principal Cities



Automatic  
ROOF  
COOLING

*Spray Method*

The logical **FIRST** step in  
any large or medium sized  
Air Conditioning program

Over 19,500,000 Square Feet of Roofs  
Cooled by **APRIL SHOWERS**. Excellent  
results recorded whether in conjunction  
with a true air conditioning system or  
alone as an "under-roof" Cooling  
System.

(Partial List of Users) E. I. duPont de  
Nemours & Co., Inc. (Stores: 19,549 sq  
ft Shipping Dept: 43,902 sq ft. Shops:  
17,772 sq ft) Martinsville, Virginia.  
• Calhoun Garment Co., (44,660 sq ft)  
Calhoun City, Mississippi.  
• American Viscose Corp., (139,120 sq ft)  
Marcus Hook, Penna.  
• Stahl-Urban Company, (64,000 sq ft)  
Brookhaven, Miss.  
• Hamilton Standard, Div. United Air-  
craft (538,500 sq ft) Windsor Locks,  
Conn.  
• Livingston Shirt Corp. (24,544 sq ft)  
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• Lockport Felt Company, (180,859 sq  
ft) Starkville, Miss.  
• Write-Right Mfg. Co., (44,352 sq ft)  
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And such others as: Lilly Tulip Co.,  
General Electric Co., Westinghouse  
Electric Co., Eastman Kodak Co.,  
Bulova Watch Co. and many others.

In addition, the Federal Government has  
used millions of square feet of **APRIL  
SHOWERS** installations. Among them  
is the 500,000 sq ft roof of the U. S.  
Naval Ordnance Building in Indi-  
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Consider these important Facts when  
planning your next Air Conditioning or  
Cooling installation

• Reduces loads of True air conditioning  
systems as much as 25 percent • Lowers  
temperatures of upper floors 8 deg to 15  
deg • Used on all types and shapes of  
roofs on Industrial, Commercial and  
Residential buildings • Increases em-  
ployee efficiency • Thermostatically con-  
trolled; no pool, no run off • Installation  
is simple, inexpensive, fool-proof • Op-  
eration and maintenance costs are negli-  
gible

The **APRIL SHOWERS** System is fully  
automatic. The Sun operates it. Re-  
quires very little water and City water,  
under normal city pressure, is usually  
adequate. No runoff. Installation and  
Maintenance Costs are low. Only finest  
materials are used. Precision workman-  
ship.

Besides cooling "under-roof" areas,  
**APRIL SHOWERS** adds longer life to  
roofs (preventing the sun from speedily  
evaporating the protective roof-coating  
oils), gives added protection in case of  
fire and acts as a lightning arrestor.

*April Showers is protected by U. S. Pat.*

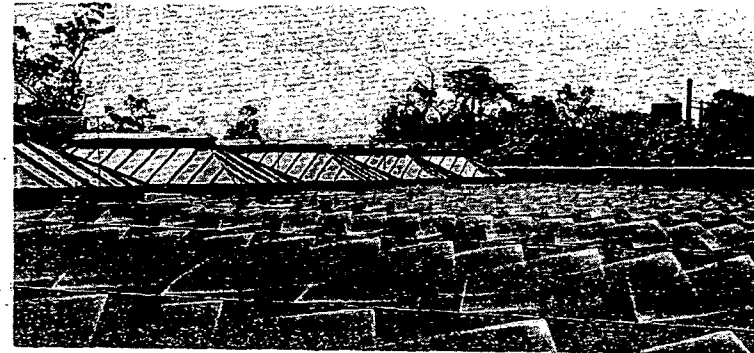
**WRITE** for complete information or  
Free Estimates. No obligations.

**Muellermist Irrigation Company, Inc.**

2612-22 South Ninth Ave., Maywood, Illinois.

**FANJET EVAPORATIVE ROOF COOLING SYSTEM**

Adapted to Practically Any Kind of Roof Surface



Tests of a sprayed roof\* show that it is  
more effective in excluding solar heat  
than a dry roof; more effective than a  
pool of water one inch deep; and more  
efficient than a pool six inches deep. For  
this reason engineers and plant managers  
are turning more and more to the sprayed  
roof as a relatively inexpensive means for  
improving working conditions in the  
absence of air conditioning, or of sub-  
stantially reducing the load where there  
is air conditioning.

**FANJET** is a low priced roof cooling  
system with unusual features. No spray  
heads are required. By an exclusive pro-  
cess (Patents pending), copper pipe of  
special size and temper is pierced in such  
a way as to produce a fan shaped spray  
of peculiar character in that there are  
both fine and large drops. The fine drops  
wet the near areas while the large drops  
reach the outer areas with intersecting  
streams. Laterals are placed eighteen  
feet apart, with the pipe pierced on both  
sides except around the outside perime-  
ters. The effect is a more evenly wetted

surface than is possible by other  
methods.

The sprays are regulated by adjustable  
automatic controls, so that the quantity  
of water applied approximately balances  
evaporation, with little if any waste.

To absorb all solar energy on a hot day  
may call for up to 36 gal of water per  
1000 sq ft per hr. This would mean an  
excessive demand rate on a large roof, so  
the roof is divided into sections to fit the  
available water supply, each being  
wetted in consecutive order. For design  
purposes allow 200 sq ft to one gallon of  
water. Evaporation from a properly  
wetted surface will go on with full effi-  
ciency for five or more minutes during  
the "off" period. The daily water re-  
quirements would be around 200 gal per  
1000 sq ft.

Water pressure at roof level should be  
enough to allow 20 psi at the valve for  
each section.

Full information and estimates on re-  
quest, without obligation.

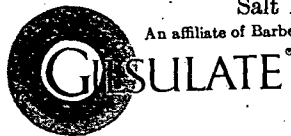
Inquiry from Dealers invited.

\* See ASHVE Transactions, Vol. 46, 1940, Research Paper 1157, p. 231

## American Gilsonite Company

Salt Lake City, Utah

An affiliate of Barber Oil Corp. & Standard Oil Co. of California



### TRIPLE-ZONE INSULATION

Gilsulate is a unique solidified hydro-carbon of high resin content which in granular form is poured directly around hot underground pipes for insulation and corrosion-protection.

#### GENERAL DATA

1. Low cost per installed linear foot
2. Easy-to-use: pour . . . tamp . . . normal pipe heat does the rest
3. Fuses itself in hours into 3 zones of permanent protection for the pipe against all commonly-encountered buried-line conditions such as acids, alkalis, roots, water, and corrosion
4. Tested and proved in actual use in hundreds of new construction and replacement installations
5. Can be used under all multiple-pipe and cramped space conditions (see illus. below)
6. Needs no housing or mechanical sheaths to protect it

7. Requires no mixing or special handling
8. Can't be punctured, obviating need to remove rocks from backfill
9. Only normal pipe spacing required; steam and condensate lines can run side by side
10. Pipe expands and contracts within Gilsulate structure
11. Makes repairs to the pipe quick, easy and economical

#### GRADES AND TEMPERATURE RANGES

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| Type A . . . . . | 220F to 300F |
| Type B . . . . . | 300F to 385F |
| Type C . . . . . | 385F to 520F |

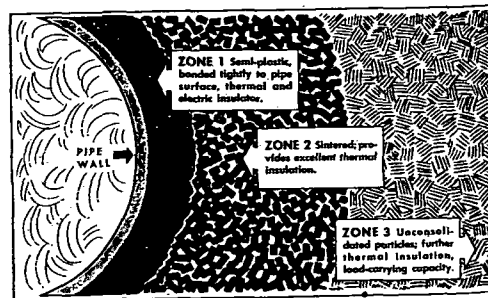
#### TRENCH SIZE

4 in. to 22 in. wider than pipe diameter,  
6 in. minimum backfill over the Gilsulate bed.

#### EFFICIENCY

Heat loss 8-12 per cent of bare pipe  
Inert to ordinary acids and alkalis  
found in soil, excellent dielectric

For further data or information, write:  
American Gilsonite Co., 134 W. Broadway,  
Salt Lake City 1, Utah, or 1145 E. Jersey  
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## Durant Insulated Pipe Company

Palo Alto, California

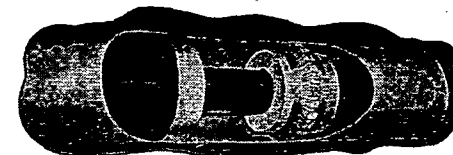
Durant International Corporation

Williamstown, New Jersey

REPRESENTATIVES IN PRINCIPAL CITIES AND CANADA



### DURANT Pre-Sealed INSULATED PIPE



Cutaway shows DURANT construction—Insulation and support sections are applied next to pipe—heavy gage galvanized steel casing is slipped over load bearing and spacer sections leaving a minimum 1 in. space which is filled with a special high melting point, non-porous asphalt. The result is a solid, compact unit, permanently waterproofed.

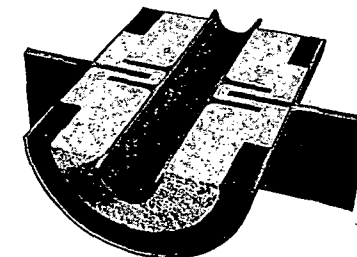
DURANT INSULATED PIPE is pre-fabricated into complete, insulated and water-proofed systems for use in underground or exposed locations. DIP is used for the conveyance of steam, hot water, refrigerants and process fluids, and for tracer type systems.

DIP is fabricated in all standard sizes—Pipe and Insulation supplied as specified—and is equally adaptable to single or multiple pipe units.

#### SPECIAL FEATURES



The DURANT patented insulated anchor eliminates contact between pipe and anchor plate—provides electrical and thermostatic insulation against heat loss and electrolytic action.



Assembly and installation of DIP units consists of joining pipe—applying insulation around pipe joint—securing connector to conduit ends—filling 1 in. space between insulation and connector with DIP special asphalt. Units may be assembled before placing in trench as shown here. No slabs, drains or supports are necessary.

The DURANT engineering staff and representatives are at your service—write or call for information estimates, or new Durant catalog No. 35.

E. B. Kaiser Co.

SINCE 1890

P. O. Box 276, 2114 West Lake Avenue, Glenview, Illinois

**EBKO**

**PIPING SYSTEMS**

REPRESENTATIVES IN PRINCIPAL CITIES

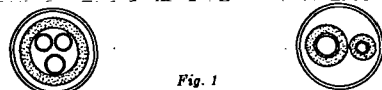
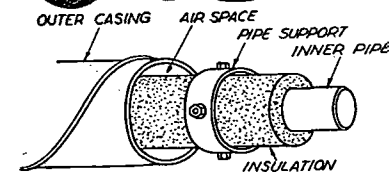
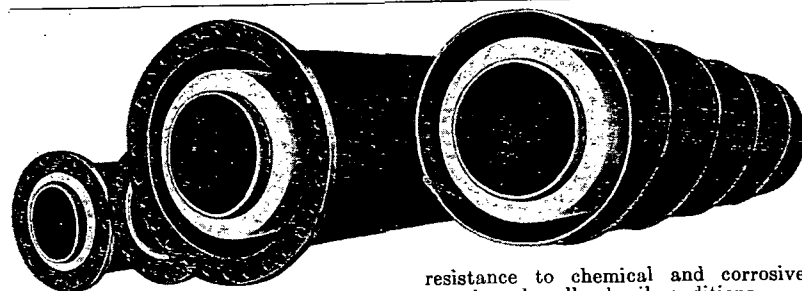


Fig. 1

EBKO underground or overhead prefabricated insulated piping systems are designed for efficient and economical distribution of steam, condensate return, refrigerants, hot and chilled water in single or multiple units (Fig. 1). Made in standard lengths—18 ft for cast iron casings; 20 ft for steel—with all fittings and accessories to complete the system. The spirally-welded, lock-seam steel casing, ranging from 8 to 14-gauge provides substantial support for the inner assembly and resists crushing loads, as does the cast iron; therefore, expensive reinforcements are unnecessary under railways and roadways. These heavy-duty casings may be assembled on the ground and lowered into the trench or hoisted into position overhead, where they can be suspended on 24 ft centers by means of clevis hangers. EBKO casings are designed for 150 psi operating pressures. These casings are protected from weather by an anti-corrosive paint. The anti-corrosive compound used on the underground systems has also proved its effective

resistance to chemical and corrosive attack under all subsoil conditions.

The inner pipe is concentrically aligned within the casing by heavy supports fastened to the inner pipe on 10 ft centers (Fig. 1). This method permits free movement of the inner assembly longitudinally yet controls any tendency for it to deflect or sag during expansion and contraction. Movement is also controlled by the EBKO anchor, an integral part of the system requiring no costly external reinforcing.

Any portion of the inner assembly can be removed after installation without major disturbance to the system. This design permits the rotation of the inner assembly, eliminating many position welds. Another important feature is the continuous, uniform, annular air space throughout the system, designed to afford maximum insulating efficiency. The insulation retains its normal efficiency and form even after being thoroughly saturated and then dried. This process may be accomplished after the system is installed. The sectional fittings permit accurate casing alignment and allow visual inspection of all inner pipe joints during tests. Standard devices for expansion relief are adaptable to an EBKO system. The steel-loop type is prefabricated and tested at the EBKO plant and permits ample unrestricted expansion without crushing the insulation. Installation costs are reduced considerably by the relatively low cost of field erection, which can be mainly performed at ground level.

All EBKO systems are completely guaranteed.

E. B. Kaiser Co.

SINCE 1890

P. O. Box 276, 2114 West Lake Avenue, Glenview, Illinois  
REPRESENTATIVES IN PRINCIPAL CITIES



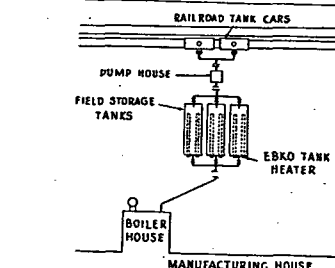
A, D, EBKO outside and inside viscous liquid systems (Fig. 2)



EBKO Piping Systems for handling viscous materials merit close investigation by those faced with this problem. Here is the system (Fig. 2-3) that handles any degree of viscosity requiring either high or low temperatures to liquefy.

EBKO provides a continuous Heating or Cooling chamber—through valves, fittings, expansion devices, and level controls. Constant temperatures are maintained thermostatically.

The initial investment is rapidly recovered through increased productive capacities. Many industries have found EBKO indispensable to their operations because of EBKO's high efficiencies and low maintenance costs. It is used to convey everything from petroleum by-products to process foods—from chem-



EBKO heavy oil system (Fig. 3)

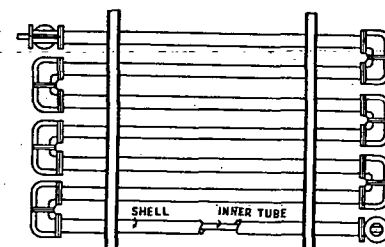
icals to paints and varnishes—waxes—fats. Anything that liquefies under temperature is conveniently and economically moved in an EBKO Piping System. EBKO systems can be used over any distance, anywhere—indoors, outdoors—underground, overhead—they can be totally submerged without peril to their efficiency or long life. All EBKO systems are guaranteed.

EBKO Heat Exchangers with the counter-flow feature are designed for high efficiencies. They are designed for various liquids and gases, pressure and capacities. All EBKO Heat Exchangers are in accordance with ASME codes. Single and Multiple Stack Type Heat Exchangers (Fig. 5)

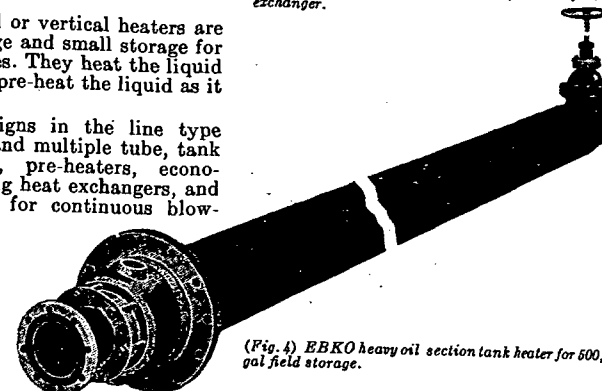
This type of Heat Exchanger assures maximum extraction. Each pass can be provided with rod-outs, eliminating disassembly in the event of stoppage. Combination Tank and Suction Heater (Fig. 4)

These horizontal or vertical heaters are designed for large and small storage for various capacities. They heat the liquid in the tank and pre-heat the liquid as it is withdrawn.

EBKO also designs in the line type heaters—single and multiple tube, tank storage heaters, pre-heaters, economizers, reclaiming heat exchangers, and heat exchangers for continuous blow-down.



(Fig. 6) EBKO flanged, single stack, counter flow heat exchanger.



(Fig. 4) EBKO heavy oil section tank heater for 500,000 gal field storage.



**Therm-O-Tile**  
REGISTERED

**H. W. Porter & Co., Inc.**  
817-G Frelinghuysen Ave., Newark 5, New Jersey

Permanent Protection and  
Insulation for Underground  
Pipe Lines.

**REID HAYDEN, INC.**

Baltimore, Md. Richmond, Va. Charlotte, N.C.

Advantages offered by Therm-O-Tile  
Conduit are:

- 1—Higher efficiency PERMANENTLY because insulation and conduit are always DRY.
- 2—Positive sealing throughout. Internal drainage assures dry, efficient insulation.
- 3—Arched construction that is stronger than required by ASTM. Ask for STRENGTH AFFIDAVITS by Pittsburgh Testing Laboratory.
- 4—"Spread-Footing" foundation. The "sidewalk" makes installation easier.
- 5—Surrounded by sealed air.
- 6—All loads are taken directly by an unyielding base.
- 7—The correct slope is PERMANENT hence no condensation pockets.
- 8—PERMANENCE assures maximum economy. Lowest ultimate cost.

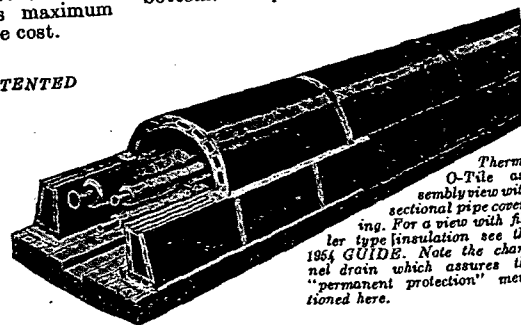
PATENTED

THERM-O-TILE

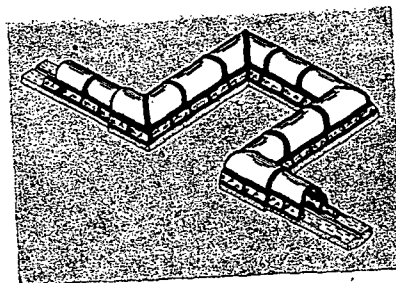
STEAM

CONDUIT

SYSTEMS



Expansion Loops. Expansion Loops may be constructed from over-sized Therm-O-Tile designed to allow proper expansion movement of the piping within the loop.



Therm-O-Tile Expansion Loop

and sagging. The original surveyor's slope is PERMANENTLY held hence condensate pockets cannot form. When installed over filled or boggy ground PERMANENCY is insured by steel reinforcement or supporting piles.

Wide Size Range. Top and base sections of the envelope are made in numerous sizes. Result: any desired section is usually made available. For complete data ask for Therm-O-Tile Bulletin.

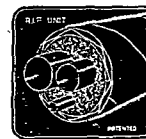
Reasonable in First Cost. Despite the many excellent features obtained in Therm-O-Tile, it is nevertheless competitive in total first cost.

Engineers — Contractors — Manufacturers. Write, phone, or wire the nearest Porter-Hayden office for estimates, recommendations, and complete specifications for the conduit and insulation on any underground pipe line project.

1650

**Ric-wiL Incorporated**

Prefabricated Insulated Piping Systems  
UNDERGROUND or OVERHEAD



Barberton, Ohio

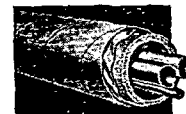
Representatives in Principal Cities

Ric-wiL Systems for central heating and process piping are engineered and insulated to specific project requirements for efficient distribution of steam, hot or refrigerated liquids and gases.



**Hel-Cor Insulated Pipe Units... Single or Multiple Pipes**

Prefabricated in 21 ft lengths with any specified combination of pipes and insulation. 16 gage helically-corrugated, hot-dip galvanized metal housing, protected with asphalt coating.



**Hel-Cor Uniline—For Oil or Process Liquids**

Similar to standard units except pipes are nested inside a laminated asbestos insulation liner—insulated from the exterior but not from each other. Designed for oil and process liquids.



**Ric-wiL Cast Iron Insulated Pipe Units**

Factory prefabricated 18 ft 6 in. lengths. Pipe and insulation housed in heavy-duty cast iron conduit. Insulation any type or thickness to meet job requirements.

**Hel-Cor Underground Systems**

Standard 21 ft prefabricated sections for efficient field installation. Single or multiple pipe Hel-Cor Units or Hel-Cor Uniline Insulated Pipe Units can be used underground or overhead.



**Hel-Cor Overhead Systems**

Prefabricated 21 ft pipe units for straight runs. Elbows, tees, anchor units and expansion loops finished at factory and delivered to job site with joint materials for simple assembly.

**Cast Iron Underground Systems**

For underground insulated piping systems where permanency and thoroughly tight joints are required. Prefabricated for easy field assembly, complete with accessories—expansion loops or joints, etc.

For full descriptive literature and technical information on Ric-wiL products and services, call or write the Ric-wiL office nearest you, or Ric-wiL Incorporated in Barberton, Ohio.

1651



## The Stillwater Clay Products Company

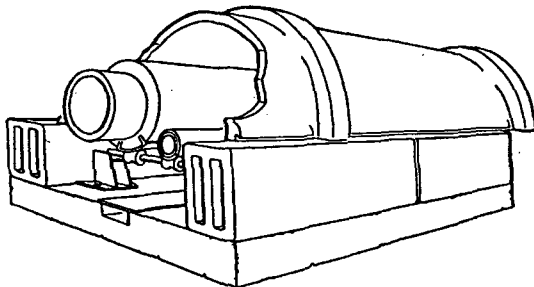
Conduit Division

Plants  
Uhrichsville, Dennison,  
and Junction City, Ohio

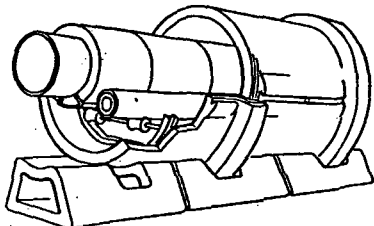
General Offices  
3334 Prospect Avenue  
Cleveland 15, Ohio

Factory Agents in Principal Cities

### Stillwater Tunnel and Round Conduit Systems



**TUNNEL SYSTEM** The most versatile of the Stillwater Conduit Systems. With Tunnel Arch in ten different sizes, and in conjunction with one of the three different sizes of Side Blocks, any combination of service piping can be accommodated.



#### ROUND SYSTEM

The Stillwater Conduit System supplied complete with Combination Underdrain and Support Structure. The complete system can be quickly installed without a concrete pad. With twelve Round sizes, each with proper size of Underdrain Support, the proper design size is available to fit any job.

Stillwater Conduit is an engineered, proven system. Its major component is Vitrified Clay—the ageless material which has withstood the test of underground use for centuries. Stillwater Conduit Systems are not affected by extremes of temperature or moisture, or the attack of corrosive soils. Vitrified Clay, being dielectric, protects the enclosed metal service piping from electrolytic disintegration.

We offer, without obligation, our Engineering Services for your proposed new project or replacement job. Complete warehouse stock assures prompt shipment of any size order with Stillwater Support Assemblies, Alignment Guides, Anchors and other accessories.

Write for the Stillwater Conduit Manual—your guide to the best in Underground Conduit Installation.

**STILLWATER Conduit Systems assure permanent protection for your underground metal piping investment.**

1652



## Z-Crete Division

Zonolite Company  
135 S. LaSalle St.  
Chicago 3, Ill.

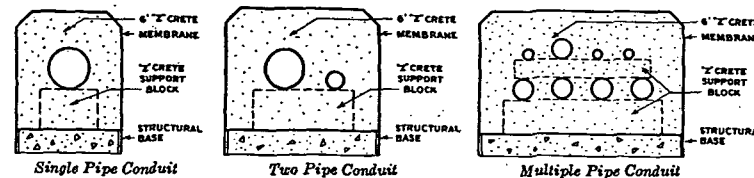
### UNDERGROUND PIPE INSULATION

**Z-CRETE\*** is a Lightweight Insulating Concrete which is poured directly and monolithically around heated underground piping.

**GENERAL DATA** The Z-CRETE system of underground insulation is a field fabrication adaptable to any size, number or arrangement of pipes. Six inches of insulation is ordinarily used on the outside of all pipes. A minimum of four inches is economical spacing between piping.

Z-CRETE insulation serves as a monolithic, jointless insulating filler around pipes. A curing and waterproofing membrane completes the installation.

Z-CRETE installations have no joints to leak heat or collect water—they are as permanent as the earth itself. Anchors, guides and expansion devices (except loops) are the same as used in any other system. The curing membrane provides external water protection and imparts a tensile strength to the conduit.



#### TYPICAL Z-CRETE CONDUITS

Commonly used designs of Z-CRETE are shown above. The single pipe and double pipe conduit consist of a structural concrete pad, pre-cast Z-CRETE support blocks on which the pipes rest, a pour of Z-CRETE insulating concrete and a curing and waterproofing membrane. The multiple pipe conduit at the right has a second pre-cast support for the upper group of pipes.

#### REINSULATION OF EXISTING CONDUITS

The ruinous effect of water on steel pipe and insulation is well known. Z-CRETE insulation restricts moisture, keeps the conduit dry. Inorganic Z-CRETE concrete naturally resists deterioration. Many existing hollow or Box Type Conduits may be reinsulated by *pumping* them full of Z-CRETE. The mass of water resistant Z-CRETE restricts the

movement of moisture, so special drainage provisions are not ordinarily required. Z-CRETE is sold and installed by licensed applicators of Zonolite Company under U. S. Patent No. 2355966—Canadian Patent No. 439356. There is an applicator near you. For further data or information, write Dept. HV-6.

\* Z-Crete is a registered trade mark of Zonolite Company.

1653

## Miracle Adhesives Corporation

Devices, Inc. Division  
 Manufacturer of Miracle Surface Anchors  
 214 East 53 St., New York 22, N. Y.  
 Representatives in all Principal Cities and in Canada

Miracle Surface Anchor method cuts costs • No wiring—No metal corner beads • Ideal for cumbersome installations.

Miracle Surface Anchors consist of perforated metal plates 2 in. x 2 in. or 2 3/4 in. x 2 3/4 in., to the center of each is welded a nail, bolt, spindle, prong or threaded stud. These Anchors are zinc and dichromate finish to resist corrosion. (Figs. 2, 3, and 5) bonded to rigid surfaces with Miracle Adhesive which is manufactured in many formulations to meet various job requirements.

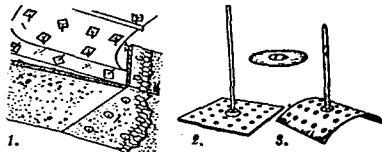


Fig. 1: Attaching Corkboard with Miracle Spindle Anchors to Ducts  
 Fig. 2: Miracle Spindle Anchor and Washer  
 Fig. 3: Curved Plate for Convex Surfaces

**Miracle Spindle Anchors**—When attached to ducts, walls, ceilings, ship hulls, deck heads, etc., will firmly support various types of insulation, such as cork, batt and fiber glass, by impaling the insulation (and wire mesh, if any) on the spindle (Fig. 1). Self clinching washers to fit over the spindles are available, (Fig. 2). Spindle Anchors are also made on a curved plate for attaching to convex surfaces (Fig. 3).

**Miracle Pronged Anchors**—For bonding thermal cellular glass and other types of block insulation to ducts, walls and ceilings. Pronged Anchors are set between rows of block insulation and prongs bent in reverse direction over blocks. For wire mesh with plaster finish, 1 prong of each Anchor is bent over block insulation, the other prong penetrating mesh, then bent over before applying plaster finish (Figs. 4 and 6).

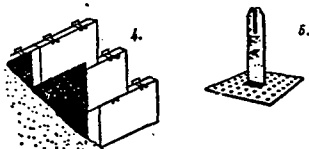


Fig. 4: Wall construction with Miracle Pronged Anchors. Fig. 5: Miracle Pronged Anchor.

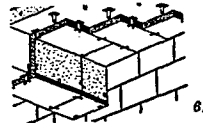


Fig. 6: Ceiling construction with Miracle Pronged Anchors.

### MIRACLE TC CLIPS

Miracle TC Clips provide an economical, fast and permanent method of fastening light pneumatic air control lines, telephone cables, and wiring, etc., without drilling to any masonry or metal surface. Each clip will support 1 lb.

For twin lines use Miracle PA-1 Pronged Anchors. For fixing lines to steel work, use Miracle Hanger Supports.

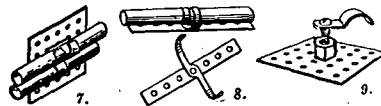


Fig. 7: Miracle PA-1 Pronged Anchors. Fig. 8: Miracle TC Clips. Fig. 9: Miracle Hanger Supports Designed for supporting small cables, tubing, air lines, etc.

### MIRACLE "Z" CLIPS

Miracle "Z" Clips consist of 2 in. x 2 in. or 2 in. x 4 in. perforated 20 gauge steel. Provides an effective and economical means of attaching wallboard, insulation board, etc. to walls when an air space is required. The hinged construction take up irregularities in surface to which they are bonded. (Figs. 10, 11 and 12).

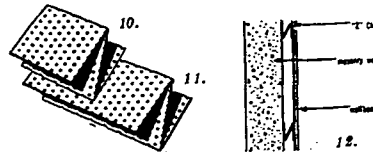


Fig. 10: Cat No. Z-22, 2 in. x 2 in. Fig. 11: Cat. No. Z-24, 2 in. x 4 in. Fig. 12: Vertical wall section illustrating Miracle "Z" Clips in position.

**Adhesives:** For Anchor installations use Miracle Anchor Adhesive for temperatures minus 40F to plus 200F or Miracle RT 1000 for minus 40F to plus 450F or when asphalt primers or compounds are involved.



## L.O.F. GLASS FIBERS COMPANY

Dept. 81-56, 1810 Madison Ave.,  
 Toledo 1, Ohio  
 Sales Offices and Distributors in Principal Cities

Microlite and Super-Fine are low-density, resilient glass fiber insulating materials, which have high thermal efficiency and sound-absorption characteristics. The high insulating efficiency found in both these materials results from the countless dead air cells formed by millions of fine glass fibers, which effectively reduce heat loss or gain.

**Application:** The light weight, flexibility and resilience of Microlite and Super-Fine make them easy to handle in large sections, easy to place properly, and easy to fasten securely by standard methods. Either material can be cut with knife or shears, and can be bent around curved surfaces and easily fitted in irregular areas. In addition, these springy, airy insulating materials are compressed and packaged in convenient rolls which save storage space in factory warehouses and in busy cutting-fabricating rooms.



Microlite and Super-Fine can be fitted quickly around the duct and supporting hangers. Light-pauge wire ties complete the job. Men like to work with L.O.F. Glass Fibers' insulation because it is so soft and flexible—so pleasant to handle.

**Properties:** Composed of minute glass fibers of consistent uniformity, bonded together in blanket form, Microlite and Super-Fine insulating materials resist fire, corrosion, vibration, settling and effects of humidity. Glass fibers are inorganic; they provide no sustenance for fungi or bacteria, and no food for rodents or insects. Inch for inch, Microlite and Super-Fine are two of the most effective of all insulating materials.

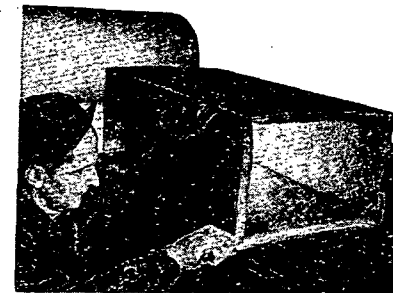
**Densities:** 1/2 lb, 3/4 lb, 1 lb, 1 1/2 lb, and 2 lb per cu ft.

**Widths:** 18, 24, 36, 48 and 72 in.

**Thicknesses:** 1/2, 3/4, 1, 1 1/2, 2, 3, 4 and 5 in.

**Lengths:** Comes in rolls from 50 to 200 ft, depending on density and thickness.

**Facings:** Microlite and Super-Fine are available with facings already applied in standard widths of 18 in., 24 in., 36 in. and 48 in. 1 in. flange available on one side or both edges for easier joint sealing. Types of facings include: Plain Vapor Barrier Paper; Reinforced Reflective Vapor Barrier Paper; Aluminum Foil (0.0025 in., 0.001 in., and 0.0007 in. thick); Vinyl Film (0.004 in. aluminum pigmented); Reinforced Duplex Paper Vapor Barrier. Also available are Vinyl and Neoprene Coatings.



Microlite and L.O.F. Super-Fine are efficient thermal and acoustical insulating linings for air supply ducts. Linings are easily applied by fastening the insulation to flat metal sheets with adhesive, and forming the duct in a brake.

**Coated Microlite or Super-Fine Duct Liner:** Either is available for all velocities up to the highest normally required. If desired, uncoated liner may be used for velocities under 3000 ft per minute.

**Noise Reduction Coefficient:** 1/2-in. liner has a noise absorption efficiency of 0.64; 1 in. of 0.80. Type No. 6 mounting used.

**Carey**  
PRODUCTS

## The Philip Carey Mfg. Company

Lockland, Cincinnati 15, Ohio

District Offices In All Principal Cities

### FIREFOIL BOARD

Firefoil Board consists of successive plies of corrugated asbestos paper sheets bonded with a special fire-resistant adhesive, treated with a chemical and hardened to make it a strong, fire-resisting and water resisting panel. There are approximately 8 layers of corrugation per inch of thickness. This results in a sheet having structurally strong, fire and moisture resisting and insulating qualities.



Standard sheet size 48 in. x 96 in. Cut sizes, available from the standard size sheets, can be cut at factory to customer's requirements.

Materials are available in thickness of  $\frac{1}{2}$  in. to and including 3 in. in  $\frac{1}{4}$  in. multiples.

The use of Firefoil Board with metal corners produces an insulated and acoustical duct construction. Other uses are for bulkheads in ships, partitions, coil housings, ovens, etc.

Firefoil Board can be easily nailed, screwed or bolted into place. It can be cut and installed with ordinary tools. Sheets are self-supporting when installed in metal channels or fastened to structural iron with bolts.

Firefoil can be used at temperatures up to 950 to 1000 F.

The "K" factor at 100 F. mean temperature is .725.

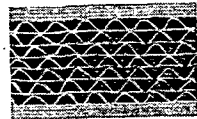
The "U" factor at 100 F. mean temperature as follows:

| Thickness         | Thermal transmittance<br>B.T.U./hr/sq ft/F. |
|-------------------|---------------------------------------------|
| $\frac{1}{2}$ "   | .68                                         |
| $\frac{3}{4}$ "   | .55                                         |
| 1"                | .46                                         |
| 1 $\frac{1}{4}$ " | .40                                         |
| 1 $\frac{1}{2}$ " | .34                                         |
| 1 $\frac{3}{4}$ " | .31                                         |
| 2"                | .28                                         |
| 2 $\frac{1}{4}$ " | .23                                         |
| 3"                | .20                                         |

Firefoil Board is recommended for interior use only and under dry conditions.

### MARINE PANEL

Marine Panel consists of corrugated asbestos sheets laminated together forming a material similar to Firefoil Board to which, on each surface a ply of  $\frac{1}{8}$  in. asbestos-cement board is bonded. It therefore has similar characteristics of Firefoil with the exception that it has added strength and durability resulting from the asbestos-cement facings.



Standard sheet size 48 in. x 96 in. Cut sizes, available from the standard size sheets, can be cut at factory to customer's requirements.

Materials are available in overall thickness of  $\frac{1}{2}$  in. to and including 3 in. in  $\frac{1}{4}$  in. multiples.

Marine Panel is recommended for partitions, coil housings, ovens, plenum chambers, interior elevator enclosures, fire resisting chambers, etc.

Its asbestos-cement facings give the material a rigid surface and an attractive gray-white appearance.

Marine Panel can be sawed and drilled as required in the field. Panels are self-supporting when installed in metal channels, or sheets can be secured to structural iron with bolts. Asbestos-cement or steel battens are used over butt joints, and corner angles of steel or galvanized iron are used at corners. Materials must be drilled prior to nailing or bolting in place. All holes should be slightly oversized.

The "U" factors at 100 F. mean temperature are:

| Thickness         | Thermal transmittance<br>B.T.U./hr/sq ft/F. |
|-------------------|---------------------------------------------|
| $\frac{1}{2}$ "   | .79                                         |
| $\frac{3}{4}$ "   | .62                                         |
| 1"                | .51                                         |
| 1 $\frac{1}{4}$ " | .43                                         |
| 1 $\frac{1}{2}$ " | .37                                         |
| 1 $\frac{3}{4}$ " | .33                                         |
| 2"                | .30                                         |
| 2 $\frac{1}{4}$ " | .24                                         |
| 3"                | .21                                         |

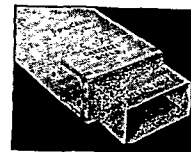
Marine Panel is recommended for interior use only and under dry conditions.

## The Philip Carey Mfg. Company

Lockland, Cincinnati 15, Ohio

District Offices In All Principal Cities

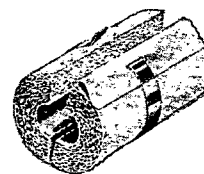
**Carey**  
PRODUCTS



### CAREYCEL FOR AIR DUCTS

Uses: A fireproof, low cost, high efficiency asbestos board for insulating ducts and all types of air conditioning equipment. Use 1 inch thickness up to 25 F difference in temperature and 80 per cent relative humidity. Recommendations for more severe conditions on request.

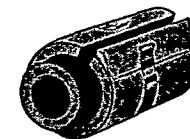
Description: Composed of 12 to 14 laminations of indented (not corrugated) asbestos felt per inch of thickness. Weight: approximately 1 $\frac{1}{2}$  lb per board foot. Sheet Size: 36 in. x 36 in., or cut to order. Blocks: 6 in. x 36 in. Thickness:  $\frac{1}{2}$  in. up.



### CAREYCEL FOR HEATING SYSTEMS

Uses: Pipe coverings and blocks for pipes, boilers, ovens and other apparatus where the temperature doesn't exceed 300 F. Use 1 inch thickness for temperatures up to 300 F.

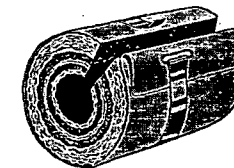
Description: Pipe covering sections 36 in. long by 1 in., 1 $\frac{1}{2}$  and 2 in. thick, finished with cotton duck jacket and bands. Blocks: 6 in. x 36 in. Sheets: 36 in. x 36 in., or cut to order. Thickness:  $\frac{1}{2}$  in. up.



### CAREY IMPERVO FOR COLD PIPES

Uses: A high efficiency insulation for cold or ice water pipes—keeps the water cold and prevents sweating. Double  $\frac{3}{4}$  inch thickness recommended for ice water pipes.

Description: Laminated insulating felt with waterproof liner and jacket. 36 in. long in  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in., double  $\frac{1}{2}$  in. and double  $\frac{3}{4}$  in. thick sections, finished with cotton duck jackets and bands.



### CAREY PROTECTO TO PREVENT FREEZING

Uses: Designed especially to reduce the danger of freezing of exposed water pipes.

Description: Consists of two inner layers of hair felt, a waterproof felt liner and an outer layer of insulating felt (wool felt). For severe conditions—exposure down to 0 F—use two-inch thickness. 36 in. long sections with cotton duck jacket and bands. Standard thickness—approximately 1 $\frac{1}{4}$  in.

## Owens-Corning Fiberglas Corporation

General Offices—Toledo 1, Ohio.

Pacific Coast Division, P.O. Box 89, Santa Clara, Cal.

OWENS-CORNING  
**FIBERGLAS**

### A COMPLETE LINE OF INDUSTRIAL INSULATIONS

#### Fiberglas Duct Insulations

Fiberglas Duct Insulations come in both rigid and flexible forms in six basic types. All deliver top insulating performance against heat and cold *plus* the additional advantage of sound control.

**Fiberglas Vapor-Seal Duct Insulation** is ideal for use on air conditioning ducts in warm and humid areas. Built-in vapor barrier of asphalt and kraft paper. Full range of thicknesses for specific temperatures.

**Fiberglas Flexible Duct Liner** is used as a sound absorber and thermal insula-

tion inside ducts. Available in two thicknesses with high NRC.

**Fiberglas Flexible Duct Insulation** can be used to provide thermal insulation on exterior of ducts of any shape.

**Faced Flexible Duct Insulation**, with facings of foils, duplex papers and reinforced laminate for vapor barrier or appearance purposes.

**Fiberglas Coated Duct Insulation** is a versatile product used for both inside and outside duct insulation.

**Fiberglas PF Duct Insulation** for covering rectangular ducts at minimum cost for efficient performance.

#### Fiberglas\* Pipe and Block Insulation

**Fiberglas PF (pre-formed) Pipe Insulation** available in all standard sizes for both low temperature and heated piping.

**Dual-Temperature Pipe Insulation** for use on cold piping or dual-temperature piping.

**Fiberglas Block Insulation and PF Insulating Boards** for small and large heated or cooled equipment.

**Aerowrap\* Pipe Insulation** for heated piping, cooled piping, steam traced lines, valves and fittings.

**Blanket-Type Pipe Insulation** for hot pipes up to 1000F, welded pipe and large pipe sizes.

**Low Pressure Pipe Insulation** for hot water and low pressure steam lines and for cold water pipe.

**Fiberglas PF Insulation**, a general-purpose insulation for heated or cooled equipment.

**Fiberglas TW-F Insulating Wool**, general-purpose insulation used for high-temperature equipment and industrial ovens.

**Metal Mesh Blankets** for breechings, tanks, ovens, and other high-temperature equipment for temperatures to 1000F.

#### Kaylo Pipe and Block Insulation

The low coefficient of conductivity, or "k," of Kaylo Heat Insulation, together with its long life at temperatures up to 1200F makes it ideal for high temperature insulation. Available in all standard sizes. Easily cut or fitted on the job. Made of hydrous calcium silicate by Owens-Illinois Glass Co. and distributed by Owens-Corning Fiberglas Corp.



For detailed information on Fiberglas Insulations look in the yellow pages for your local Fiberglas Distributor-Contractor or write Dept. 44, Owens-Corning Fiberglas Corporation, Toledo 1, Ohio.

\* FIBERGLAS (Reg. U.S. Pat. Off.) and AEROWRAP are trade-marks of Owens-Corning Fiberglas Corporation.



## SONOCO PRODUCTS COMPANY

Construction Products Division

Main Office and Plant, Hartsville, S. C.

LOS ANGELES, CALIF. PHILLIPSBURG, N. J. AKRON, IND.  
LONGVIEW, TEXAS BRANTFORD, ONTARIO SONOCO DE MEXICO, MEXICO, D.F.

### SONOAIRDUCT® FIBRE DUCT

for slab-floor, warm air perimeter heating systems



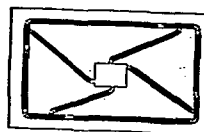
Made especially for gas and oil fired warm air, slab-floor perimeter heating systems where the duct is to be encased in dense aggregate concrete. Widely used and approved by engineers, architects and contractors. Saves time, labor and money without lowering the quality of construction.

Designed to comply with *FHA* minimum property requirements. It is lightweight and easy to handle. Available in lengths up to 50 ft long which can be sawed to exact lengths on the job. Fits all standard metal elbows, T's, registers, etc. Aluminum foil lined and wrapped with asphalt duplex kraft.

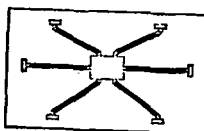
Also available is **SONOAIRDUCT-XP** fibre duct for crawl, basement and attic space, gas or oil fired warm air systems. Lined with aluminum foil and outer wrapped with 16-lb asbestos. Same sizes as regular SONOAIRDUCT.

#### SONOAIRDUCT SIZES AND WEIGHTS

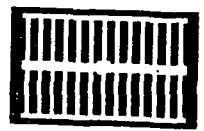
| Inside Diameter | Wall Thickness | Approx. Wt. Per M Feet | Approx. No. Ft in 40-ft Carload |
|-----------------|----------------|------------------------|---------------------------------|
| 2"              | 0.125"         | 267 lbs                | 60,000 ft                       |
| 3"              | 0.125"         | 322 lbs                | 39,000 ft                       |
| 4"              | 0.150"         | 616 lbs                | 22,400 ft                       |
| 5"              | 0.150"         | 766 lbs                | 14,700 ft                       |
| 6"              | 0.175"         | 1,058 lbs              | 10,300 ft                       |
| 7"              | 0.200"         | 1,399 lbs              | 8,000 ft                        |
| 8"              | 0.200"         | 1,592 lbs              | 6,500 ft                        |
| 9"              | 0.225"         | 2,003 lbs              | 5,000 ft                        |
| 10"             | 0.225"         | 2,220 lbs              | 4,400 ft                        |
| 11"             | 0.225"         | 2,438 lbs              | 3,600 ft                        |
| 12"             | 0.225"         | 2,654 lbs              | 3,000 ft                        |
| 14"             | 0.250"         | 3,212 lbs              | 2,160 ft                        |
| 16"             | 0.300"         | 4,660 lbs              | 1,512 ft                        |
| 18"             | 0.300"         | 5,232 lbs              | 1,080 ft                        |
| 20"             | 0.375"         | 7,223 lbs              | 1,080 ft                        |
| 22"             | 0.375"         | 7,931 lbs              | 720 ft                          |
| 24"             | 0.375"         | 8,641 lbs              | 684 ft                          |
| 26"             | 0.375"         | 9,349 lbs              | 576 ft                          |
| 28"             | 0.375"         | 10,058 lbs             | 576 ft                          |
| 30"             | 0.400"         | 11,472 lbs             | 432 ft                          |
| 32"             | 0.400"         | 12,227 lbs             | 324 ft                          |
| 34"             | 0.400"         | 12,982 lbs             | 288 ft                          |
| 36"             | 0.400"         | 14,075 lbs             | 288 ft                          |



For warm air perimeter loop systems.



For warm air perimeter radial systems.



For warm air perimeter lateral systems.

## American 3 Way-Luxfer Prism Co.

431 So. Dearborn St., Chicago 5, Ill.



Over 50 years' experience in all types of rooflighting and ventilation

**AMERICAN 3-WAY TOP-LIGHTS AND TOP-BRITES**  
Bring Free Daylight into Interiors... the Scientific Way to  
Transform Daylight into Pleasant, Uniform, Room Light

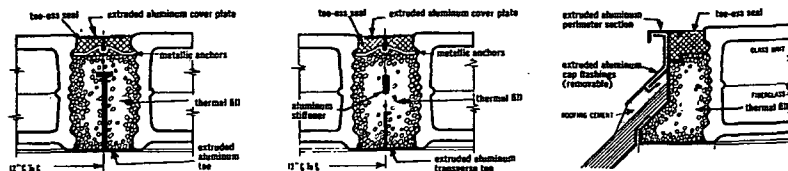
American 3 Way TOP-LIGHTS consist of uniquely designed glass blocks of prism structure which are assembled into special insulated grids to make up standard panel units of various sizes. These panel units are installed on the roof according to carefully developed specifications whereby one end of the panel is oriented northward within a rotation of 30 deg.

Daylight is automatically transformed as it passes through the specially designed glass prisms. The TOP-LIGHT serves as a sort of traffic director for the various types of daylight that fall on it. The extremely bright rays of sunlight are rejected\*... softer, more comfortable light is given unrestricted passage... and all light is diffused and directed downward in a wide flood of comfortable roomlight.

The diffusion and rejection eliminates traveling "bright spots" such as may appear under ordinary daylighting mediums when the sun travels from east to west.

The hollow semi-vacuum glass blocks substantially reduce solar heat transfer during the hot summer months assuring cooler and more comfortable conditions below than can be expected with ordinary skylighting methods. The blocks also greatly reduce any tendency for condensation on the room side.

The glass blocks are set in aluminum grids surrounded by an insulation fill properly treated, covered and sealed with Tee-Ess compound for protection and weatherproofing. The factory-assembled and sealed panel is designed to carry customary roof loads, yet is comparatively light in weight.



Cross section of joint between blocks viewed from north-south ends

Cross section of joint between blocks viewed from east-west ends

Cross section of grid perimeter showing the flashing

### MADE IN STANDARD SIZES

Whenever possible standard sizes should be ordered because they cost less and can be delivered quicker. Special sizes can be made to order at higher costs up to 22 square feet or up to 6 ft 2 in. in any one direction. Special size orders should specify direction of north and structural members.

### On the Job Directions

Each TOP-LIGHT has a large label on its upper surface which clearly shows: (1) direction of north, (2) direction of structural members, (3) code number. It also has directions for the general contractor and step by step instructions for the roofing contractor.

\* For areas such as stairwells, corridors, etc., where maximum light transmission is most important, TOP-BRITE glass blocks can be specified instead of TOP-LIGHT blocks.

|                              |                                                             |
|------------------------------|-------------------------------------------------------------|
| glass unit size              | 10 $\frac{3}{4}$ " x 10 $\frac{3}{4}$ " x 3 $\frac{3}{4}$ " |
| modular unit size            | 12" x 12"                                                   |
| approx. weight               | 16 lbs per sq ft                                            |
| live load                    | 40 lbs per sq ft                                            |
| maximum span (aluminum grid) | 6 ft                                                        |
| maximum area (prefabricated) | 22 sq ft                                                    |
| minimum slope for drainage   | 3 $\frac{1}{4}$ " per ft                                    |

**IT'S THE MODERN TREND** to flood interiors with the cheerful environment of natural, uniform daylight... automatically controlled by American 3 Way TOP-LIGHTS and TOP-BRITES.

## OWENS-ILLINOIS

GENERAL OFFICES • TOLEDO 1, OHIO

GLASS BLOCK AND TOPLITE PANELS

TWO ① PRODUCTS

**GLASS BLOCK PANELS.** Owens-Illinois Glass Block are hollow, hermetically sealed glass units containing a  $\frac{3}{4}$  vacuum. They are laid in mortar to form light-transmitting panels in vertical walls. Owens-Illinois Glass Block provide quality-controlled daylighting by glass areas which reduce heat loss, surface condensation and infiltration in cold weather and heat gain in warm weather.

**TOPLITE PANELS.** Owens-Illinois Toplite Panels are made of hollow, partially evacuated and hermetically sealed glass units, prefabricated at the factory into panels of insulated aluminum-grid construction. Used horizontally in roofs, Toplite Panels offer controlled daylighting with reduced heat loss, surface condensation and solar heat gain.

**THERMAL INSULATION.** The coefficients of heat transmission 'U' for panels of O-I Glass Block and Toplite are as follows:

| Size of Block                                 | U* (Btu/sq Ft/Hr/F Temp. Difference) |
|-----------------------------------------------|--------------------------------------|
| 5 $\frac{3}{4}$ " Sq                          | .60                                  |
| 7 $\frac{3}{4}$ " Sq                          | .56                                  |
| 11 $\frac{3}{4}$ " Sq                         | .48                                  |
| 11 $\frac{3}{4}$ " Sq with Glass Fiber Insert | .52                                  |
| 11 $\frac{3}{4}$ " Sq with Glass Fiber Insert | .44                                  |
| Toplite Panels                                | .58                                  |

**SURFACE CONDENSATION.** Because of the low over-all, air-to-air heat transfer, the exterior air temperatures which will produce condensation on panels of O-I Glass Block and Toplites are much lower than that for ordinary single glass. This permits higher humidities to be maintained where needed for winter air conditioning for comfort or for industrial processes.

**INFILTRATION.** Panels of glass block which are laid in mortar provide a barrier against infiltration. Dusts, drafts, and

air and vapor leakage are minimized. Natural ventilation requirements can be met by installing windows in glass block panels.

**SOLAR HEAT GAIN.** Complete instantaneous solar heat gain data for Owens-Illinois Glass Block designs for all exposures are given on Pages 305 through 307 of this GUIDE. The O-I design numbers which compare with the ASHAE type numbers are as follows:—

| ASHAE Type No. | O-I Block Design Nos.      |
|----------------|----------------------------|
| I              | 307, 316, 330, 331, 370    |
| II             | 340                        |
| III            | 340 with Fiberglass Insert |
| IVA            | 365                        |
| V              | 363                        |

A new O-I Block design, No. 80-F, is now available which has a much lower maximum solar heat gain than any of those shown in THE GUIDE. This reduction is due to the fact that this block reflects a high percentage of the solar energy which is incident on the exterior at the time of year when it reaches a maximum. Calculations of the solar heat gain through this block are now available. Confirming tests are being run. Solar heat gain through Toplite Panels is much less than that through single-glass or plastic skylights, due to the fact that Toplite Panels reflect a high percentage of the solar energy when the sun is at high altitude angles as in the spring and summer months.

**DESIGN AND SIZES.** Owens-Illinois Glass Block are made in a variety of face designs and in three standard sizes (5 $\frac{3}{4}$  in. sq, 7 $\frac{3}{4}$  in. sq, and 11 $\frac{3}{4}$  in. sq—all three are 3 $\frac{3}{4}$  in. thick). Mortar joints of  $\frac{1}{4}$  in. thickness are recommended.

Prefabricated Toplite Panels are available in four standard sizes (3 ft x 3 ft, 4 ft x 4 ft, 3 ft x 6 ft and 4 ft x 5 ft—all four are 3 $\frac{1}{2}$  in. thick). Complete technical data, description and details will be gladly sent. Write: Kimble Glass Company, subsidiary of Owens-Illinois, Department HV, P. O. Box 1035, Toledo 1, Ohio.

# PITTSBURGH CORNING CORPORATION

Dept. AW6, One Gateway Center, Pittsburgh 22, Pennsylvania



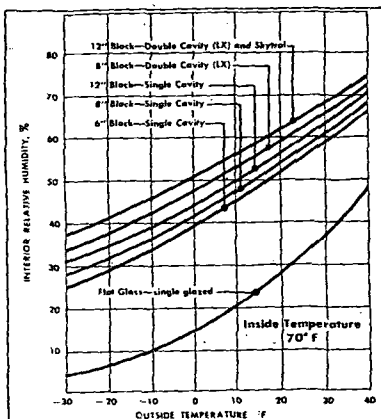
# PC GLASS BLOCKS

## THERMAL INSULATION

PC Glass Blocks allow economical use of large glass daylighting areas, reduce heat loss in cold weather and heat gain in warm weather because each PC Block contains a sealed-in dead-air space that is an effective retardant to heat transfer. See Section C, Table 20, Page 200 of this Guide.

## SURFACE CONDENSATION

Because of their high insulating value, condensation will not start forming on the room side of PC Glass Block panels until outside air has reached a temperature much lower than that necessary to produce condensation on single-glazed windows. The accompanying chart shows at what temperatures condensation will form. Note that LX, Suntrol and Skytrol blocks—in which a fibrous glass screen creates a double cavity—provide maximum insulation value.



Outdoor temperature required to produce condensation on the room side surface of PC Glass Block panels.

## SOLAR HEAT GAIN

The use of glass blocks for light-transmitting areas results in a marked reduction in solar heat gain as compared with ordinary windows. This factor is of considerable advantage in buildings that

are properly air-conditioned, but does not eliminate the need for adequate ventilation or shading in non-air-conditioned rooms. PC Suntrol blocks, with green diffusing screen, cut heat gain an additional 25 per cent.

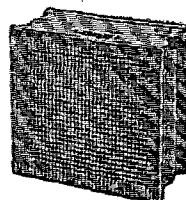
For data on solar heat gain through PC Glass Blocks, see Tables 19 through 23 in Chapter 13. Types listed are the following PC patterns:

Type I—Argus, Argus Parallel Flutes, Decora, Vue  
Type II—Bristol  
Type III—Bristol LX  
Type IV—Esses  
Type V—Prism A, Prism B

## PC GLASS BLOCKS AID AIR-CONDITIONING

The chief aims of air-conditioning—temperature control, humidity control and cleansing of air—are aided by the use of PC Glass Blocks. Heat loss is less in winter—heat gain is less in summer. Solar heat transmission and radiation are significantly reduced. Dirt, drafts and moisture cannot filter in, for each panel is a tightly sealed unit.

## PATTERNS SIZES INSTALLATION



PC Glass Blocks are made in three sizes: 6 in., 8 in., and 12 in. square. All are 3 3/4 in. thick. They are available in decorative and functional patterns—the latter designed for control of transmitted daylight and solar radiation. Usually they are laid up in panels with 1/4 in. mortar joints. Any mason can install PC Glass Blocks; no special tools are required. Insulated skylights that eliminate many of the problems of ordinary skylights can be constructed using PC Skytrol blocks. For complete details, write the above address. In Canada: 57 Bloor St. W., Toronto, Ontario.

# PITTSBURGH CORNING CORPORATION

Department S-6, One Gateway Center, Pittsburgh 22, Pa.



# FOAMGLAS®

the cellular, stay-dry insulation

## What FOAMGLAS is

FOAMGLAS is an entirely unique thermal insulation. Its light-weight, strong, rigid structure provides the combination of the two essentials for efficient, long-lasting insulating performance. FOAMGLAS is completely inorganic and has a closed cellular structure. It is made of glass, expanded about fifteen times into minute, non-connecting, hermetically sealed cells.

This sealed cellular structure makes FOAMGLAS water-proof and vapor-proof, preventing moisture absorption which impairs greatly the effectiveness of many insulations. Being inorganic, FOAMGLAS is fireproof, rot-proof and vermin-proof.

These inherent characteristics have enabled FOAMGLAS users to benefit from its long-lasting, constantly-high insulating performance. That is why FOAMGLAS is very rapidly gaining recognition as the ideal insulation for roofs, ceilings, walls, and floors of all kinds of buildings, as well as hot and cold piping, tanks and other equipment.

## How FOAMGLAS can benefit you:

| Properties               | Benefits                                                          |
|--------------------------|-------------------------------------------------------------------|
| Absorption               | 0                                                                 |
| Acid Resistance          | Impervious to common acids and acid fumes                         |
| Combustibility           | Incombustible                                                     |
| Compressive Strength     | 100 lbs/sq in.                                                    |
| Hygroscopicity           | No increase in weight in 240 days in air at 90% relative humidity |
| Density                  | 9 lbs/cu ft (ave.)                                                |
| Thermal Conductivity (k) | 0.38 Btu/hr/sq ft/°F/in.                                          |
| At 50° F                 |                                                                   |
|                          |                                                                   |



For Building Roofs, Ceilings, Walls and Floors. At Winston-Salem, FOAMGLAS' high strength permitted insulating parking deck-roof of Sears Roebuck's air conditioned store. In your building, moisture-proof FOAMGLAS insulation can help maintain air conditioning system efficiency.



For Ducts. Light-weight blocks of FOAMGLAS were easily applied to these metal air conditioning ducts at the Moses H. Cone Memorial Hospital, Greensboro, North Carolina.



For Piping. FOAMGLAS pipe insulation (available for up to 36 in. pipe size) was applied on this welded pipe carrying cold water for the system air conditioning Pittsburgh's new Gateway Center skyscrapers.

For full technical information, please write for our new catalogs indicating which of the above uses of FOAMGLAS you are most interested in. Address Dept. S-6, Pittsburgh Corning Corporation, One Gateway Center, Pittsburgh 22, Pa.

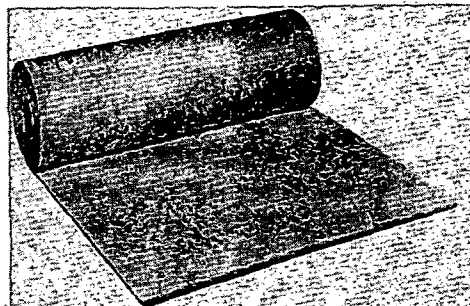


# Pittsburgh Plate Glass Company

FIBER GLASS DIVISION

One Gateway Center

Pittsburgh 22, Pennsylvania



Pittsburgh Superfine insulation is composed of extremely fine glass fibers, ranging upward in diameter from only 3/100,000 of an inch. It's an exceptionally lightweight, efficient thermal and acoustical insulating material. When specifications call for controlled heat or cold—or you need sound absorbed or vibration deadened—here are some of the advantages Pittsburgh Superfine Fiber Glass insulation provide:

**High Thermal Efficiency**—Thermal conductivity,  $k$ , at a mean temperature of 75 F is 0.22 to 0.27 Btu/sq ft/hr/deg F/in. thickness, depending on density. Effective for both high and low temperatures ranging up to 500 F.

**Fine Acoustical Properties** Noise reduction coefficient of a 1 in. thickness is as high as 0.80 with the sound absorption curve showing high efficiencies in the ranges of the most irritating noise.

**Light Weight, Easy to Handle**—Added load in any application is virtually negligible. Density as low as 0.6 pound per cubic foot. Readily cut with knife, shears, or die. Can easily be sewed and quilted, glued, tacked or taped into position.

**Flexible, Resilient, Tough, and Soft** Can be used on round or irregularly shaped objects and spaces as easily as in conventional layers. Fits closely into corners and tight spots quickly and easily, without damage to its structure.

**Saves Vital Space**—In use: Higher insulating efficiency means less thickness of Superfine required, as compared to ordinary insulation. In shipment: Packaged compressed to reduce shipping and storage space.

**STANDARD SPECIFICATIONS**—Pittsburgh Superfine is available in standard roll widths of 18 in., 24 in., 36 in., 48 in., 54 in. and 72 in. It can be supplied in any desired slit down to 2 in. Rolls are wound on 2 in. tubes and wrapped in heavy kraft paper. Superfine is also available in special lengths on request. It can be furnished vinyl coated, or with various paper, cloth or foil facings.

| Type              | Density (lbs per cu ft) | Thickness (inches) | Approx sq ft per lb | Typical Roll Lengths (feet) | Approx OD of Rolls (inches) |
|-------------------|-------------------------|--------------------|---------------------|-----------------------------|-----------------------------|
| S-314             | 0.6                     | 1/4                | 40                  | 100                         | 18                          |
|                   |                         | 1/2                | 20.7                | 100                         | 22                          |
|                   |                         | 3/4                | 13.3                | 100                         | 26                          |
|                   |                         | 1                  | 10                  | 100                         | 30                          |
|                   |                         | 2                  | 6.7                 | 100                         | 38                          |
| S-315             | 0.75                    | 1/4                | 64                  | 100                         | 10                          |
|                   |                         | 1/2                | 32                  | 100                         | 16                          |
|                   |                         | 3/4                | 21.3                | 100                         | 20                          |
|                   |                         | 1                  | 16                  | 100                         | 23                          |
|                   |                         | 1 1/4              | 10.7                | 100                         | 26                          |
| S-316             | 1.0                     | 1/4                | 8                   | 100                         | 28                          |
|                   |                         | 1/2                | 5.3                 | 50                          | 27                          |
|                   |                         | 3/4                | 4                   | 100                         | 10                          |
|                   |                         | 1                  | 3                   | 100                         | 14                          |
|                   |                         | 1 1/4              | 2.4                 | 100                         | 17                          |
| S-317             | 1.5                     | 1/4                | 16                  | 100                         | 17                          |
|                   |                         | 1/2                | 10.7                | 100                         | 20                          |
|                   |                         | 3/4                | 8                   | 100                         | 24                          |
|                   |                         | 1                  | 6                   | 100                         | 34                          |
|                   |                         | 1 1/4              | 5.3                 | 100                         | 39                          |
| S-318             | 2.0                     | 1/4                | 32                  | 100                         | 13                          |
|                   |                         | 1/2                | 16                  | 100                         | 18                          |
|                   |                         | 3/4                | 12                  | 100                         | 22                          |
|                   |                         | 1                  | 8                   | 100                         | 25                          |
|                   |                         | 1 1/4              | 6                   | 100                         | 31                          |
| S-319             | 3.0                     | 1/4                | 24                  | 100                         | 13                          |
|                   |                         | 1/2                | 12                  | 100                         | 23                          |
|                   |                         | 3/4                | 8                   | 100                         | 27                          |
|                   |                         | 1                  | 6                   | 100                         | 32                          |
|                   |                         | 1 1/4              | 4                   | 50                          | 29                          |
| S-105 (Air-craft) | 0.6                     | 1/4                | 16                  | 100                         | 16                          |
|                   |                         | 1/2                | 8                   | 100                         | 23                          |
|                   |                         | 3/4                | 5.3                 | 100                         | 28                          |
|                   |                         | 1                  | 4                   | 50                          | 26                          |
|                   |                         | 1 1/4              | 3                   | 40                          | 14                          |



Lancaster, Pennsylvania

DISTRICT OFFICES IN MAJOR CITIES

## Low Temperature Insulations

**Corkboard**—Moisture resistant, strong, durable, lightweight, easy to handle. Sizes: 36 in. long; 12 in., 18 in., 24 in., 36 in. wide; 1 in., 1 1/2 in., 2 in., 3 in., 4 in., 6 in. thick. K factor: 0.27.

**LT\* Cork Coverings**—low-cost, easy-to-apply insulations for lines operating at temperatures down to -30 F. Made of precision cut segments of corkboard, cemented to 3-ply vaporproof paper. Thickness: 3/8 in., 1 1/2 in., 2 in., 2 1/4 in.

**Armaflex\***—flexible plastic insulation for fast installation on copper tubing and other hard-to-insulate lines. For temperatures from 32 to 200 F. K factor: 0.28. Inside diameters: 3/8 in., 1/2 in., 1 1/2 in., 1 3/8 in.

**Armaglas\* PF Insulation**—all-purpose, easy-to-apply insulation for tanks, vessels and equipment. Size: 24 in. x 48 in. Densities from 3.5 to 9 lbs per cu ft.

**Armaglas AB Board**—a rigid glass fiber board for cold room walls, ceilings and partitions. Coated with asphalt. Size: 12 in. x 36 in. 6 lb and 9 lb densities.

## Heat Insulations

**Armtemp\***—strong, mineral wool insulation for tanks, ducts and other heated surfaces. In block form for temperatures up to 1900 F; in blankets for temperatures up to 1200 F.

**Armabestos\***—asbestos fibers formed into pipe covering and block. Pipe covering, A-7 for temperatures up to 750 F; A-12 for temperatures up to 1200 F. Block for use up to 1200 F.

**Armaglas Pipe Coverings**—a glass fiber insulation for temperatures up to 400 F. Plain or with aluminum foil vapor jacket. In 3 ft long sections for pipes up to 33 in. in size. Copper tubing sizes from 3/8 in. to 6 in.

**Armaglas WA Pipe Covering**—flexible, light-weight blankets for wrapping around lines operating up to 600 F. Furnished 3/4 in. thick and compressed to 1/2 in. in application.

**Armaglas Blanket Type Pipe Covering**—for irregularly shaped pipes operating up to 1000 F. 1 in., 1 1/2 in., 2 in., 3 in., 4 in. thick. Length: 2 in.

**Armaglas Low-Pressure Pipe Covering**—for cold water, hot water and low-pressure steam lines. Preformed of glass

fibers in 3 ft. molded half-sections. Fits pipe sizes up to 8 in. and copper tubing up to 3 in.

**Armaglas PF Insulation**—an all-purpose material for use on tanks and vessels operating up to 400 F. Comes in panels and boards; in 7 densities from 2.5 to 10.5 lbs per cu ft.

**Armaglas Insulating Wool**—comes in rolls, batts and shredded; for many industrial applications where temperatures go up to 1000 F. Thicknesses: 3/4 in. up to 3 1/4 in.

**Armaglas Metal Mesh Blankets**—for large, hard-to-insulate equipment. Made of glass fibers faced on one or both sides with wire mesh or metal lath. For temperatures to 1000 F. Sizes: 2 ft x 8 ft, 2 ft x 4 ft. Thicknesses from 1 in. to 6 in.

**Armaglas Block Insulation**—for boilers, breechings, tanks and other process equipment operating up to 400 F. 6 in. and 12 in. wide, 36 in. wide. 3/4 in., 1 in., 1 1/4 in., 2 in. thick.

## Duct Insulations

**Armaglas PF Duct Insulation**—low-cost insulation for exterior duct surfaces. Size: 24 in. x 48 in. Thicknesses: 1/2 in. and 1 in. For temperatures up to 400 F.

**Armaglas Coated Duct Insulation**—has a neoprene finish to provide good painting surface and prevent air erosion. Up to 250 F.

**Armaglas Vapor-Seal Duct Insulation**—both thermal insulation and sound absorber with built-in vapor barrier. For cool air ducts where condensation is a problem. 24 in. x 48 in. size; 3/4 in., 1 in., 1 1/2 in., 2 in. thicknesses. Up to 250 F.

**Armaglas Flexible Duct Insulation**—All-purpose insulating blanket and sound conditioning for fast application on hot or cold ducts of any size or shape. Up to 250 F.

**Armaglas Flexible Duct Liner**—Neoprene-coated and used as sound-absorbing insulation inside warm air or cooling ducts. 36 in. wide; 1/2 in. and 1 in. thicknesses. Up to 250 F.

## Armstrong Contract Service

This complete, nationwide service provides materials, engineers, supervisors, work crews, research and testing facilities. Your nearest Armstrong office will furnish prompt estimates, technical assistance and product information without obligation.



## The Celotex Corporation

General Offices  
120 South LaSalle Street, Chicago 3, Ill.

# CELOTEX

REG. U. S. PAT. OFF.

**Celotex Insulation Board Products** are made by felting long, tough cane fibers into strong, rigid boards. Manufactured under the exclusive Ferox\* Process. Ferox-treated Celotex board has been demonstrated by laboratory tests and years of use to be protected effectively against dry rot and termite attack. Integrally waterproofed.

**Celotex Insulating Sheathing**—For use in frame construction under wood siding, wood or asbestos shingles, stucco, or masonry veneer. *Double-Waterproofed*—integrally treated, then asphalt-coated on all surfaces. Exceeds government vapor permeability requirements.

Sizes: 4 ft wide x 8 and 9 ft long x  $2\frac{5}{32}$  in. or  $\frac{1}{2}$  in. with square edges. 2 ft x 8 ft x  $2\frac{5}{32}$  in. with V-type tongue and groove on long edges.

*Celotex 4 ft wide  $2\frac{5}{32}$  in. Sheathing, applied vertically without corner bracing, greatly exceeds racking strength requirements set forth in FHA Technical Circular No. 12 (racking strength at least equal to horizontally-applied wood sheathing with let-in bracing is minimum requirement).*

### Celotex Roof Insulation

**Regular**—Natural cane fiber board surface. Provides excellent bond for pitch or asphalt. Meets requirements for Roof Insulation Board (Class C) of Federal Specifications LLL-F-321b, Commercial Standard CS42-49 of U. S. Department of Commerce, and ASTM Specification C208. Sizes: 23 in. x 47 in., 24 in. x 48 in. Thicknesses:  $\frac{1}{2}$  in., 1 in.,  $1\frac{1}{2}$  in., 2 in.

**Preseal**—Coated with special asphalt on all surfaces and edges for additional moisture protection. Size: 24 in. x 48 in. Thicknesses:  $\frac{1}{2}$  in., 1 in.,  $1\frac{1}{2}$  in., 2 in.

**Channel-Seal**—Specially fabricated with  $1\frac{1}{16}$  in. x  $\frac{1}{16}$  in. bevel on underside of all edges to form interconnecting channels for equalizing air pressure between roofing and deck. Asphalt-coated all surfaces

and edges. Size 24 in. x 48 in., thicknesses 1 in.,  $1\frac{1}{2}$  in., and 2 in. Conductance, "C," of 0.33 Btu for nominal one inch thickness after coating.

**Flexcell\* Expansion Joint Filler**—Cane fiber felted into strong, resilient boards, then saturated with durable asphaltic compound. For expansion joint uses, perimeter insulation for concrete floors at grade, sill sealer, plate sealer, and vibration isolation. Thicknesses of  $\frac{1}{4}$  in. to 1 in. in various lengths and widths.

**Cemesto\* Structural Insulating Panels**—Completely fabricated panels for curtain walls, roof decks, partitions, air conditioning duct and roof machinery enclosures. Consist of cane fiber board core surfaced on both sides with layer of cement-asbestos board. Sizes: 4 ft wide x 6 ft to 12 ft lengths. Special sizes available. Thicknesses:  $1\frac{1}{16}$  in.,  $1\frac{1}{8}$  in.,  $1\frac{3}{8}$  in., 2 in.

**Celotex Spun Rock Wool Products**—Regular Blankets, full- or semi-thick, 15 in. x 96 in., 15 in. x 48 in., 15 in. x 24 in. Utility Blanket, 15 in. x 96 in. Reflective Blankets, standard thickness, 15 in. x 96 in. Also Loose, Granulated and Hand-Pouring Rock Wool.

**Q-T\* Ductliner**—Sound absorbing material designed for duct lining in air-conditioning systems. Made of rock wool and special binder. Withstands air duct humidity, is fire-resistant and will not support combustion. Thermal conductivity of 0.30.

**Celotex Sound-Conditioning Products**—Complete line of specialized acoustical materials to comply with every requirement, specification, or building code. Distributors in principal cities.

**Celotex Interior Finishes**—Tile Board, Finish Plank, Building board—triple-duty products that build, decorate, insulate. Variety of sizes and finishes.

\* Reg. U. S. Pat. Off.

For detailed information on all Celotex products, see Sweet's Files or write The Celotex Corporation

1666

## The Dow Chemical Company

Plastics Sales, Midland, Michigan



### STYROFOAM

**RIGID LOW TEMPERATURE BOARD INSULATION PROVIDES  
EXCEPTIONAL RESISTANCE TO WATER, ASSURES  
LONG SERVICE LIFE**

You'll find that Styrofoam® . . . Dow's rigid low temperature board insulation . . . is right for *your* job. Styrofoam combines *all* the factors you want: high thermal resistance, low original cost, long service life and a minimum of maintenance.

Commercial applications in many fields prove Styrofoam is an excellent rigid-type low insulation material. Its closed cellular structure provides exceptionally high resistance to water and water vapor. Styrofoam's low "K" factor (0.25 Btu/sq ft/hr/F/ inches at a mean temperature of 40°F) assures maximum thermal efficiency

Styrofoam is available in two grades: Styrofoam 22 (regular) and Styrofoam 33. (self-extinguishing). For more detailed information contact your nearest sales office. Atlanta • Boston • Buffalo • Chicago • Cincinnati • Cleveland • Detroit • Houston • Los Angeles • Minneapolis • New York • Philadelphia • St. Louis • San Francisco • Seattle.

### STYROFOAM GIVES YOU ALL THESE ADVANTAGES FOR:

Pipe Covering • Insulated Vehicles • Refrigeration Equipment • Low Temperature Rooms • Perimeter Insulation

- High Thermal Resistance
- Water Resistance, freedom from capillarity
- Long Insulation Life
- Low Cost Installation, Maintenance, Operation
- Odorless
- Resistant to Rot and Mold
- Light Weight
- Easy to Fabricate
- Sizes for any job

Thicknesses: 1,  $1\frac{1}{2}$ , 2,  $2\frac{1}{2}$ , 3, 4, 5 in.—Widths: 10 in. and 12 in.—Lengths: 36 in. and 9 ft.

1667

INSULITE DIVISION • Minnesota  
General Office: 500 Investors Bldg.,



and Ontario Paper Company  
Minneapolis 2, Minnesota

## INSULITE®

### STRUCTURAL INSULATION BOARD

For 42 years engineers and architects have specified Insulite materials for architectural uses, interior finish, and for other thermal insulation and sound control uses. Insulite materials have proved their merit through actual performance on the job.

#### STRUCTURAL MATERIALS

**Condensation Control**—To prevent condensation within walls, authorities recommend "sealing the warm side and venting the cold side" of the wall. Insulite Insulating Wool Batts or Blankets provide the necessary vapor barrier on the warm side of the wall, thereby reducing the flow of vapor into inner wall areas. On the cold side of the wall, vapor-permeable Bildrite Sheathing allows surplus vapor to escape toward the outside.

**Bildrite® Sheathing**—A tough, durable, insulating sheathing material made from new wood fibers. Protected throughout by an integral asphalt treatment. Bildrite (4 ft width) has more than twice the bracing strength of horizontal wood sheathing.  $\frac{23}{32}$ -in. thick. Sizes: 2 x 8 ft (V-joint on long edges) . . . 4 x 8 ft to 4 x 12 ft (square edges). Thermal conductivity: 0.37 Btu per inch thickness. Also available is  $\frac{1}{2}$ -in. Graylite Sheathing.



Applying Bildrite Sheathing

#### SHINGLE-BACKER

Shingle-Backer is a fast-applying, insulating undercourse material for double-coursed, shingled walls. Made from  $\frac{5}{16}$ -in. insulation board, waterproofed throughout with asphalt.

There are two Shingle-Backer Systems. For wood-shingled sidewalls, Shingle-Backer panels take the place of low-grade wood undercourse shingles. Makes faster,

easier, better-looking shingled walls at low cost. Two widths: 13 $\frac{1}{2}$  in. for 12-in. shingle exposure, 15 $\frac{1}{2}$  in. for 14-in. shingle exposure. Four ft long.



Applying shingles and Shingle-Backer

A different Shingle-Backer System is used for asbestos-cement siding shingles. 11 $\frac{3}{4}$ -in. Shingle-Backer is used to give modern shadow-lines. Also protects against breakage, helps sound condition house.

Both systems give added insulation, greater structural strength and weather resistance. No building paper is required. Can be applied over Bildrite and Graylite® Sheathing.

#### ROOF INSULATION

Insulite Roof Insulation is fabricated from either Ins-Lite or Graylite insulation board. The  $\frac{1}{2}$ -in. thickness has square edges. The 1, 1 $\frac{1}{2}$ , and 2-in. thicknesses are multiple layers stapled or cemented together. Available with either square or offset edges. Size: 24 in. x 48 in.

#### INSULATING WOOL

Insulite Insulating Wool is made from famous "Fiberglast," consisting of millions of long glass fibers bonded together with a thermo-setting resin. Available in the following forms: roll blankets, batt blankets, utility batts, plain batts and pouring wool.

**Perimeter Insulation**—Fiberglass Perimeter Insulation guards against heat loss in basementless houses. Meets F.H.A. and specific job requirements. Type AE-6 (asphalt enclosed), Type PF-615 (paper faced) and Type PF-619 (paper faced, load bearing).

#### INDUSTRIAL INSULATION

Choose from Six Types

(1) **Low Density Ins-Lite®**—a low density board with high insulating efficiency and maximum sound absorption. Density 10.0 to 12.5 lbs/cu ft.

(2) **Medium Density Ins-Lite**—an insulating board which provides efficient insulation and structural strength. Density 12.5 to 15.0 lb/cu ft.

(3) **High Density Ins-Lite**—designed to be used where insulation and structural strength are required. Density 15.0 to 17.5 lbs/cu ft.

(4) **Low Density Graylite**—a highly efficient insulating board, integrally treated with asphalt for increased strength and resistance to water absorption. Density 13.5 to 16 lbs/cu ft.

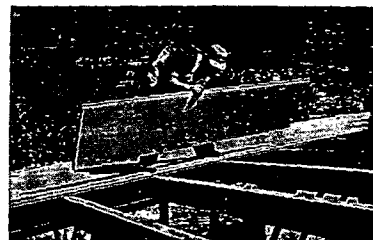
(5) **Medium Density Graylite**—an insulating material integrally treated with asphalt. Has high strength and resistance to water absorption. Density 16.0 to 18.5 lbs/cu ft.

(6) **High Density Graylite**—an insulating material with maximum strength and resistance to water absorption. Density 18.5 to 21 lbs/cu ft.

#### INTERIOR FINISHES

**Roof Deck**—A 3-in-1 fiber board product for roofs that serves as decking, insulation and finished ceiling. Ceiling side has white, textured, flame-resistant surface. Available with or without vapor barrier. Size: 2 x 8 ft panels 1 $\frac{1}{2}$  in., 2 in. and 3 in. thicknesses.

**Graylite Building Board**—A durable board, integrally treated with asphalt for maximum strength and moisture resistance. Thermal conductivity is 0.37



Applying Insulite Roof Deck

\* Reg. U. S. Pat. Off.

Btu per in. thick. Sizes: 4 x 8 ft to 4 x 12 ft. Thicknesses:  $\frac{1}{2}$ ,  $\frac{3}{4}$ , and 1 in.

**Primed Graylite Building Board**—Graylite Building Board with a prime coating for easy painting. Sizes: 4 x 8 ft to 4 x 12 ft. Thicknesses  $\frac{1}{2}$  and  $\frac{3}{4}$  in.

**Smoothlite® Interior Board**—A natural-colored, factory-coated board, gloss finish. 67 per cent light reflection. Sizes: 4 x 6 ft to 4 x 12 ft. Thicknesses:  $\frac{3}{8}$  and  $\frac{1}{2}$  in.

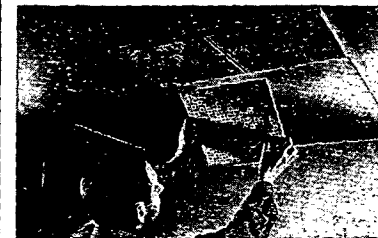
**Wevelite® Interior Board**—A practical, low-cost interior board with flame-resistant finish in white. Sizes: 4 x 6 ft to 4 x 12 ft. Thickness  $\frac{1}{2}$  in.

**Durolite® Tileboard**—A textured flame-resistant finished board, in white and light ivory colors. Has flanged tongue-and-groove joint. Thickness:  $\frac{1}{2}$  in. Sizes: 12 x 12 in. to 16 x 32 in.

**Durolite Plank**—Flanged tongue-and-groove joints. Textured, flame-resistant surface finish:  $\frac{1}{2}$  in. thickness. Colors: ivory, pale green, sunlite yellow, and woodtone. Sizes: 8, 12, and 16 in. wide; and 8 and 12 ft long.

**Fiberlite® Acoustical Tileboard**—A low-cost, highly efficient acoustical tile, has effective flame-resistant white finish. Sizes: 12 x 12 in. to 12 x 24 in. Thicknesses:  $\frac{1}{2}$  and  $\frac{3}{4}$  in.

**Acoustilite® Perforated Tileboard**—A rugged, sound-absorbing tileboard for residential and commercial interiors. Standard tile units contain 484 cleanly-drilled holes.  $\frac{1}{2}$  or  $\frac{3}{4}$  in. thickness. Also random drilled Acoustilite Tileboard in  $\frac{1}{2}$  or  $\frac{3}{4}$  in. thickness. White finish has high light reflection. Has effective flame resistant finish. Size: 12 x 12 in.



Applying Random Acoustilite

#### HARDBOARD PRODUCTS

Insulite HardBoard is a rigid, durable, wood-fiber material with tremendous strength. Available in a range of densities from 55 to 68 lb per cu ft. Thicknesses from  $\frac{1}{8}$  to  $\frac{3}{4}$  in. Sizes from 3 x 4 ft to 4 x 16 ft.

† Reg. U. S. Pat. Off.—Made by Owens-Corning Fiberglas Corp.



## Johns-Manville

Executive Offices: 22 East 40th Street, New York 16, N. Y.  
Offices in All Large Cities

### Home Insulation



Applying Spintex batts in new home

#### For Existing Homes and Buildings: J-M Spintex "Blown" Home Insulation

J-M Spintex Home Insulation is nodulated mineral wool which is blown pneumatically into the spaces between studs in outer walls and between roof rafters or attic floor joists. Insulation thickness in walls corresponds to stud depth, approximately  $3\frac{3}{8}$  in. The uniform fill assures maximum thermal efficiency. This type of insulation is sold and installed only by carefully selected experienced and officially franchised J-M Blown Home Insulation Contractors.

For complete information on J-M Spintex "Blown" Home Insulation and its application, write the address above or call your local Johns-Manville office.

#### Airacoustic® Sheets for lining Air-Conditioning Ducts

J-M Airacoustic Sheets provide a fire-safe, sound-absorbing material developed for use in ventilating ducts. Since they absorb a large percentage of the sound that strikes them, they provide a highly effective means of reducing

undesirable duct noises. Composed of rock wool and a suitable binder, Airacoustic Sheets are available in size 24 in. x 36 in., and in thicknesses of  $\frac{1}{2}$  in. and 1 in.

#### Spintex® Duct Insulations

Spintex Duct Insulations are incombustible... provide high insulating efficiency and long service life. Their low installed cost is the result of Johns-Manville's long experience in developing scientifically correct insulations and

proper methods of application. They are furnished as blankets and semi-rigid boards. The densities range from 2 to over 6 lb per cu ft, providing flexible and stiff materials for round or rectangular ducts.

#### For New Construction: Spintex® Batts and Blankets

Johns-Manville Spintex Batts and Blankets are made of spun rock wool. Instead of short, coarse fibers, this J-M spinning process produces long, fine fibers which make better, more firmly felted batts and blankets that are stronger, lighter in weight, more resilient, and have greater uniformity throughout. They are rotproof, fireproof, and assure the homeowner of maximum year-round comfort, protection and winter fuel savings.

SPINTEX BATTS are strong and sturdy. They will not break down under rough handling but hold their factory-made shape and uniform thickness... will not crumble or fray when cut to fit irregular spaces. Each batt has a vapor seal backing to protect against the passage of abnormal humidity and a tacking flange for ease of installation.

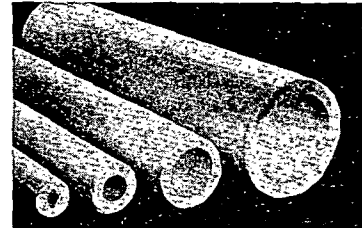
Spintex Batts are furnished Full-Thick and Semi-Thick. Full-Thick Batts have an average thickness of  $3\frac{1}{4}$  in.; Semi-Thick, an average thickness of 2 in. Both types are available in sizes 15 x 24, 15 x 48, 19 x 24, 19 x 48, 23 x 24 and 23 x 48 inches.

SPINTEX BLANKETS, made of the same firmly-felted long fiber spun rock wool, are fully enclosed in a permeable wrapping with an approved vapor seal backing and a tacking flange.

Thick Blankets, approximately 3 in. in thickness, are furnished in sizes 15 in. x 48 in. and 23 in. x 48 in.; Medium Blankets, approximately 2 in. thick, in sizes 15 in. x 64 ft, 23 in. x 64 ft, 15 in. x 8 ft and 23 in. x 8 ft; and Service Blankets, approximately  $1\frac{1}{2}$  in. thick, in sizes 15 in. x 8 ft and 23 in. x 8 ft.

### Pipe and Boiler Insulations

#### J-M FIBROCEL®



J-M Fibrocel Pipe Insulation is a molded silica insulation developed by Johns-Manville for use on hot, cold and chilled water lines, low pressure steam pipes, and dual service heating and cooling systems. It can't shrink or expand which means no more gaping, unsightly joints with accompanying heat leakage. Its firm, hard texture resists deformation and its combination of thermal properties and recommended wall thicknesses in the services for which it is designed provide maximum economical insulation effectiveness. Fibrocel resists decay, fire and vermin. Lightweight, precision-formed for exact fit, and easy to cut and work on the job, it speeds application and keeps costs at a minimum.

Fibrocel is furnished in three jacket styles: Fibrocel C with standard or special weight canvas jacket for steam, hot or cold water service from 60F to 300F; Fibrocel G with glazed white plastic-coated paper jacket for steam, hot or cold water service from 60F to 300F; and Fibrocel VB with vapor barrier jacket, recommended for use on pipes subject to sweating and particularly adapted for dual service heating and cooling systems between 35F and 225F.

#### PRE-SHRUNK ASBESTOCEL®

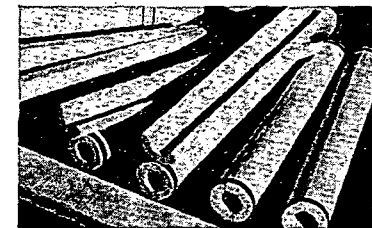
Cellular type insulation made up of alternate layers of plain and corrugated asbestos felts for use on pipes conveying low pressure steam and hot water. Three finishes: Glazed White, Asbestos Paper and Canvas. Furnished in 3-ft sections to fit standard pipe sizes\* and in standard thicknesses of 2 to 8 plies, each ply approx.  $\frac{1}{4}$  in. thick. Temp. limit, 300F.

#### ASBESTOCEL® SHEETS AND BLOCKS

For insulating medium and low pressure boilers, feed water heaters, warm air ducts, etc. Furnished 6 to 36 in. wide, 36 to 96 in. long, from  $\frac{1}{2}$  to 4 in. thick.

\* Also available to fit straight runs of copper tubing with nominal diameters of  $\frac{3}{8}$  in. and up.

#### J-M 85% MAGNESIA



The high insulating value and permanence of J-M 85% Magnesia Block and Pipe Insulation have been proved over many decades of satisfactory, trouble-free service. Blocks are furnished 18 and 36 in. long; 3 and 6 in. wide (flat or curved), 1 through 4 in. thick; 9 and 12 in. wide (flat only),  $1\frac{1}{2}$  through 4 in. thick. Pipe insulation is furnished in 3-ft lengths in sectional or segmental form for all standard pipe sizes, in nominal thicknesses up to 3 in.\* Temp. limit 600F.

#### SUPEREX® COMBINATION

Superex Combination Insulation (an inner layer of J-M Superex, a material with high heat resistance, and outer layer of J-M 85% Magnesia, a material with great insulating value) is recommended for temperatures from 600F to 1900F. Both Superex and 85% Magnesia are available in sectional and segmental pipe covering and in block form.

#### ROCK CORK®

Rock Cork is made of mineral wool and an asphaltic binder molded into sheets and pipe insulation for all low temperature service. It is strong, durable, and will not support vermin. Because of its unusual moisture-resistance, its high insulating value is maintained in service.

Furnished in sheets 18 in. by 36 in., (18 in. by 18 in. available in 1 in. thickness only), in 1,  $1\frac{1}{2}$ , 2, 3 and 4 in. thicknesses. Lagging, for curved surfaces, supplied 18 in. long by  $1\frac{1}{2}$  through 4 in. thick, 2 to 6 in. wide, depending on diameter. Pipe covering furnished in Ice Water, Brine, and Heavy Brine thicknesses, for all commercial pipe sizes.\* Discs also available to a 36 in. max. diameter.

#### DETAILS ON REQUEST

For further information about J-M Insulations and J-M Application Service, write Johns-Manville, 22 East 40th St., New York 16, N. Y.

## Kimberly-Clark Corporation

Neenah, Wisconsin

**KIMSUL** A PRODUCT OF  
Kimberly-Clark

**INSULATION** 

NEW YORK 17, N. Y., 250 PARK AVENUE  
ATLANTA 3, GEORGIA, 900 PEACHTREE ST., N. E.  
CHICAGO 3, ILLINOIS, 8 S. MICHIGAN AVENUE  
SAN FRANCISCO 4, CALIF., 155 SANSOME STREET

### Reflective and Pyrogard



**KIMSUL\*** is unique among building insulations and acoustical materials because it is made of many individual plies—each one a continuous separate layer of soft, clean, creped, asphalt-treated cellulose fibers. Each ply is controlled carefully in manufacture both as to thickness and crepe structure. The result is

a flexible blanket, inherently uniform in thickness—an important factor in a thermal or sound insulating material. The Kimsul plies and cover of the creped Pyrogard\* or creped Reflective Vaporseal are held together with rows of strong stitching that prevent sifting and settling. No heat-leaking thin spots, no money-wasting thick spots in the Kimsul blanket. Reduced to  $\frac{1}{2}$  its installed volume for easier shipment, handling and storage, the Kimsul blanket is expanded in installation. The stitching controls expansion to the density of a high degree of efficiency.

**KIMSUL IS NOW MADE IN THREE TYPES—KIMSUL 48 SHEATHING BLANKET—PYROGARD KIMSUL REFLECTIVE KIMSUL.**

**Kimsul 48—Sheathing Blanket** is Reflective Kimsul Insulation manufactured by the Kimberly-Clark Corporation to a width of over 48 inches, pre-cut to eight foot lengths which makes it possible to build a more heat-tight, air-tight and vapor-tight dwelling wall at lower cost than ever before.

**Kimsul "48" Sheathing Blanket** retains the recognized insulating qualities of chemically treated wood fibres arranged in multi-ply layers of air cells that are well known in Kimsul insulation material. It is a recognized fact that this construction of an insulating material produces outstanding results.

**Sheathing Blanket's** wood fibre construction, extremely tough, three-ply, heat reflective, vapor sealing cover give the American home building industry a material which minimizes the problems of vapor and heat transmission which have always been most difficult to solve economically.

#### SOME FEATURES OF KIMSUL 48 SHEATHING BLANKET



Positive insulation in close framing areas. No heat loss or cold air leaks in areas that couldn't be sealed before Kimsul "48".



Positive insulation around electrical receptacles and behind conduit. Repairs and replacements of these items do not damage the insulating material.



Complete insulation between the cold exterior wall and metal ductwork. Minimizes heating expense... gives greater comfort.

\* T. M. Reg. U. S. Pat. Off.



Positive seal of exposed sub-floor ends. Eliminates cold drafts and heat losses.

### Pyrogard and Reflected KIMSUL\*

Kimsul is also available for all conventional ceiling, wall, and floor construction in Pyrogard and Reflective types. . . The differences in the two types are: Reflective Kimsul has a cover of aluminum foil that acts both as a vapor barrier to shut out condensation, and as a highly efficient reflective surface to turn back radiant heat. Reflective Kimsul has strong reflective tacking flanges for easy, secure attachment to framing. For heat flow downward, Reflective Kimsul provides additional insulating value. Pyrogard Kimsul has the fire-resistant cover.

**Fire-Resistant**—Special permanent chemical treatment makes Kimsul resist fire. **Pyrogard\* Fire-Resistant Cover**—(safety feature of Pyrogard Kimsul) resists flame-spread.

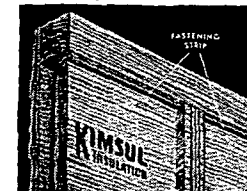
**Creped Aluminum Foil Cover**—(a feature of Reflective Kimsul) reflects heat, shuts out condensation.

**Moisture-Resistant**—asphalt treatment of each ply sheds water.

**Resists Mold, Rot, Vermin**—The materials of which Kimsul are made offer no subsistence to vermin or insects. Special chemical treatment resists mold and fungus.

**"k" Factor**—0.27 Btu/sq ft/hr/F.

**Air Space**—is a prime requisite. Use a vapor-permeable building paper under exterior finish. Ventilation in attics and floors should never be omitted. Use approximately one sq ft of louver area for 1000 sq ft of ceiling area.



Reflective KIMSUL insulated. Edge of fastening flange folded over face of framing completes the vapor seal.

#### RESISTANCE FACTORS AND PRODUCT SPECIFICATIONS

| RESISTANCE VALUES (1)            |                  |                      |              |                |                |                                             |           |                                    |                                         | PRODUCT SPECIFICATIONS |  |
|----------------------------------|------------------|----------------------|--------------|----------------|----------------|---------------------------------------------|-----------|------------------------------------|-----------------------------------------|------------------------|--|
| TYPE                             | GRADE            | WALL                 | CEILING      |                | FLOOR          | APPROX. SQ FT PER ROLL STANDARD ROLL WIDTHS |           | APPROX. NET WEIGHT PER 1,000 SQ FT | APPROX. SHIPPING WEIGHT PER 1,000 SQ FT |                        |  |
|                                  |                  | Heat Flow Horizontal | Heat Flow Up | Heat Flow Down | Heat Flow Down | 16, 20, 24 inch                             | 48 inches |                                    |                                         |                        |  |
|                                  |                  |                      |              |                |                |                                             |           |                                    |                                         |                        |  |
| Pyrogard Kimsul (Red Package)    | Commercial Thick | 1.85                 | 1.85         | 1.85           | 1.85           | 200 Sq Ft                                   | 500 Sq Ft | 68 Lbs                             | 75 Lbs                                  |                        |  |
|                                  | Standard Thick   | 3.70                 | 3.70         | 3.70           | 3.70           | 200                                         | 500       | 120                                | 126                                     |                        |  |
|                                  | Double Thick     | 7.40                 | 7.40         | 7.40           | 7.40           | 100                                         | 250       | 225                                | 236                                     |                        |  |
| Reflective Kimsul (Grey Package) | Medium Thick     | 5.07                 | 4.63         | 6.87           | 6.94           | 200                                         | 500       | 134                                | 140                                     |                        |  |
|                                  | Double Thick     | 7.80                 | 7.40         | 9.64           | 9.70           | 100                                         | 250       | 195                                | 205                                     |                        |  |

#### APPROX SQ FT PER ROLL OR CARTON ("48")

| Kimsul "48" | Grade | Approx Sq Ft Per Roll or Carton ("48") | Approx Shipping Weight Per Roll or Carton ("48") |
|-------------|-------|----------------------------------------|--------------------------------------------------|
| "48" A      | 3.28  | 640 Sq Ft                              | 75 Lbs                                           |
| "48" B      | 3.28  | 832                                    | 97                                               |
| "48" C      | 3.38  | 1024                                   | 120                                              |

#### SOUND DEADENING AND ABSORPTION

Kimsul is effective both in deadening sound and absorbing it. It will absorb sound originated by diaphragmatic action, and sound leaks, as well as cushioning furring strip type construction. Kimsul prevents bridging or short circuiting of sound-resisting construction during erection. The average coefficients of sound absorption of Kimsul are:

Double Thick 75%  
Standard Thick 55%  
Commercial Thick 40%

Kimsul should be spaced from one to six inches from reflecting surface, with cover side away from sound source to obtain greater absorption at lower frequencies.

#### CONSTRUCTION DETAILS AND HEAT FLOW (U) FACTORS

| KIMSUL GRADE                | HEAT FLOW HORIZONTAL |    | HEAT FLOW UP |    | HEAT FLOW DOWN |    | HEAT FLOW DOWN |    |
|-----------------------------|----------------------|----|--------------|----|----------------|----|----------------|----|
|                             | "U"                  | %  | "U"          | %  | "U"            | %  | "U"            | %  |
| Uninsulated                 | .25                  | —  | .69          | —  | .48            | —  | .28            | —  |
| Pyrogard Commercial Thick   | .15                  | 40 | .25          | 64 | .20            | 58 | .16            | 43 |
| Kimsul 48 Sheathing Blanket | .14                  | 43 | —            | —  | —              | —  | —              | —  |
| Pyrogard Standard Thick     | .12                  | 52 | .17          | 75 | .15            | 69 | .12            | 57 |
| Pyrogard Double Thick       | .08                  | 68 | .10          | 85 | .09            | 81 | .08            | 71 |
| Reflective Medium Thick     | .10                  | 60 | .15          | 78 | .10            | 79 | .09            | 68 |
| Reflective Double Thick     | .08                  | 68 | .10          | 85 | .08            | 83 | .07            | 75 |

\* "K" Factor (KIMSUL plies) 0.27\* authority of J. C. Peebles, Armour Institute. (Does not include value of reflective cover). \* Factors expressed in Btu/hr/sq ft/°F; k, per inch of thickness; "U", per assembled section of construction. Calculation based on FHA Technical Circular No. 7, dated Jan. 1949. % = % of uninsulated heat flow stopped in the insulated construction. Resistance of Kimsul 48 is 3.28 authority F. B. Rowley, University of Minnesota. (Includes value of reflective cover w/o air space.)

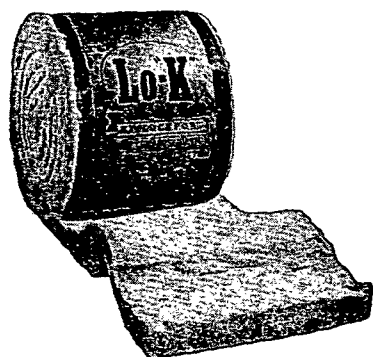
\* T. M. Reg. U. S. Pat. Off.

## Lockport Mills, Inc.

Thermal and Acoustical  
INSULATION

Dept. C.

Lockport, N. Y.



**Moisture-Resistant**—Chemical treatment, combined with natural protective coating on cotton fibres, enables cotton to effectively resist moisture. Prevents rot and mildew.

**Smooth Texture**—No sharp particles to irritate the skin.

**Flexible**—Cotton batt may be expanded or contracted to fit any enclosure.

**Easy to Warehouse and Handle.** Offers far more "compressibility." Requires one-third the trucking and warehouse space of ordinary insulation.

**Simple and Economical to Install.** Saves from 25 to 40 per cent in costs.

**Designed to Maintain Maximum Utility.** Resists all types of deterioration. Won't sag or settle. Packaged in Rolled Form.

**Thicknesses**—inches: 1, 1½, 2, 3, 3½. **Width**—16, 20, 24 in. centers. **Lengths**: Standard from 12 ft up.

INSULATING VALUE OF VARIOUS INSULATORS<sup>a</sup>

The coefficients of conductivity (k value) are expressed in Btu per hour per square foot per degree Fahrenheit per 1 in. of thickness.

| Type of Insulation                                    | Wgt. per Cu Ft | k <sup>b</sup> Value |
|-------------------------------------------------------|----------------|----------------------|
| Cotton: Insulating Batt                               | .875           | 0.24                 |
| Rock Wool: Fibrous material made from rock            | 10.00          | 0.27                 |
| Mineral Wool: Fibrous material made from mineral slag | .....          | 0.27                 |
| Glass Wool: Fibrous material made from glass slag     | 1.50           | 0.27                 |
| Rigid Insulation made from sugar cane fibre           | 13.50          | 0.33                 |
| Chemically treated wood fibre between layers of paper | 3.62           | 0.25                 |
| Pei grass between layers of paper                     | 3.40           | 0.25                 |
| Stitched and creped expanding fibrous blanket         | 1.50           | 0.27                 |
| Shavings: Various from planer                         | 8.80           | 0.41                 |
| Corkboard: No binder added                            | 7.00           | 0.27                 |
| Rigid insulation made from wood fibre                 | 15.90          | 0.33                 |

<sup>a</sup> Compiled from Chapter 9, 1954 Edition.

<sup>b</sup> "k" indicates temperature conductivity.

**Thermal Conductivity**—The "k" value for cotton is 0.24 Btu/hr/sq ft/degree F/inch. (See table.)

**Light Weight**—Weight of 1 cu ft is 7½ lb. (See table.)

**Flame-Proofed**—Withstands 1800° blow torch heat.

- 1674

## The Pacific Lumber Company

100 Bush Street, San Francisco 4, Calif.



IDEAL FILL INSULATION

FOR REFRIGERATION OR

AIR CONDITIONED STRUCTURES

## REFRIGERATION REQUIREMENTS COMPLETELY FULFILLED BY VOID-FREE PALCO WOOL

Extremely low thermal conductivity over a wide range of mean temperatures is due to low conductance through the material itself, void-free application providing full insulation without pockets or joints, and virtual elimination of convection current losses. Initial and operating economy result from low material cost, simple structural requirements, ease of installation, efficiency minimizing refrigerating equipment requirements, and permanent effectiveness proved through exhaustive in-place field tests. Fire retardant by nature, *Palco Wool* is further protected by the unique *Saferized* process. Odorless, repellent to rodents and insects, and moisture resistant, *Palco Wool* is ideal for freezers, coolers, controlled atmospheres.

## AIR CONDITIONING EFFICIENCY INCREASED BY PALCO WOOL IN HOME OR COMMERCIAL USE

Maximum performance of home or commercial air conditioning and heating equipment is assured by *Palco Wool's* unique combination of qualities. It is recognized to have one of the highest efficiency ratings of all insulations. Permanent resilience guards against settlement, providing full insulating effectiveness for the life of the building. Not only is natural fire retardance increased by the unique *Saferized* process, but *Palco Wool* also resists breakdown or melting under high temperatures. Free from odors, non-irritating, moisture resistant, repellent to rodents and insects, *Palco Wool* has proved its effectiveness for public or private building insulation. Low cost, ease of installation, and light weight recommend it from the standpoint of architects, designers, applicators and users.

## WRITE FOR THESE HELPFUL BOOKLETS AVAILABLE ON REQUEST

## NEW REFRIGERATION INSULATION MANUAL

Handy illustrated reference manual covering details of design and construction for freezers, coolers, and controlled atmospheres. Vapor proofing, void-free application of *Palco Wool* Insulation, U values of various types and thicknesses of insulated walls and ceilings, and other valuable data are presented in easy-to-follow drawings, photographs, charts and text, compiled by experienced refrigeration engineers.



## FACTS ABOUT HOME INSULATION

Attractive new booklet outlining the economic and comfort advantages of proper home insulation, showing where, how and when to insulate. Written in layman's language to help air conditioning and insulation merchandisers present a sound effective sales story.

**OTHER TECHNICAL DATA AVAILABLE**—*In-Place Tests*, design data developed through refrigerated wall tests. *Engineering Reports*, on-the-job findings covering operation over periods of several years. *Samples of Palco Wool Insulation*.

1675

**Tectum Division** • Peoples Research and Manufacturing Company  
General Offices: 105 South Sixth Street, Newark, Ohio

**Tectum**®

**SIDEWALL INSULATION**

**Sales Offices:**

ATLANTA, GEORGIA—333 Candler Building

CHICAGO 4, ILLINOIS—855 Board of Trades Building

COLUMBUS 15, OHIO—3560 Le Veque-Lincoln Tower

PHILADELPHIA 3, PA.—Suite 2713-2719 Lewis Tower

Tectum is composed of fine grade select wood fibers and a chemically-stable, inorganic, water-insoluble hydraulic cement binder. Widely used in commercial and industrial buildings, Tectum's benefits are so numerous that it practically obsoletes other type materials of comparable cost.

- It's insulating
- It's structural
- It's acoustical
- It's non-combustible
- It's good-looking
- It's light weight
- It's easily worked
- It's fungus, termite and rot-resistant
- It's dimensionally stable

Tectum gives you everything you want in sidewall insulation *plus* low original cost... long service life... and negligible maintenance. Seldom do you find a product that fills so many needs.

Use Tectum to form insulated outside walls or partitions between areas—it also provides a noncombustible fire barrier. Meeting or exceeding normal insulating requirements, Tectum has high thermal qualities because of the nature of its cellular structure. When used as a roof deck, with built up roofing, Tectum provides "U" values from 0.22 to 0.15. This same structure provides acoustical values, supplying noise reduction coefficients up to 0.85, depending on thickness.\*

Install Tectum Sidewall Insulation with screws or clips—it's quickly erected and may be sawed, kerfed, mortised or nailed with standard woodworking tools. Once installed, Tectum may be spray painted or left its natural, off-white shade.

For complete information on Tectum see your nearest sales office, or write for *Bulletin No. C-100*, (Sidewall Insulation) or No. A-100 (Roof Decks).

\* Thickness, 1 1/4 in. to 3 in.; Widths, 24 in., 30 in. and 32 in.; Lengths, 48 in. to 96 in.

**Wood Conversion Company**

Dept. 220-6 First National Bank Building

St. Paul 1, Minnesota

NEW YORK

CHICAGO  
BUFFALO

BOSTON  
ST. PAUL

KANSAS CITY  
SAN FRANCISCO

DETROIT

ATLANTA

**EFFICIENT INSULATION FOR EVERY NEED**

For many years a leader in the insulation field, Wood Conversion Company manufactures a complete line of flexible fiber and rigid insulation for all industrial and domestic purposes. This insulation is the product of scientific research, and is especially designed to embody the most desirable qualities for every use. Backed by the name of Wood Conversion Company this insulation assures high efficiency and long, satisfactory service.

**Balsam-Wool\* Sealed Blanket Insulation** is a flexible insulation. The insulation blanket is made from new wood fibers, completely enclosed on both sides and edges with heavy asphalt saturated and coated kraft liners.

Years of practical application and constant testing are behind each of these Balsam-Wool features—

- Integral, continuous vapor barrier
- Sturdy wind barrier
- Special spacer flange

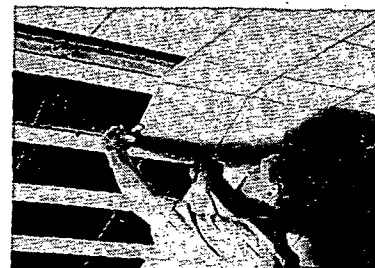
- Double bonding of mat to liner
- Rot and termite treatment
- Highly fire retardant

In addition, Balsam-Wool is manufactured under rigid quality control; proved by more than a quarter century of experience.

**Tufflex**—A soft, felted blanket material with exceptional insulating and cushioning qualities. Tufflex is made from clean, new, cellulose fibers, felted and bonded into a fleecy, homogeneous mat, processed to resist mold and vermin.

It may be moisture resistant or absorbent. Surfacing of kraft paper can be furnished on one or both sides; cottonette or scrim can be applied to one side of the plain mat. Where the use requires, Tufflex Type "U" can be furnished with a fire retardant treatment.

The soft, but firm, felted construction of Tufflex gives the properties of low transmittal of heat, sound or vibration, and of holding its shape after being cut.



Applying Nu-Wood Interior Finish



Applying Balsam-Wool Sealed Insulation

**NU-WOOD\* STRUCTURAL INSULATION**

**Nu-Wood Interior Finish**—A multiple-purpose wood fiber material available in tile, plank and board. Nu-Wood insulates, decorates and quiets noise. Nu-Wood's colors are soft and harmonious—will not fade. The Nu-Wood interior finish line includes Sta-lite, an insulating interior finish with more than 70 per cent light reflection.

\*Reg. U. S. Pat. Off

**Nu-Wood Sheathing**—A strong, structural insulating sheathing in 1/2 in. and 25/32 in. thickness, asphalt impregnated offering complete moisture protection.

**Nu-Wood Roof Insulation**—Will fill all requirements of Federal specification LLL-F-321b. Furnished in any practical thickness.

M-47-718



## American Flange & Manufacturing Co. Inc.

30 Rockefeller Plaza, New York 20, N. Y.  
Plaza 7-2200

# Ferro-Therm

Reg. U. S. Pat. Off.

### METAL INSULATION

FULLY PROTECTED BY U. S. AND FOREIGN PATENTS



Ferro-Therm is Stapled Permanently in Place

Ferro-Therm Metal Insulation, available from sheets of aluminum or steel with a special alloy coating, reflects 90 per cent to 95 per cent of all radiant heat. This high reflectivity, combined with extremely low heat storage capacity, provides maximum insulating efficiency in a minimum overall thickness.

### Reflects Heat from Either Side

Ferro-Therm's high reflectivity enables it to resist the penetration of heat from either side. During the winter it reflects heat in; during the summer it reflects heat out—assuring year 'round comfort and a considerable saving in fuel. Installed in ceiling (or roof) and exterior walls, Ferro-Therm reduces fuel costs by

an average of 25 per cent to 30 per cent. In ceiling (or roof) alone, Ferro-Therm will reduce fuel costs by 15 per cent to 20 per cent. During the summer, the installation of Ferro-Therm metal insulation will reduce temperatures in the house by 10 F to 12 F.

### Gives the Protection of Metal

Because Ferro-Therm is metal (1) It is not only non-combustible, it is an effective fire stop for wooden framework; (2) It prevents the penetration of termites, rodents and insects; (3) It does not absorb moisture or convey any wood-rotting moisture in framing members; (4) It does not settle or pack down, as the sheets are stapled permanently in place. (5) It is absolutely permanent.

### Ferro-Therm is Easy to Install

Ferro-Therm takes up considerably less space than mass insulation of equivalent efficiency. Laboratory tests and thousands of applications have demonstrated that a wall of Ferro-Therm will provide insulating efficiency equivalent to mass insulation approximately twice as thick. And Ferro-Therm can be installed easily, quickly and economically. The sheets take up considerably less space than mass insulation. And they are light—easy to transport and handle. One man can install 1000 to 1200 sq ft of Ferro-Therm in a day.

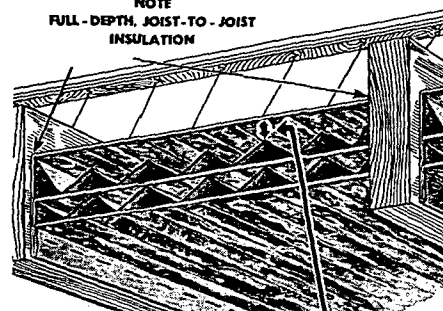
1678

## Infra Insulation, Inc.

525 Broadway, New York, N. Y.

Telephone: WOrth 4-2241

NOTE  
FULL-DEPTH, JOIST-TO-JOIST  
INSULATION



NOTE FULL ONE-INCH EXTRA AIR SPACE

FOR COLD  
STORAGE,  
CRAWL  
SPACES

FOR  
CEILINGS,  
WALLS,  
FLOORS.

Infra Insulation Type 6 has 3 tough, aluminum sheets, 6 heat-ray-reflective surfaces, two outer, and four rows of inner reflective spaces. (Total, 6 reflective spaces.) Easily and quickly installed between wood joists, furring strips, steel trusses, studs, purlins, metal beams and girders, it gives the entire area between, up to the very edges, full, uniform-depth protection against heat flow and vapor flow. The normal installation rate between wood joists is 2,000 sq ft a day per man. The 2½ cu ft carton contains 500 sq ft, weighs 52 lbs. For 12 in., 16 in., 20 in., and 24 in. centers.

Heat flow through wall space, which is air, is about 7 per cent by Conduction; 15 per cent to 28 per cent by Convection; and by Radiation, 65 per cent to 80 per cent.

**RADIATION:**—Each of Infra's 6 aluminum surfaces has a low absorptivity and emissivity of only 3 per cent, and a high reflectivity, 97 per cent, for radiation. The surfaces of most building materials have an absorptivity and emissivity of about 90 per cent with about 10 per cent reflectivity.

**CONDUCTION:**—Infra's 6 deep air spaces have low density, therefore slight conduction. One sq ft of Type 6 weighs only 1¼ oz, a ratio of 296 parts air to 1 part mass.

**CONVECTION; VAPOR:**—Each of the 3, continuous, 375 ft long, tough aluminum sheets has almost ZERO permeability to heated air, cold air, and water vapor. Infiltration under flat stapled flanges is slight. Each of the 2 fiber separators and 3 aluminum sheets retard flow of heat by CONVECTION.

**NON-CONDENSATION-FORMING:**—The 2 fiber separators which permanently prevent metal-to-metal contact, and the 3 aluminum sheets create FOUR inner rows of reflective air spaces. This scientific construction, and the low heat storage capacity, minimize condensation formation on or within this type of insulation.

Infra Insulation uses 99.4 per cent pure aluminum, made to special 3 per cent emissivity specifications, 0.002 in. and 0.0009 in. thick where exposed. It has 52 lb and 17 lb bursting strength (Mullen Test), and 80 grams and 28 grams tearing strength. This is up to 2600 per cent tougher than commonly used foils of less than 0.0005 in. thickness. Even tougher are Infra's newest, 3-ply, laminated aluminum sheets.

**FIRE:**—Because its aluminum surfaces have very low emissivity (3 per cent) and a high melting point (1220F), Infra has often prevented the spread of fire.

**SANITARY:**—Infra is inhospitable to insects, and DOES NOT RETAIN odors. Mechanics like to work with Infra. It is CLEAN, free of DUST or lint, permanently free from floating particles.

Write for a free copy of "Heat Flow by RADIATION in Building Structures, Simplified Physics," a new, 48-page, illustrated manual by Alexander Schwartz, president of Infra Insulation, Inc.

1679



## Silvercote Products, Inc.

161 East Erie Street, Chicago, Ill.

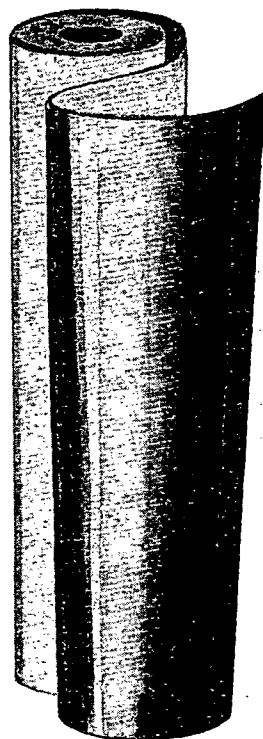
### SILVERCOTE\* REFLECTIVE INSULATION

**Silvercote Heat Reflective Surfaces**—The silver-like surface of Silvercote reflective insulation consists of a polished, heat reflective coating applied to a special kraft paper. The importance of using a Silvercote radiant heat reflective surface in modern building construction is obvious when it is realized that from 50 to 80 per cent of the heat transferred across a normal air space is in the form of radiation.

#### REFLECTIVE SHEET INSULATIONS IN ROLLS

**SILVERCOTE DUPLEX**—A thin flexible vapor barrier and insulation consisting of two sheets of Silvercote paper bonded together with asphalt. This material, containing two exposed Silvercote surfaces, weighs approximately 50 lbs per thousand sq ft and is manufactured in 500 sq ft rolls in widths of 36 in. or 52 in. to span two 16 in. or 24 in. standard framing spaces. These widths permit bow-in of the Silvercote over the room side of the framing members to form an air space between the insulation and the interior finish. The water vapor permeability of Silvercote Duplex is 0.23 grains per sq ft per hour per inch of mercury vapor pressure difference.

**SILVERCOTE SIMPLEX**—An economical vapor permeable reflective insulation designed for use where a vapor barrier is not required. Silvercote Simplex is a single sheet of special kraft paper coated on both sides with the Silvercote surface. It weighs approximately 30 lbs per thousand sq ft and is manufactured in 500 sq ft rolls in 36 in. or 52 in. widths to span two 16 in. or 24 in. standard framing spaces. These widths permit bow-in of the Silvercote over the exterior side of the framing members to form an air space between the insulation and the exterior sheathing. The water vapor permeability of Silvercote Simplex is 99.2 grains per sq ft per hour per inch of mercury vapor pressure difference.



Silvercote in rolls distributed by: Bird & Son, Inc., and The Flintkote Co.

\* Reg. U. S. Pat. Off.

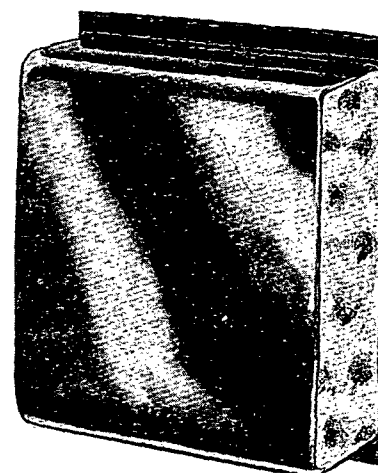
## Silvercote Products, Inc.

161 East Erie Street, Chicago, Ill.

### SILVERCOTE\* REFLECTIVE INSULATION

#### ON BLANKETS

#### SILVERCOTE REFLECTIVE SURFACE ON VAPOR BARRIER SIDE



A popular building insulation available in various thicknesses and faced on the vapor barrier side of the blanket with Silvercote paper. Manufacturers of this type of reflective blanket apply an asphalt coating to the back of the Silvercote paper for the twofold purpose of bonding the insulation material to the Silvercote paper and to lend vapor resistant properties to the blanket at the room side of the insulation.

#### SILVERCOTE REFLECTIVE SURFACES ON BOTH SIDES

A deluxe insulation material utilizing the full insulation value of blanket insulation, air spaces and two heat reflective surfaces. This double reflective blanket is manufactured with Silvercote Paper on the vapor barrier side and the breather side.

#### AVAILABLE UPON REQUEST

Silvercote's Handbook of "U" Values, 108 page illustrated booklet listing 12,852 "U" values of various walls, floors and ceilings—Silvercote's Handbook of "U" Values is unique in that it provides summer as well as winter "U" values. The Handbook's special listing of ceiling "U" values, indicating characteristics of downward heat flow will be of interest to those who are concerned with summer comfort as well as winter fuel savings.

#### SILVERCOTE REFLECTIVE SURFACE ON BREATHER SIDE OF BLANKET INSULATIONS

Silvercote paper is vapor permeable and can therefore be used on the breather side of a blanket. When space permits the use of only one air space in conjunction with thick blanket insulations, it is desirable that the air space be adjacent to the cold side (breather side). For this reason, many prominent manufacturers of mineral wool now furnish their reflective blanket with Silvercote on the breather side.

\* Reg. U. S. Pat. Off.

# ALFOL

INSULATION

## Reflectal Corporation

A Subsidiary of Borg-Warner Corp.

310 So. Michigan Ave., Chicago 4



### ALFOL MULTIPLE LAYER REFLECTIVE INSULATION

Introduced in 1929, ALFOL was one of the first reflective insulation blankets. Today, after nearly three decades of continuous development, ALFOL still is in the lead. Its patented blanket design insures high thermal efficiency, positive condensation protection and rapid, low cost application. Ideal for all types of residential, commercial and industrial use. ALFOL is also favored in air conditioned structures, where the superiority of reflective insulations provides substantial cooling economies.

**What ALFOL is:** Insulation consists of multiple aluminum foil sheets that automatically space themselves on application to form two, three or four reflective air spaces. The number of these spaces varies with ALFOL Type, but all types have a liner sheet of rugged, vapor-proof paper that provides continuous moisture protection and positive application support.

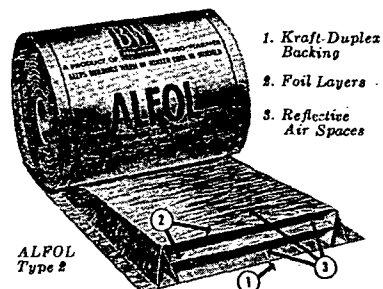
**How ALFOL works:** Radiant heat, as you know, normally accounts for 55 to 80 per cent of all heat loss through walls, roof or floor. Of all radiant heat, ALFOL foil sheets instantly, continuously reflect 95 per cent (or emit but 5 per cent). And the captive air spaces between these foil surfaces curb heat loss through convection and conduction to check all forms of thermal loss.

**Practical advantages of ALFOL:** Thermal efficiency is the big factor, but there are other reasons for ALFOL popularity. Its heavy liner provides sag- and rip-resisting application and a continuous vapor barrier. Its light weight ( $\frac{1}{2}$  lb/sq ft) cuts rafter load. And ALFOL is as clean, odorless, durable as aluminum itself. Priced low . . . with compact design offering added savings in handling and application.

#### Other REFLECTAL insulation products

**ALFOL ASBESTOS:** for central gas and oil heating equipment, water heaters, ranges, radiant heating seal and for all high temperature insulating requirements.

**ALFOL JACKETING:** for refrigerator cars, trucks and other low temperature work.



ALFOL is quick and easy to apply: You simply cut to length and staple across the faces of studs, joists or rafters.

#### An ALFOL Type for every purpose:

Type 1—2 reflective air spaces. 12 in., 16 in., 24 in. widths.

Type 1A—2 reflective air spaces, for furred-out masonry. 16 in. widths only.

Type 2—3 reflective air spaces, our top seller! 12 in., 16 in., 20 in. widths.

Type 3—3 reflective air spaces with foil base layer. 12 in., 16 in., 24 in. widths.

Type 4—4 reflective air spaces for top efficiency. 16 in., 20 in., 24 in. widths.

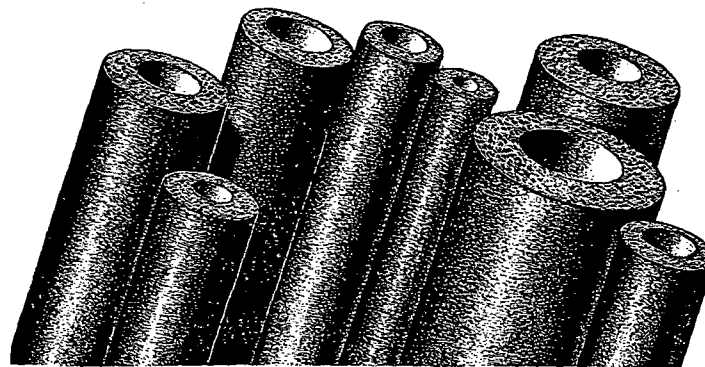
All ALFOL Types immediately available in handy 500 or 250 sq ft rolls.

Write Dept. ASH for free data book.

## B. F. Goodrich

SPONGE PRODUCTS DIVISION

274 Derby Place, Shelton, Conn.



### B. F. Goodrich SPONGEX® Molded Cell-Tite® TUBING for moisture-proof insulation

Spongex Molded Cell-Tite tubing is made of tough, flexible rubber with uniform non-connecting cell structure. Especially efficient and convenient for pipe insulation, it will not absorb moisture nor support combustion. Insulation value is excellent.

#### Easy application

Wherever used, Spongex Molded Cell-Tite may be easily secured with air-drying adhesive. Short lengths of tubing may be slipped on; longer ones may be slit lengthwise, snapped over pipe and adhesive applied to cut edges. These edges will not absorb moisture.

#### Low water absorption

Spongex Molded Cell-Tite meets ASTM specifications. Weight gain is under 10 per cent after 24 hours immersion in water; under 5 per cent after 3 minutes additional atmospheric pressure.

#### Efficient insulation

Thermal conductivity of Spongex Molded Cell-Tite is 0.28 at 75F with no deterioration in service.

#### Low shrinkage and aging

Spongex Molded Cell-Tite has no appreciable change after 7 days at 200F. Resistance to weather-aging is good. Linear shrinkage, when aged 4 weeks at 158F is under 10 per cent, most shrinkage occurring in the first week.

#### Wide range of density and firmness

Standard grades of Spongex Molded Cell-Tite are ASTM 12 or 13 (from 5-13 psi to compress a one square inch disc to 75 per cent of its height). Can be made in practically any firmness. Density varies, depending upon size and firmness, averaging 10 lb per cubic foot for soft, 15-20 lb per cu ft for medium, and 20-30 lb per cu ft for firm.

#### Many sizes

Spongex Molded Cell-Tite tubing is made with standard outside diameters of  $\frac{3}{4}$  in., 1 in.,  $1\frac{1}{4}$  in.,  $1\frac{1}{2}$  in., and can be made  $1\frac{5}{8}$  in.,  $1\frac{3}{4}$  in., and 2 in. Almost any inside diameter is available up to  $\frac{1}{4}$  in. of the outside diameter. Lengths up to 50 ft facilitate ease and simplicity of installation.

#### Variety of colors

Black is standard and can be furnished as non-staining to lacquer, enamel or plastic. (Tested for 24 hrs under ultraviolet light or for 10 days at 158F). Any one color available for requirements of 7,500 ft or more. White, if specified, would be off-white.

Please write for more information

## Kaiser Aluminum & Chemical Sales, Inc.

General Sales Office, Palmolive Building, Chicago 11, Illinois

EXECUTIVE OFFICE, KAISER BUILDING, OAKLAND 12, CALIFORNIA

### KAISER ALUMINUM SHADE SCREENING\*

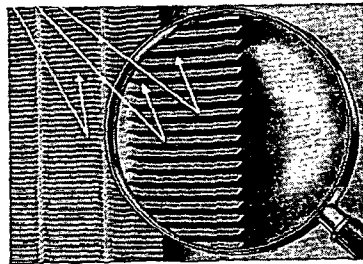
\* Patented

Kaiser Aluminum Shade Screening is scientifically designed to keep interiors cool by blocking hot sun rays. Shade Screening is being widely used in conjunction with air conditioning systems to reduce the solar load—thus permitting more economical operation by reducing the work load.

The effect of using Kaiser Aluminum Shade Screening is shown on these

graphs prepared by Kaiser Aluminum engineers following a test procedure similar to that used at the ASHAE Laboratory (1, 2) during experimental work on the shading of sunlit glass. The accompanying charts illustrate the amount of instantaneous heat gain to a room both through unshaded windows and windows protected with Kaiser Shade Screening.

Kaiser Aluminum Shade Screening has 17.5 louvers per inch permanently tilted at a downward angle. This stops sun rays before they hit the window glass. With sun angle (apparent) at 37 deg 100 per cent of sun rays are blocked. At 30 deg, 85 per cent. At 25 deg, 75 per cent. At 15 deg, 55 per cent. At 0 deg, 30 per cent. Thus Shade Screening can reduce the amount of instantaneous heat gain through unshaded windows by as much as 78 per cent, while still providing insect protection.



#### TYPICAL CALCULATIONS OF COOLING LOAD REDUCTIONS

DURING PERIOD OF EXTREME MIDSUMMER SOLAR RADIATION AT 40° N. LATITUDE.

Shade Screening reduces the load on air-conditioning units . . . permits use of smaller units. These typical calculations show how this is possible:  
FIGURING 24 WINDOWS ON THE EAST SIDE 3 1/4' x 6'

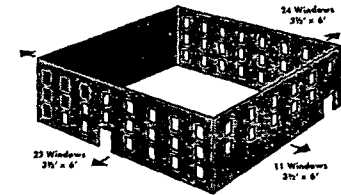
Total area 3 1/4' x 6' x 24 = 504 Sq. Ft.  
Use 10:00 A.M. peak load  
Instantaneous Heat Gain through Unshaded Windows BTU/HR  
504 Sq. Ft. x 138 BTU/HR per Sq. Ft. . . . 69,500  
Instantaneous Heat Gain through Windows shaded by Kaiser Aluminum Shade Screen  
504 Sq. Ft. x 35 BTU/HR per Sq. Ft. . . . 17,650

Quantity of Heat Gain Blocked by Shade Screen . . . 51,850  
Heat Blocked = 4.31 tons\* of refrigeration

FIGURING 23 WEST WINDOWS 3 1/4' x 6'

Total area 3 1/4' x 6' x 23 = 483 Sq. Ft. BTU/HR  
Use 4:00 P.M. peak load  
Instantaneous Heat Gain Unshaded Windows . . . 111,000  
Instantaneous Heat Gain through Windows shaded by Kaiser Aluminum Shade Screen . . . 34,800

Quantity of heat blocked by Kaiser Aluminum Shade Screen . . . 76,200  
Heat Blocked = 6.35 tons\* of refrigeration



FIGURING 11 SOUTH WINDOWS 3 1/4' x 6'

Total Area = 3 1/4' x 6' x 11 = 231 Sq. Ft. BTU/HR  
Use 12:00 noon peak load  
Instantaneous Heat Gain Unshaded Windows . . . 26,800  
Instantaneous Heat Gain through Windows shaded by Kaiser Aluminum Shade Screen . . . 8,550

Quantity of heat blocked by Kaiser Aluminum Shade Screen . . . 18,250  
Heat Blocked = 1.52 tons\* of refrigeration

\* 1 ton of refrigeration = 12,000 BTU/HR

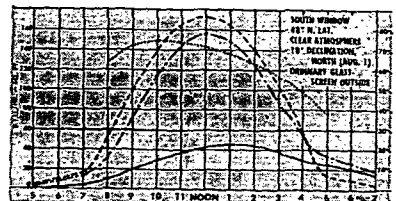
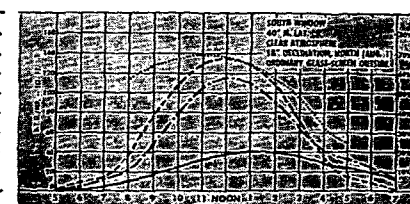
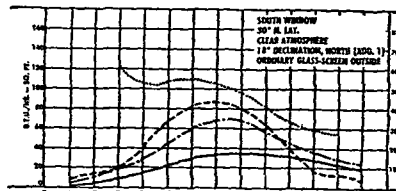
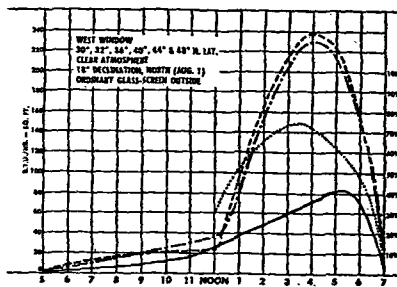
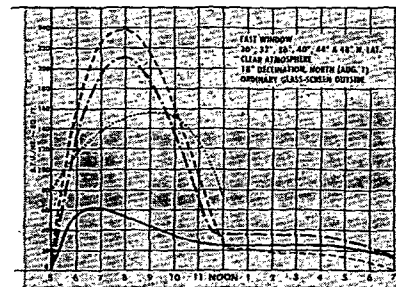
### KAISER ALUMINUM SHADE SCREENING

The instantaneous heat gain measurements included *transmitted* direct solar radiation plus the *absorbed* heat gained by convection and re-radiation plus transmission of heat through the glass caused by inside-outside temperature differentials. Kaiser Aluminum Shade Screening reflects more heat than other

commonly used materials thus the screening itself remains cool and emits at a very low rate.

These factors of high reflectivity and low emissivity combine with the sun-blocking feature of Shade Screening to produce cooler interior temperatures.

----- Total Solar Load  
----- Instantaneous heat gain through unshaded windows.  
----- Instantaneous heat gain through windows protected by Kaiser Aluminum Shade Screening.  
..... % of heat blocked.



1. ASHVE Research Report, "The Shading of Sunlit Glass—An analysis of the effect of Uniformly Spaced Flat Opaque Slats," by G. V. Parmelee and W. W. Aubele, June 1952.

2. ASHVE Research Report, "The Shading of Sunlit Glass—An Experimental Study of Slat-Type Sun Shades," by G. V. Parmelee, W. W. Aubele, and D. J. Veld, October 1952.

**T. R. FINN & COMPANY INC.**

Industrial Division

200 Central Avenue Hawthorne, New Jersey  
Specialists in Shock and Vibration Control**RUBBER-IN-SHEAR VIBRATION MOUNTINGS**

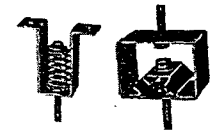
Widely used for isolating vibration, shock and noise on air conditioning and similar machinery. Rated load from 40 to 4000 lbs. Complete, ready-to-use. Catalog RS-55.

**"FLOATING PILLOW" VIBRATION MOUNTING**

Heavy duty, high-deflection rubber-in-shear mountings for efficient isolation of vibration, shock and noise of medium and heavy weight air conditioning equipment. Load range from 500 to 2500 lbs. Catalog FP-55.

**FLOATING RAIL VIBRATION MOUNTINGS**

Rubber-in-Shear bases for use under pumps, compressors and fan-motor sets. A complete, ready-to-use mounting supplied to specification. Catalog FR-55.

**VIBRATION HANGERS**

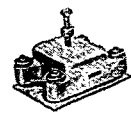
Two types, Rubber-in-Shear (35-1500 lbs.) and Steel Spring (50-1000 lbs.), prevent transmission of noise from suspended equipment and piping systems. Catalog VH-55.

**SOUNDZORBER**

Wire-reinforced, fabric-wrapped rubber pipe for reduction of water line noise and vibration. Sizes from ½ to 12 in. I.D. with I.P.T. male fittings or with integral full-faced rubber flanges backed up with Series 15 or 30 steel flanges. Catalog SZ-55.

**ISOLANT**

The unusually high structural strength and resiliency of this special material provides excellent isolation of vibration, shock and noise. For use under massive air conditioning equipment and heavy machinery. Load range up to 6000 lbs per sq ft. Catalog IS-55.

**STEEL SPRING VIBRATION MOUNTINGS**

For superior vibration, shock and noise isolation of difficult-to-isolate low speed machinery, heavy air conditioning equipment, and for protection of delicate instruments. Load range from 100 to 6500 lbs. Catalog SS-55.

**FLEXZORBER**

Seamless flexible bronze tubing covered with woven wire braiding and with standard copper tube female "slip fittings" welded on both ends. Used to minimize noise and vibration in rigid piping conveying Freon in air conditioning and refrigeration units. Slip fittings sizes from ½ to 8 in. I.D. Catalog FZ-55.

**EXPANDZORBER**

Stainless steel, welded diaphragm type packless expansion joints used for control of vibration, expansion, and contraction in steam, chemical, oil and gas lines. Working pressure from vacuum to 1000 psi at -300 to +1800 F. Sizes from ½ to 72 in. with steel flanges or welded fittings. Catalog EZ-55.

**ENGINEERING COUNSEL**

Our engineering staff is always at your service to solve your individual problem. We shall be pleased to submit to you our analysis and recommendation for an efficient and economical solution to your vibration problems.

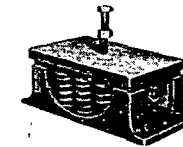
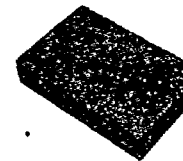
**The Korfund Company, Inc.**

48-01R 32nd Place, Long Island City 1, New York

Representatives in Principal Cities. See "KORFUND" in local phone directory or in "Thomas" Register.

Specialists in Vibration &amp; Noise Control for Over Half a Century.

For a discussion of Vibration control theory and chart for determining deflections required, see "Controlling Vibration From Machine Mountings" at end of Chapter 41. If in doubt about product selection, submit data on make, type, rpm and model number of equipment and type of floor for specific recommendations, without obligation.

**Series L Isolator****Vibro-Hanger****Elasto-Rib Pad****Vibracork****New Motor Base with Built-in Slide Rails****Duplex Bases**

**STEEL SPRING VIBRO ISOLATORS** provide greater deflections with isolation efficiencies approaching 100 per cent. Though more expensive than rubber or cork, they are satisfaction guaranteed and provide maximum overall economy because: they eliminate bolting, speed equipment installation, usually eliminate special foundations, permit trouble-free upper floor installations, and will usually outlast the machine. **THE SERIES L VIBRO ISOLATORS** contain from one to twelve steel springs of proper stiffness depending upon the loading and deflection desired. Loading: 75 to 23,000 lbs. Maximum deflection 1¼ in. (special designs available for higher loads or larger deflections). Isolators are usually installed directly under machines (occasionally under steel bases or foundations supporting equipment). They have adjustable snubbers to control movement and built-in leveling bolts, a Korfund feature for over 30 years.

**SERIES V VIBRO HANGERS:** load range 20 lb to 3,800 lb. Maximum normal deflection 1 in. (larger deflections on request). For suspended equipment installations, also as vibration-absorbing pipe hanger.

**RUBBER AND CORK** provide good sound insulation. However, rubber is not very effective as a vibration absorber for disturbances below 1200 cpm, is fair from 1200-1800, and good above 1800. Cork is effective only above 1800 cpm.

**SERIES R RUBBER-IN-SHEAR HANGERS:** Similar to spring hanger illustrated but incorporating rubber mountings of varying stiffnesses for loads from 10-1,000 lb.

**ELASTO-RIB** has a core of high-grade cork plate, permanently bonded between two layers of deep-grooved, Neoprene rubber. Just set the machine on Elasto-Rib—no fastening to floor is normally required but can be cemented or bolted if desired. Excellent sound insulation characteristics. Loading up to 60 lb per square inch. Also furnished as Elasto-Rib Dampers with load distributing top plate and built-in leveling bolt.

**ARMSTRONG'S VIBRACORK & KORFUND LIGHT DENSITY MACHINERY CORK** are strong, durable machinery isolation plates made of pure cork granules compressed and baked under pressure with accurately controlled density. Furnished in three densities for loads from 400-8,500 lb per square foot. 1 in., 2 in., 3 in., thicknesses. Plates 12 in. x 36 in.

**DUPLEX TWIN RAIL FAN & MOTOR BASES:** Rugged construction and built-in chocks to maintain alignment. Rubber or cork isolation. Advantages of separate fan and motor bases: no motor noise transmitted through ducts—complete adjustability permits job-site changes in motor position, belt length, rotation, equipment bolt location—quicker delivery of drawings and bases—easier handling—lower transportation costs. Integral type bases also available.

FOR ADDITIONAL DATA, SEE SWEET'S FILES OR WRITE FOR CATALOG



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Engineers and Manufacturers of Vibration Control Devices  
Representatives in Principal Cities. See "Thomas Register".

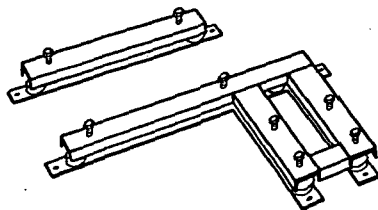


Fig. 1. Type RB. Rubber-in-Shear Base.



Fig. 2. Type RB. Base End Section.



Fig. 3. Type VMRH Rubber Hanger

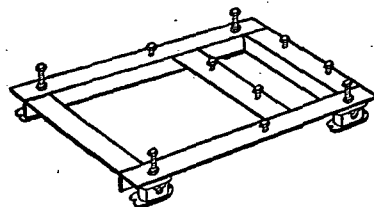


Fig. 4. Structural Base with Spring Mounts

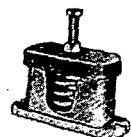


Fig. 5. Spring-Flex Mount



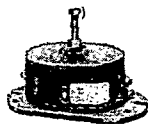
Fig. 6. Type RSH. Rubber-in-Shear and Spring Hanger.

Pad Type Materials are available in molded cross-rib neoprene as shown in Fig. 9, cork plates of thicknesses ranging from  $\frac{1}{2}$  in. to 4 in. as shown in Fig. 10, or in a bonded cork and neoprene pad, as illustrated in Fig. 11.

Send for complete Flexible Hose and Vibration Control Data Book which includes tables of recommended isolation efficiencies for critical and non-critical area applications.



Type R mount. Fig. 7.



Spring-Flex Mount Fig. 8



Shear-Flex Pad Fig. 9



Cork-Flex Pad Fig. 10



Cork-Rib Pad Fig. 11

Structural Steel Vibration Bases for Fans and Motors, Pumps, Compressors and Air Handling Units prevent motor misalignment, excessive belt wear and reinforce cast iron pump bases. Bolt hole locations are predetermined and fixed so that the vibration base becomes a template for lining up the equipment and securing it in place.

Rubber-in-Shear is generally used where a static deflection of  $\frac{3}{8}$  in. maximum is adequate. Mountings are permanently fastened between structural channels and flat steel base plates, as shown in Figures 1 and 2.

Spring Mountings with bonded acoustical pads are recommended for the more critical locations. Static deflections up to  $1\frac{1}{2}$  in. provide isolation efficiencies approaching 100 per cent. Structural angles form a rigid floating platform for the equipment as shown in Fig. 4. The mounting used is shown in Figure 5.

Individual Mountings are used under equipment that does not require a supplementary base. Rubber-in-Shear mountings typically illustrated in Fig. 7 can be furnished for individual loads of 5 to 2,000 lbs. Spring mountings as illustrated in Figures 5 and 8 support loads ranging from 50 to 18,000 lbs. Spring mountings are manufactured with built in leveling and damping devices.

Vibration Hangers using either rubber-in-shear or steel springs or a combination of both prevent the transmission of vibration and noise through the suspension rods. Open housings, not shown, or closed housings as shown in Figures 3 and 6 are made for attachment directly to the ceiling or insertion in the suspension rods. Standard hangers are made for loadings of 50 to 1,000 lbs. Special units on request.

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Engineering magazine for the men who design systems and specify equipment

This monthly engineering magazine (established 1904) is read by the engineers—by whomever employed—who design, specify, install, and maintain systems for heating, ventilating, air conditioning, piping, plumbing, industrial refrigeration, process steam, and related services. These systems are installed in industrial plants, hospitals, office buildings, hotels, stores, schools, colleges, theaters, churches, institutions, government buildings, military installations, housing projects, etc. Readers include: Consulting engineers; engineers with architects, with large engineering-type contractors, with utilities; engineers with industrial plants and with large buildings; and others. To these men AIR CONDITIONING, HEATING AND VENTILATING brings, month after month, a steady stream of crisply-written articles on the best current practice, boiled-down research results, mathematical short-cuts, handy tables, charts and Data Sheets.

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## Heating & Plumbing Equipment News

The "new equipment" magazine serving Contractors and Wholesalers

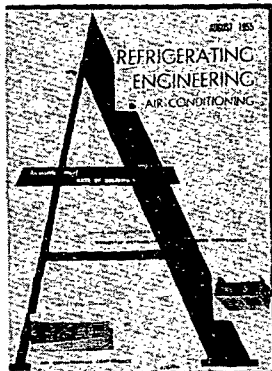
This monthly "new equipment" magazine, published in tabloid format, reaches by controlled circulation 35,000 contractors, wholesalers and other groups concerned with the sale and installation of heating and plumbing equipment. Only publication that reaches all these categories: Radiator and warm-air heating contractors, oil-burner dealers, gas-burner dealers, plumbing contractors, and the wholesalers and distributors who supply all the foregoing. Editorial content consists of concise, illustrated articles describing new and improved equipment, materials, and tools placed on the market, also new catalogs and bulletins issued by manufacturers. Inquiries total over 100,000 per year for information about specific products such as: Boilers, furnaces, gas-burners, oil-burners, toilets, sinks, pipe, fittings, valves, pumps, pipe-cutting and threading tools, hot water heaters, room coolers, water softeners, dishwashers, controls, insulation, and many others. Sample copy and advertising facts upon request.

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## American Society of Refrigerating Engineers

234 Fifth Avenue, New York 1, N. Y.



The most rapidly growing magazine in the refrigeration field

**L**ONG acknowledged the most authoritative periodical in the field, *Refrigerating Engineering* has added steadily to the practical value of its contents, and its number of readers has grown in proportion. This magazine is a must for men who keep in touch with all that is new and important in refrigeration and air conditioning. The annual subscription price is \$4.

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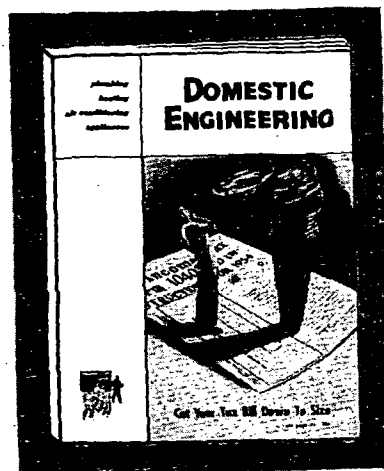
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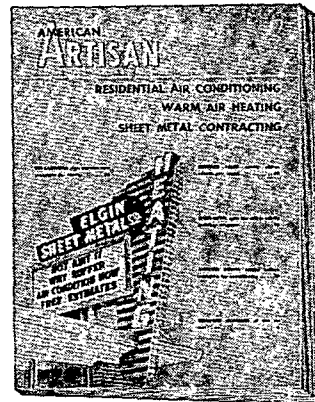
Heating, Piping & Air Conditioning carries the JOURNAL of the ASHAE as well as its own regular editorial section. Its field is that of industry and large buildings. It is devoted to the design, installation, operation, and maintenance of heating, piping and air conditioning systems in plants, commercial, institutional and public buildings.

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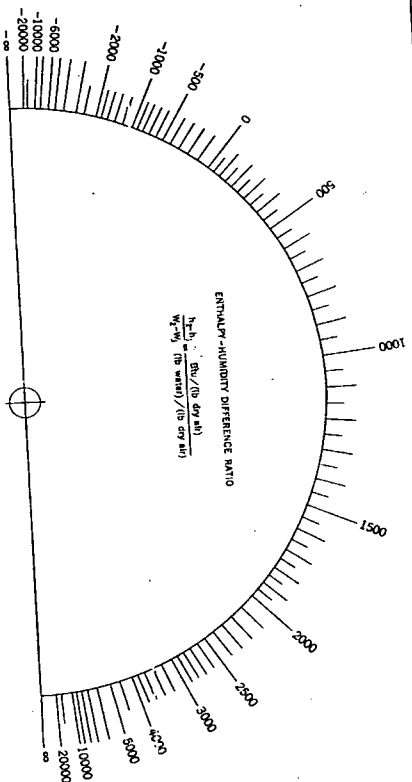
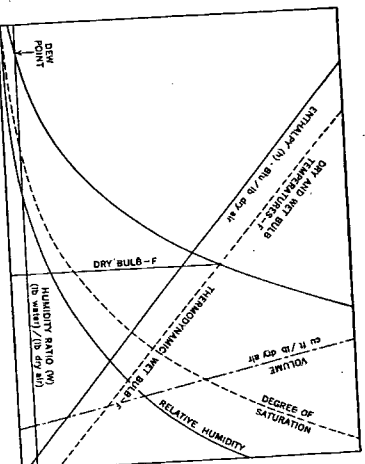


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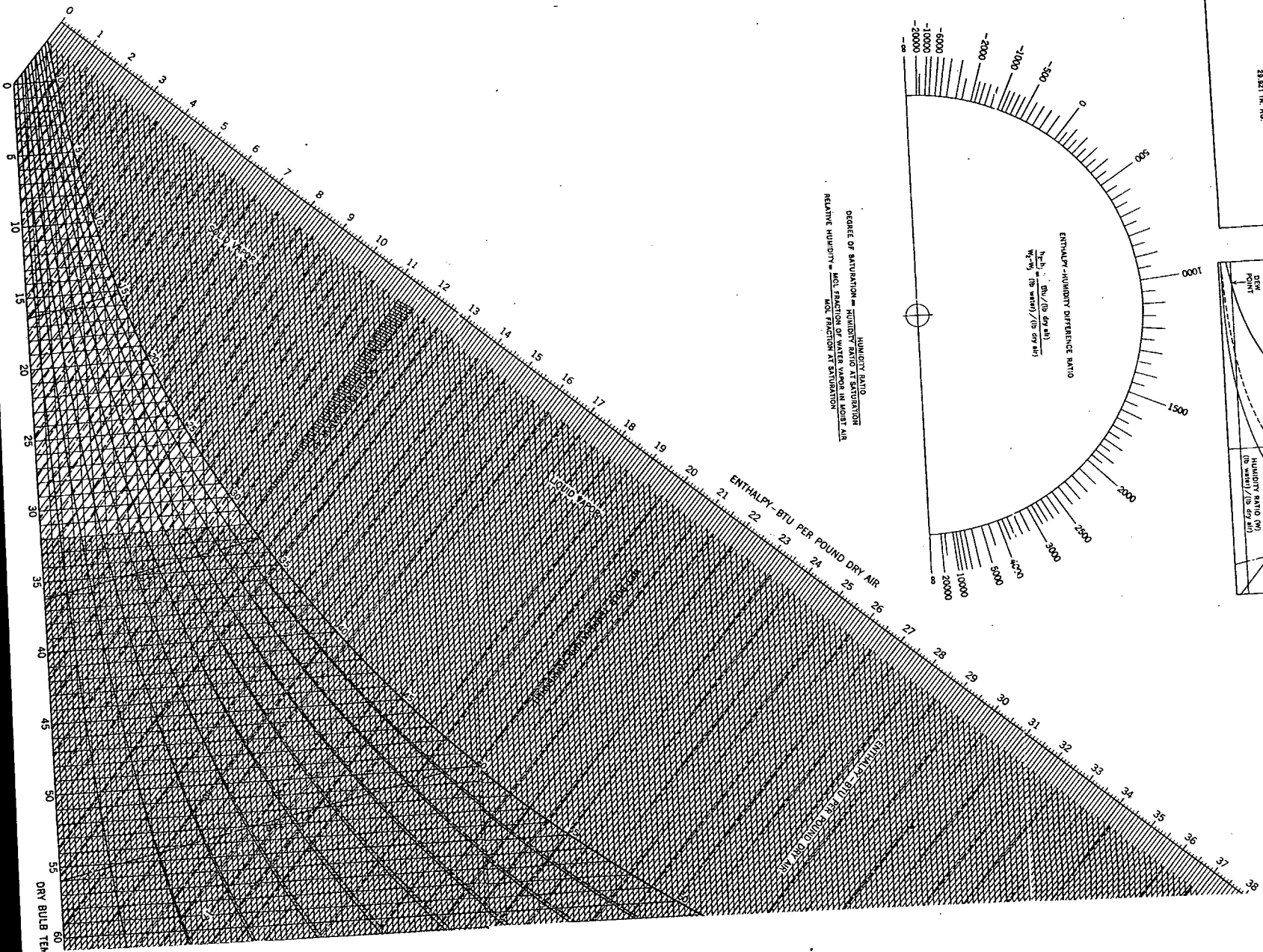


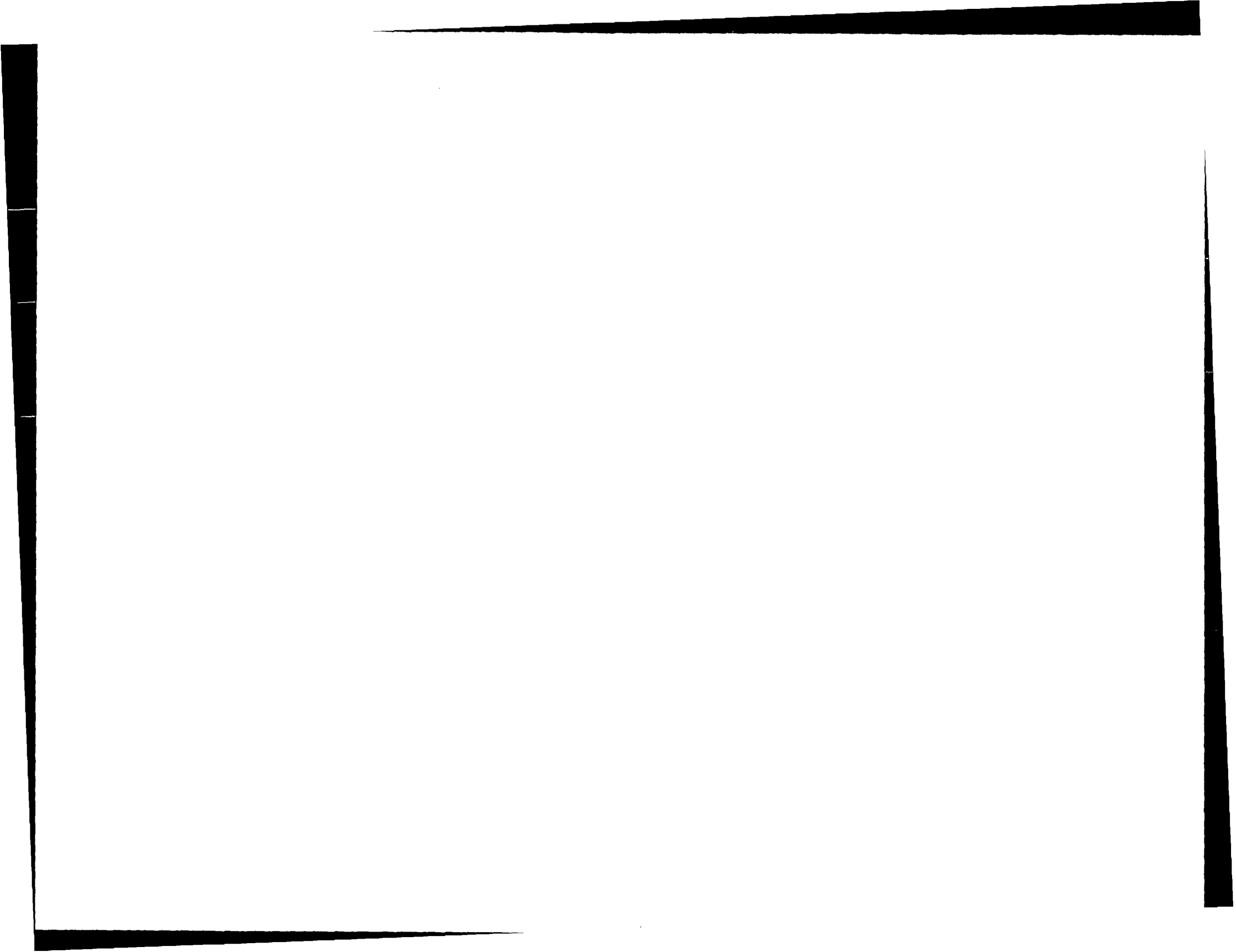
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29.921 IN. HG.

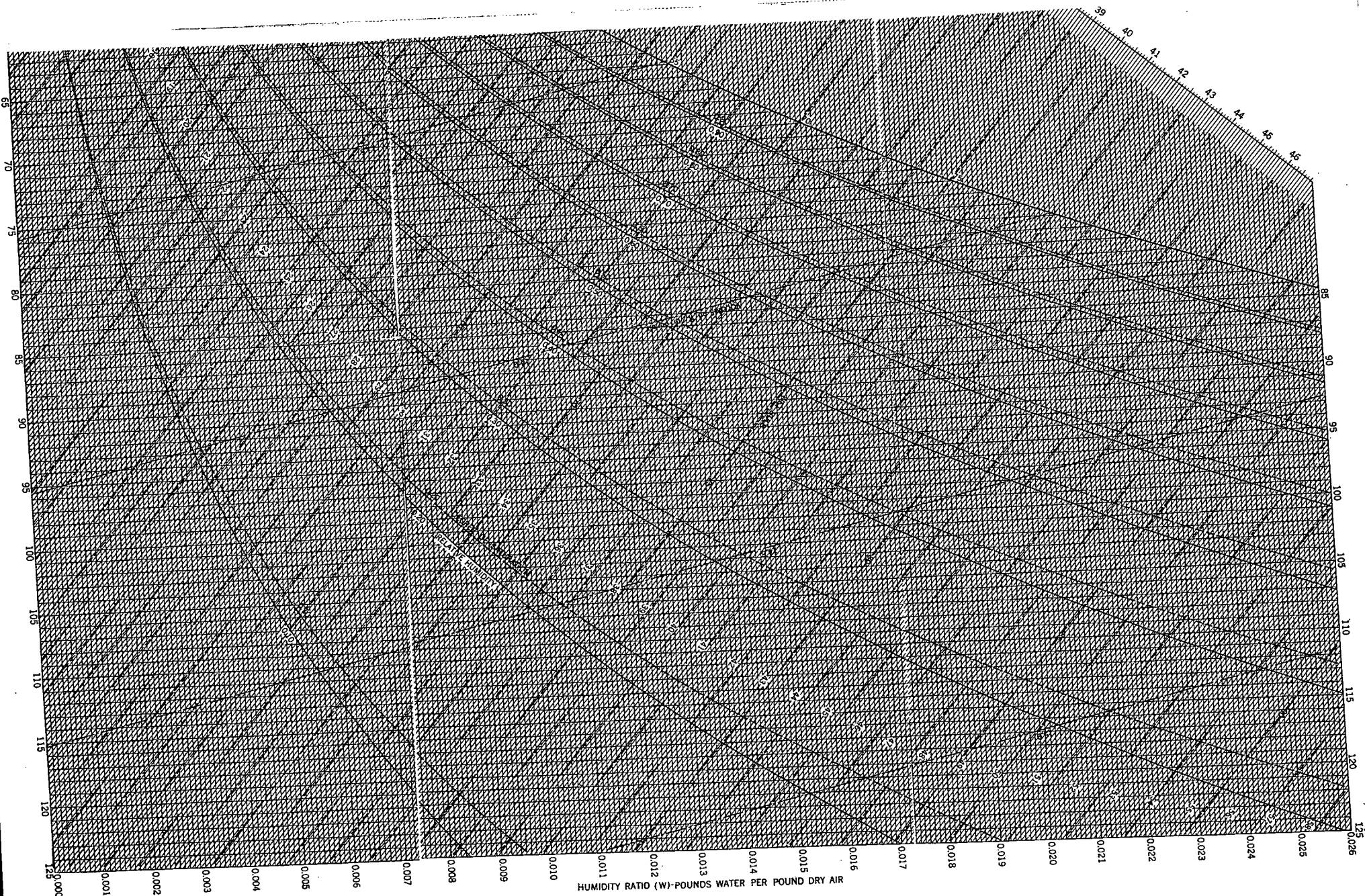


DEGREE OF SATURATION = HUMIDITY RATIO AT SATURATION  
MO. FRACTION OF WATER VAPOR IN SATURATED AIR  
RELATIVE HUMIDITY = MO. FRACTION AT SATURATION

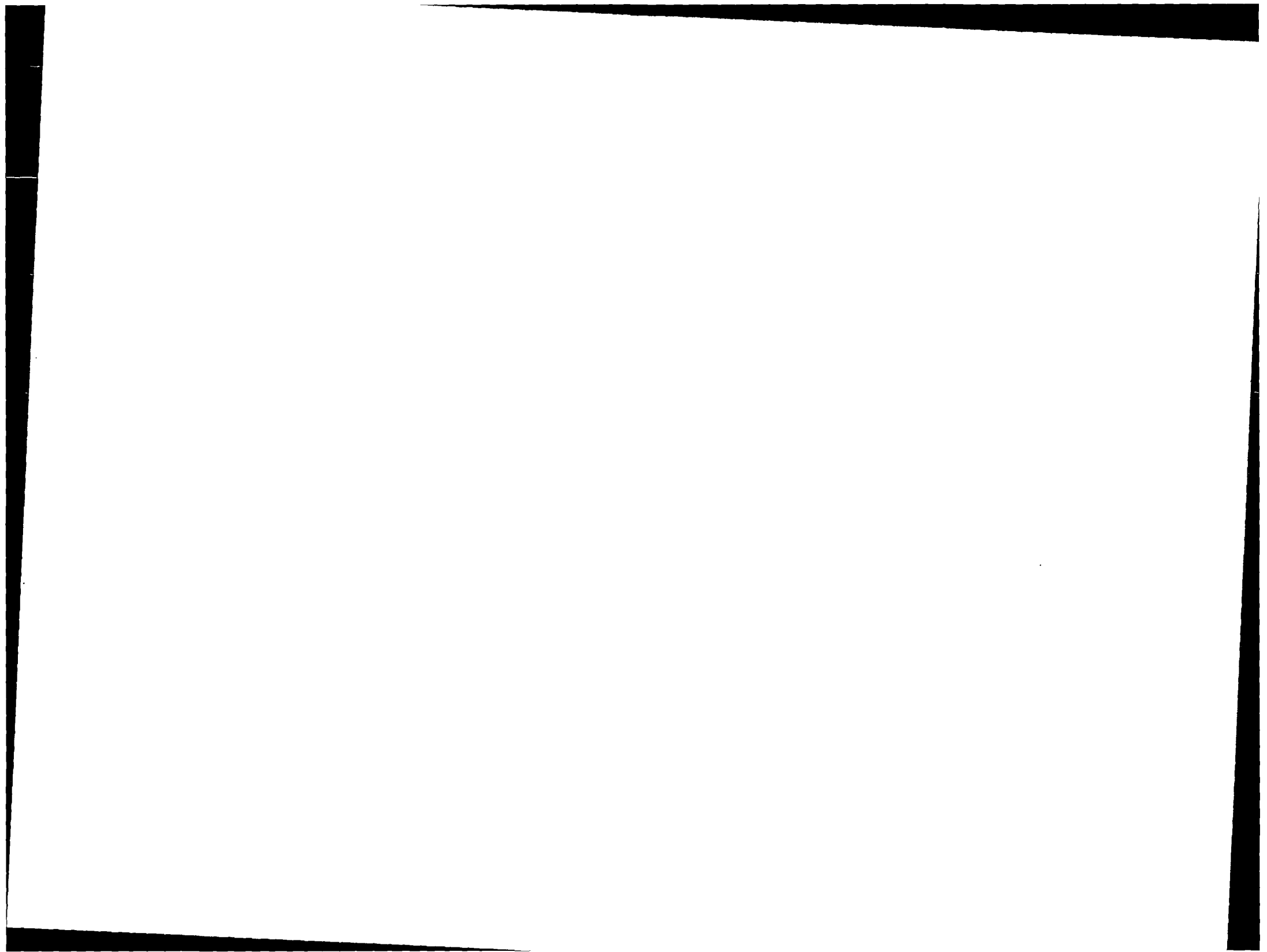


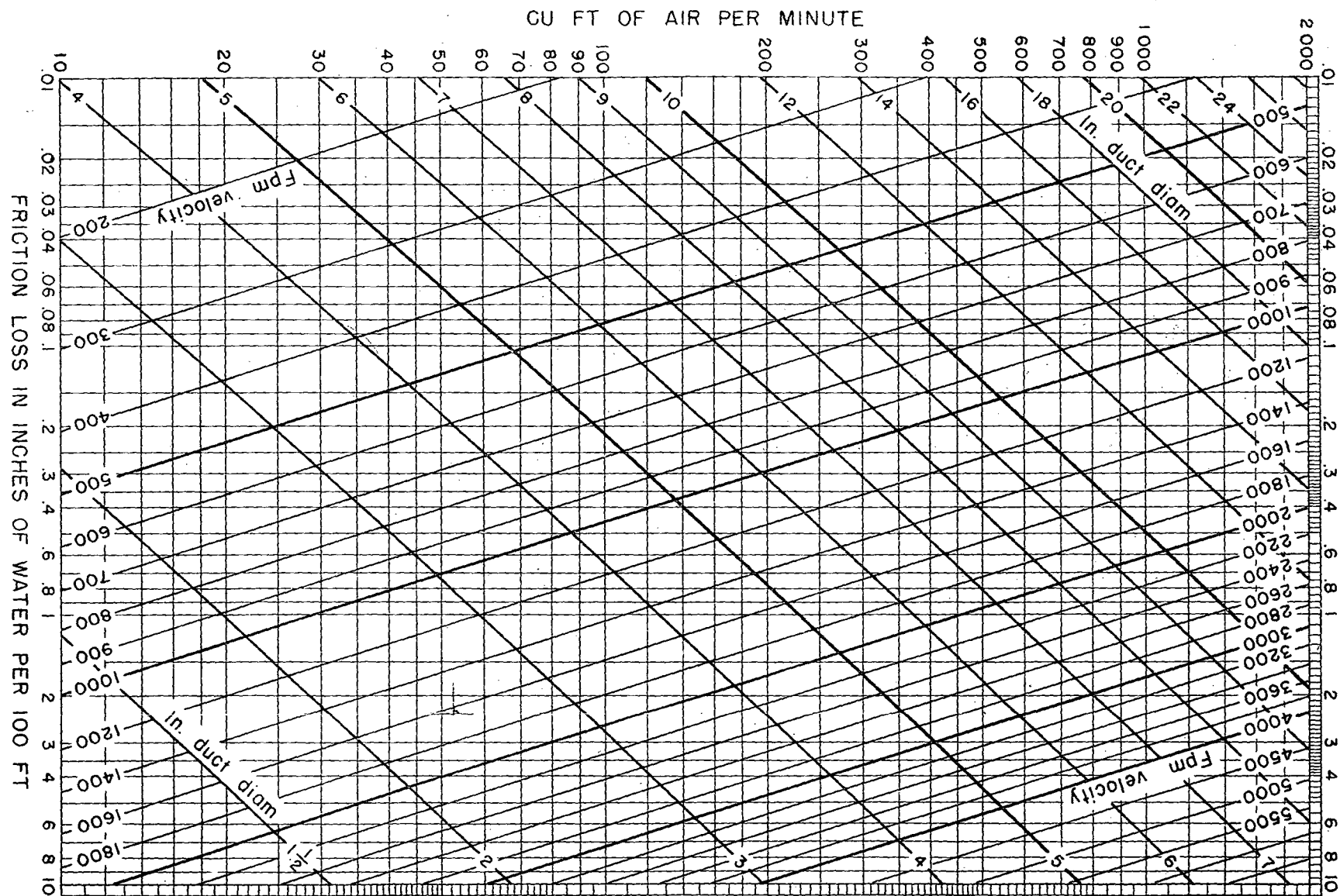


TEMPERATURE - FAHRENHEIT

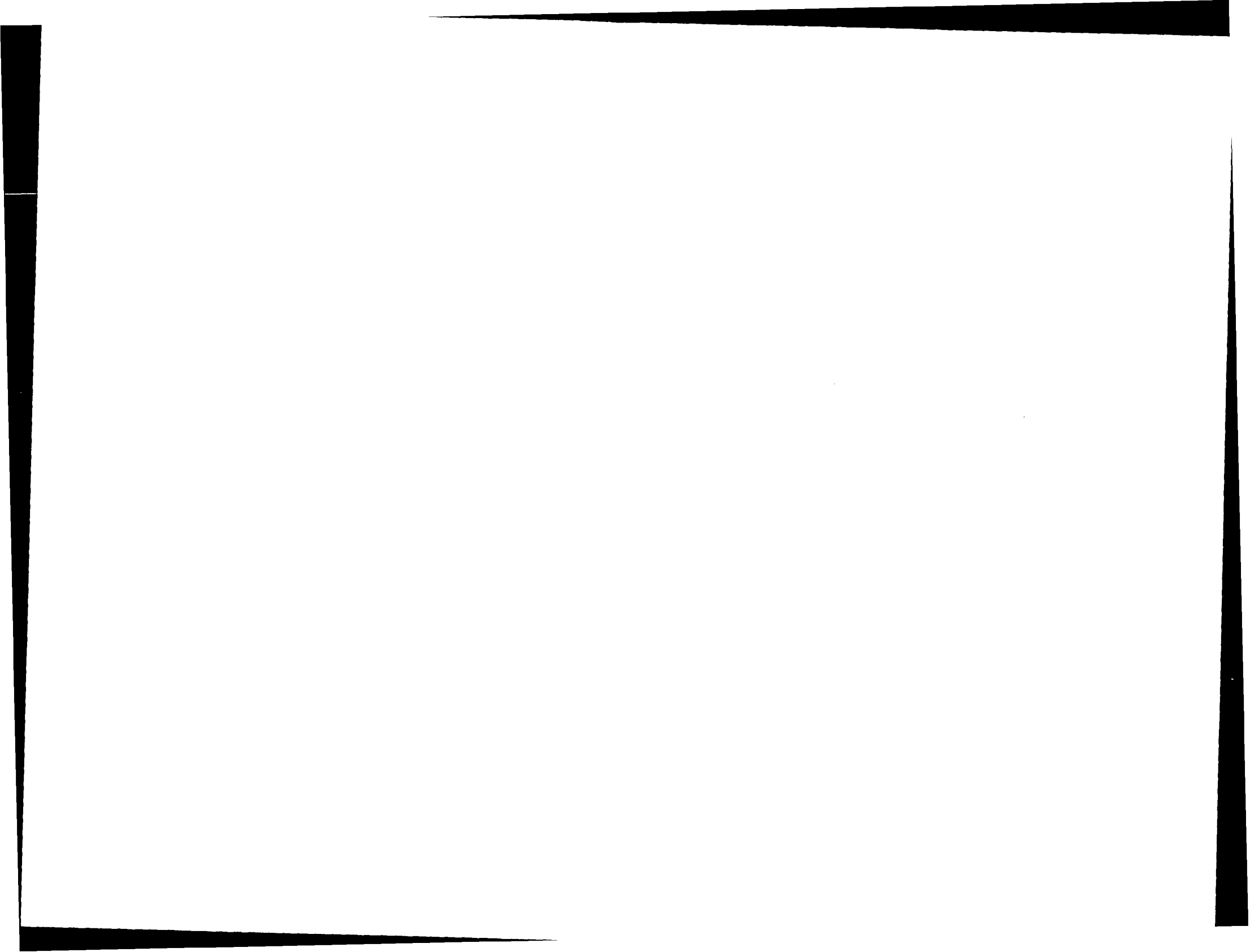


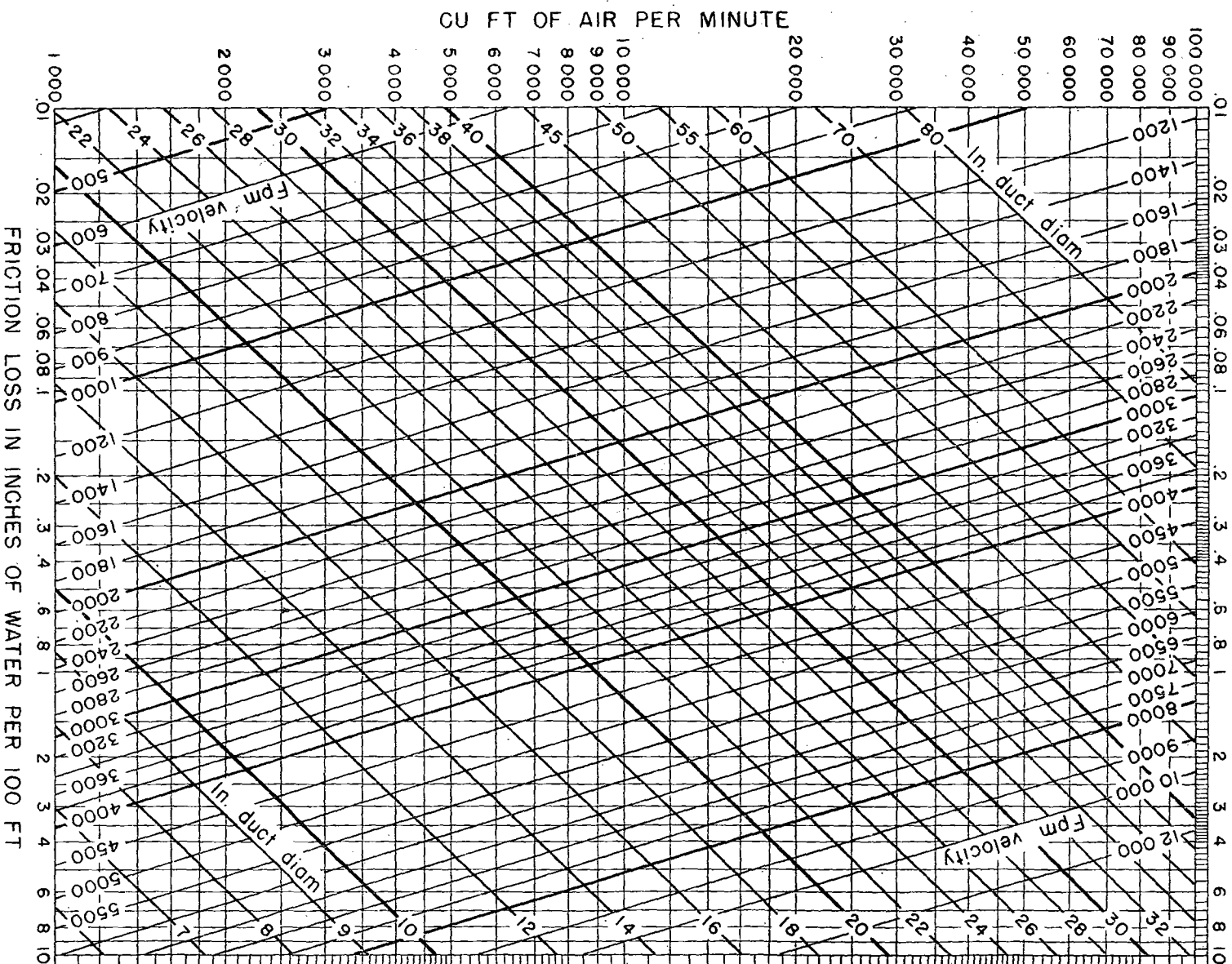
HUMIDITY RATIO (W)-POUNDS WATER PER POUND DRY AIR











## FRICTION OF AIR IN STRAIGHT DUCTS

HEATING VENTILATING AIR CONDITIONING GUIDE

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BASED ON STANDARD AIR OF 0.075 LB PER CU FT DENSITY FLOWING THROUGH AVERAGE, CLEAN, ROUND, GALVANIZED METAL DUCTS HAVING APPROXIMATELY 40 JOINTS PER 100 FT. NO SAFETY FACTOR INCLUDED. CAUTION: DO NOT EXTRAPOLATE BELOW CHART.

