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HEATING VENTILATING AIR CONDITIONING GUIDE

1948

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: THE ROLL OF MEMBERSHIP OF THE SOCIETY; COMPLETE INDEXES TO TECHNICAL AND CATALOG DATA SECTIONS.

Vol. 26

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PREFACE TO THE 26th EDITION

THE 26th edition of The Heating, Ventilating, Air Conditioning Guide continues the tradition of previous Guides in presenting current engineering practice and up-to-date products of manufacturers.

Among the chapters given most extensive revision in the 1948 edition, the following should be noted:

Chapter 10, Air Contaminants, contains revised limits for toxic gases, vapors, fumes, mists and dusts, in conformity with recent conclusions of industrial hygienists.

Chapter 11, Instruments and Measurements, has been enlarged to include a greater number of instruments, as well as more information on test methods and the use of instruments.

Chapter 12, Physiological Principles, incorporates some additional findings based upon recent research.

Chapter 13, Air Conditioning in the Prevention and Treatment of Disease, has been revised to agree with current thought and research.

Chapter 14, Heating Load, includes an enlarged list of approximately 350 localities, including city office and airport stations, for which weather data and design temperatures are given. The list includes data obtained from the U. S. Weather Bureau and Canadian Air Services, Meteorological Division. A new map showing isotherms of outdoor temperature has been provided.

Chapter 15, Cooling Load, has been increased to 45 pages to permit inclusion of an enlarged list of 315 localities for which weather data are listed. The chapter has also been rewritten to assist the user in applying the principles of periodic heat flow, and the data from most recent ASHVE research on solar heat transmission.

Chapter 20, Estimating Fuel Consumption for Space Heating, includes an enlarged list of 211 U. S. cities and 25 Canadian cities showing monthly degree-day values. The information has been obtained from latest statistics of the U. S. Weather Bureau and Canadian Air Services, Meteorological Division.

Chapter 21, Gravity Warm Air Systems, has been rearranged to facilitate use of the design tables.

Chapter 22, Mechanical Warm Air Systems, contains an added section referring to method of designing large systems.

In Chapter 23, Steam Heating Systems and Piping, revised descriptions of various types of systems keep the chapter up to date. Many new diagrams have been added to illustrate current practice.

In Chapter 25, Radiators, Convectors and Coils, there has been added a section on baseboard radiation.

In Chapter 26, Unit Heaters, Unit Ventilators, Unit Humidifiers, piping diagrams and text have been changed to comply with current practice.

In Chapter 27, Pipe, Fittings and Welding, the section on welding has been expanded with reference to proper welding procedure and applicable code requirements.

Chapter 30, Electric Heating, includes an enlarged list of pertinent references.

Chapter 32, Fans, has been improved by addition of typical sound level curves to the fan performance curves. A new diagram illustrating accepted designations of direction of rotation and discharge for fans has been added. The chapter also contains a section on attic fans which has been transferred from Chapter 36.

Chapter 34, Automatic Control, has been rewritten to include more detailed treatment of typical controls and control combinations for all types of systems.

Chapter 36, Unit Air Conditioners, Unit Air Coolers, has been revised and improved in both text and illustrations.

Chapter 37, Spray Apparatus, has been rearranged and includes new information on design and use of air washers, cooling towers and spray ponds.

Chapter 40, Air Distribution, has been completely revised by the ASHVE Technical Advisory Committee on Air Distribution and Air Friction. It contains new definitions and formulas for air distribution. Charts have been included for graphical solution of problems involving flow of air from slots and jets, residual velocity and size of openings. Information on location of outlets has been enlarged, and more information is given on control of air streams in spaces.

Chapter 10

AIR CONTAMINANTS

Classification of Air Contaminants; Sizes of Airborne Particles; Air Pollution by Smoke, Ash and Cinders; Smoke Abatement; Odor Nuisance; Maximum Allowable Concentrations of Industrial Air Contaminants; Flammable Gases and Vapors; Combustible Dusts; Atmospheric Pollen; Airborne Bacteria

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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 substances such as: solid or gaseous diluents for the prevention of explosions; germicidal mists or 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.

The control of air quality 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, windstorm, 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, using distinctions that are necessarily arbitrary in some cases.

CLASSIFICATION OF AIR CONTAMINANTS

Dusts, 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 or man-made processes, such as crushing, grinding, milling, drilling, demolition, shovelling, conveying, screening, bagging and sweeping. Some of these forces *produce* dust from larger masses, while the others simply *disperse* materials that are already in dust or pulverized form. Generally, particles are not called *dust* unless they are smaller than about 100 microns in size. 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 much larger size and this tendency may facilitate removal from air under controlled conditions.

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 characteristically 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. The 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, the size and specific gravity of the particle, the wind velocity, the orientation of the collecting surface, and the 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.

The great bulk of industrial dust particles is of the order of 1 micron in size. Tremendous numbers are also present in the sub-microscopic range below 0.5 micron, but those below 0.1 micron are not believed at

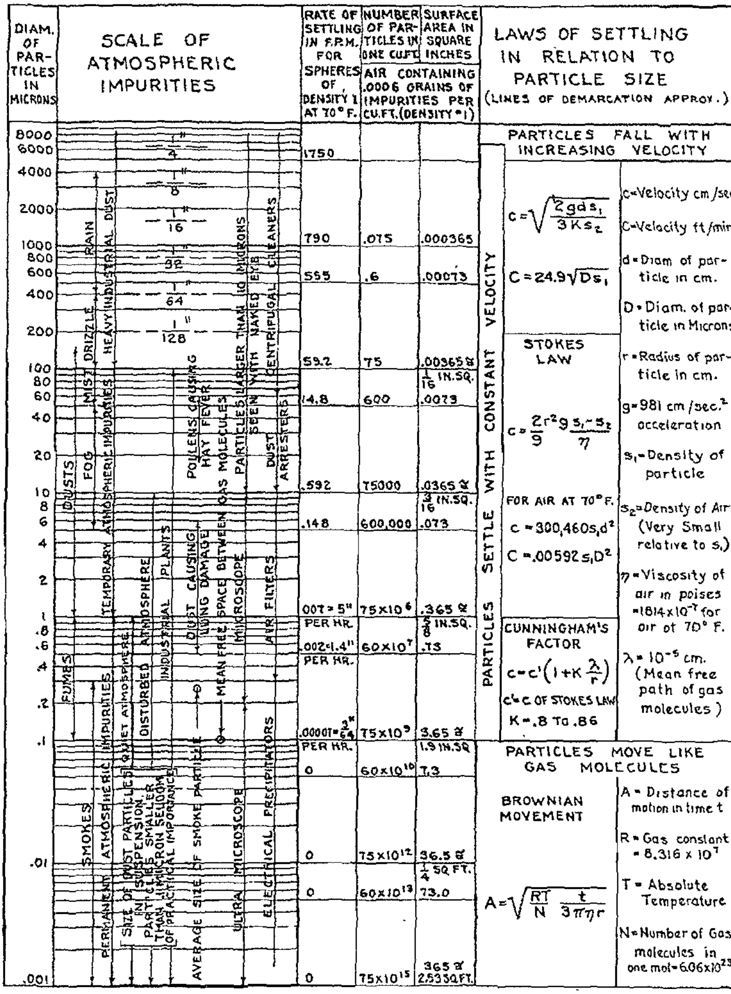

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FIG. 1. SIZES AND CHARACTERISTICS OF AIRBORNE PARTICULATE MATTER

present to be of any 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 their supporting gases (Brownian Movement).

The survey[1] of atmospheric pollution in 14 American cities conducted from 1931 to 1933 indicated the average size of outdoor dust particle to be 0.5 micron, as collected by the Owens jet dust counter and measured under the microscope. The 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, the intensity and quality of the light, and the nature of the background or the 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. The 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 than the openings of the screen through which it has passed, if the particle

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

shapes deviate considerably from the spherical form [2]. 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

The 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 [3, 4, 5]. 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

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 is 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.

Time, temperature and turbulence are fundamental requirements for smokeless combustion. Increase of any one of these factors will reduce

TABLE 2. DUST CONCENTRATION RANGES

LOCATION	GRAINS PER 1000 CU FT[a]	MILLGRAMS 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

[a]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.

the quantity of smoke discharged, although excessive turbulence in furnances may increase the output of ash and cinders. Special care must be taken in hand firing the bituminous coals. (See Chapters 16, 17 and 18 for further discussion on fuel burning technic).

Legislative measures at the present time are largely concerned with reduction of the visible smoke discharged from chimneys of boiler plants. Practically all ordinances limit the number of minutes in any one hour that smoke of a specified density may be discharged, as measured by comparison with a Ringelmann Chart (Chapter 11, Instruments and Measurements). Ordinances generally do not make specific provision for control of the corrosive and irritant gases, such as oxides of sulphur and nitrogen discharged with the gases of combustion. Where high sulfur coals are burned, sulfur gases present a serious hazard to property, health and vegetation.

In foggy weather the accumulation of these gases in the lower strata of the atmosphere may be such as to cause irritation of the eyes, nose and respiratory passages, and possibly even more dangerous consequences. The Meuse Valley (Belgium) fog disaster (1930) has become a classic example in the history of gaseous air pollution. It is believed that sulfur dioxide and other toxic gases released in a rare combination of atmospheric calm and dense fog were responsible for about 60 human deaths, injuries to several hundred persons, and also the death of many domestic and wild animals.

Absorption of Solar Radiation

The 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[6] by actinic methods demonstrated that ultraviolet light intensity in the country was 50 per cent greater than in the city. In New York City[7] a loss as great as 50 per cent in visible light was found by photo-electric cell.

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 the installation of air cleaning devices, the alteration of manufacturing processes, or by legal termination of the offensive operation in residential or commercial districts.

The 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 much 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, and best of all, substitution of less offensive materials whenever possible[8, 9, 10, 11].

The control of air quality within buildings ventilated for human occupancy is discussed in Chapter 12. 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 the maximum allowable concentrations for industrial air contaminants as currently accepted in most sections of the country. They apply to *exposures of 8 hours per day*, and refer to the quantities of contaminant permissible in the *workers' breathing zone*. Some of these figures may be altered as the result of continuous research, and some may differ from those in force in a few cities or states. The

TABLE 3. PHYSIOLOGICAL RESPONSE TO GASES AND VAPORS[a]

Concentrations in Parts of Substance per Million Parts of Air by Volume (ppm)

SUBSTANCE	RAPIDLY FATAL	DANGEROUS TO LIFE IN ½ TO 1 HR	MAXIMUM ALLOWABLE CONCENTRATION FOR DAILY EXPOSURES
Acrolein	2,000	100	0.5
Ammonia	5,000	2,500	100
Amyl acetate	....	....	200
Aniline	....	200	5
Arsine	250	10	0.05
Benzene (benzol)	20,000	5,000	100[b]
Bromine	500	40	1
Butyl acetate	....	10,000	200
Carbon dioxide	100,000	50,000	5,000
Carbon disulfide	2,000	1,000	20[b]
Carbon monoxide	4,000	1,000	100[b]
Carbon tetrachloride	50,000	....	50
Chlorine	1,000	10	1
Dichlorobenzene	....	....	50
Dichloroethyl ether	....	500	15
Ether (diethyl)	....	35,000	400
Ethyl acetate	40,000	10,000	400
Ethyl alcohol	....	....	1,000
Ethylene dichloride	....	4,000	100
Formaldehyde	....	....	10[b]
Gasoline	....	....	500
Hydrogen chloride	1,000	....	10
Hydrogen cyanide	200	100	20
Hydrogen fluoride	....	50	3
Hydrogen sulfide	600	200	20[b]
Methyl acetate	....	....	200
Methyl alcohol (Methanol)	....	....	200[b]
Methyl bromide	20,000	2,000	20
Methyl chloride	150,000	20,000	100
Methylene chloride	....	....	500
Monochlorobenzene	....	....	75
Nitrobenzene	....	....	1
Nitrogen oxides	300	100	25[b]
Phosgene	50	5	1
Phosphine	1,000	400	0.05
Styrene	....	....	400[b]
Sulfur dioxide	400	150	10
Tetrachloroethane	7,000	....	5
Tetrachloroethylene	....	....	100
Toluene (toluol)	20,000	5,000	200
Trichloroethylene	....	....	200[b]
Turpentine	....	....	100
Xylene (xylol)	20,000	5,000	200[b]

[a]Adapted from: *Manual of Industrial Hygiene*, by W. M. Gafafer et al, U. S. Public Health Service (W. B. Saunders Co., 1943); *Analytical Chemistry of Industrial Poisons, Hazards and Solvents*, by M. B. Jacobs (Interscience Publishers, 1941); *Noxious Gases*, by Henderson and Haggard (Reinhold Publishing Co., N. Y., 1943). 1947 report of the Committee on Threshold Limits of the American Conference of Governmental Industrial Hygienists; and other authoritative sources.
[b]Adopted by the *American Standards Association* (American Standard Z-37).

prudent engineer will design equipment using these values as the *upper* limits of air contamination, and will incorporate a reasonable margin of safety in his estimates of ventilation capacity.

Information on the properties and effects, with respect to health, of

TABLE 4. MAXIMUM ALLOWABLE CONCENTRATIONS OF DUSTS, FUMES AND MISTS[a]

SUBSTANCE	MILLIGRAMS PER CUBIC METER, DAILY EXPOSURES[b]
Antimony	0.1
Arsenic; arsenic trioxide	0.15[c]
Cadmium, and compounds	0.1[c]
Chlorodiphenyls	1.0
Chromic acid mist and Chromates (as CrO_3)	0.1
Fluorides	2.5
Lead; lead carbonate; lead chloride; lead nitrate; lead oxides; lead sulfate	0.15[c]
Manganese, and compounds	6.0[c]
Mercury, and compounds	0.1
Pentachloronaphthalene	0.5
Selenium	0.1
Tellurium	0.1
Trichloronaphthalene	5.0
Trinitrotoluene	1.5
Zinc oxide fume	15.0

[a]Adapted from: Manual of Industrial Hygiene, by W. M. Gafafer, et al, U. S. Public Health Service (W B. Saunders Company, 1943); and other authoritative sources.
[b]1 milligram per cubic meter = 0.44 grain per 1000 cu.ft.
[c]Adopted by the *American Standards Association* (American Standard Z-37).

TABLE 5. MAXIMUM ALLOWABLE CONCENTRATIONS OF DUSTS[a]

SUBSTANCE	MILLION PARTICLES PER CUBIC FOOT OF AIR, DAILY EXPOSURES[b]
Aluminum oxide abrasive	15–100
Asbestos	5
Carborundum (silicon carbide)	15–100
Cement (Portland)	50–100
Coal (less than 5 per cent quartz)	50–100
Dusts containing less than 10 per cent *free* silica	10–100
Granite	10– 25
Gypsum (hydrated calcium sulfate)	50–100
Limestone (calcium carbonate)	50–100
Marble (calcium carbonate)	50–100
Mica	10–100
Nuisance dusts (non-toxic, non-silica)	50–100
Quartz (silicon dioxide)	5
Sand (silica, silicon dioxide)	5
Sandstone	5
Silica (*free* or uncombined silicon dioxide)	5
Silicates (combined silicon dioxide)	15–100
Slate	15–100
Talc	10– 50
Total (maximum concentration for mixed dusts)	50–100

[a]Adapted from: Study of Asbestosis in Asbestos Textile Industry, U. S Public Health Service Bulletin No. 241, 1938; Industrial Dust, by Drinker and Hatch (McGraw Hill Book Co., 1936); Industrial Code Bulletin No. 35, New York State Department of Labor; recommendations of state and local industrial hygiene agencies compiled by the American Conference of Governmental Industrial Hygienists; and other authoritative sources.
[b]Includes only particles from 1 to 10 microns approximately, as determined by the light field microscope counting technic, using the 10× objective. Dark field counts (and the corresponding allowable concentrations) are anywhere from 2 to 100 times the light field counts for the same sample, according to the proportion of dust smaller than 1 micron (See Industrial Dust, Chapter VII, by Drinker and Hatch, McGraw Hill Book Co.)

specific industrial air contaminants has developed rapidly within the past decade into an extensive literature. Some of the more readily available publications are listed at the end of this chapter.

Table 6. Approximate Limits of Flammability of Single Gases and Vapors In Air at Ordinary Temperatures and Pressures[a]

Gas or Vapor	Lower Limit Per cent by Volume	Upper Limit Per cent by Volume	*Closed Cup* Flash Point F Deg[c]
Acetaldehyde	4.0	57	−17
Acetone	2.1	13.0	0
Acetylene[b]	2.5	80	....
Allyl alcohol	2.4	....	70
Ammonia	16.0	27.0	....
Amyl alcohol	1.2	....	91
Amyl chloride	1.4	....	....
Amylene	1.6	....	....
Benzene (benzol)	1.4	8.0	12
Benzyl chloride	1.1	....	140
Butane	1.6	8.5	−76
Butyl acetate	1.7	15.0	72
Butyl alcohol	1.7	....	84
Butylene	1.7	9.0	....
Carbon disulfide	1.0	50	−22
Carbon monoxide	12.5	74	....
Crotonaldehyde	2.1	15.5	55
Cyclohexane	1.3	8.4	1
Cyclopropane	2.4	10.3	....
Decane	0.67	2.6	115
Dichloroethylene (1, 2)	9.7	12.8	43
Diethyl selenide	2.5	....	....
Dioxan	2.0	22.2	65
Ethane	3.1	15.0	....
Ether (diethyl)	1.7	48.0	−20
Ethyl acetate	2.2	11.5	24
Ethyl alcohol	3.3	19.0	55
Ethyl bromide	6.7	11.3	....
Ethyl cellosolve	2.6	15.7	104
Ethyl chloride	3.6	14.8	−58
Ethylene	3.0	34.0	....
Ethylene dichloride	6.2	15.9	56
Ethyl formate	2.7	16.5	−4
Ethyl nitrite	3.0	....	−31
Ethylene oxide	3.0	80	....
Furfural (125 C)	2.1	....	140
Gasoline	1.3	6.5	−50
Heptane	1.0	6.0	25
Hexane	1.2	6.9	−7
Hydrogen cyanide	5.6	40.0	0
Hydrogen	4.1	74	....
Hydrogen sulfide	4.3	45.5	....
Illuminating gas	5.3	31.0	....
Iso-butyl alcohol	1.7	....	82
Iso-pentane	1.3	....	....
Iso-propyl acetate	1.8	7.8	43
Iso-propyl alcohol	2.5	....	53
Methane[b]	5.0	15.0	....

[a]Adapted from: Limits of Inflammability of Gases and Vapors, by H. F. Coward and G. W. Jones (U. S. Bureau of Mines, Bulletin No. 279, 1939); 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*).
[b]Turbulent mixture.
[c]*Closed cup* refers to the equipment used in flash point determinations.

TABLE 6. APPROXIMATE LIMITS OF FLAMMABILITY OF SINGLE GASES AND VAPORS IN AIR AT ORDINARY TEMPERATURES AND PRESSURES[a] (Continued)

GAS OR VAPOR	LOWER LIMIT PER CENT BY VOLUME	UPPER LIMIT PER CENT BY VOLUME	*Closed Cup* FLASH POINT F DEG°
Methyl acetate	3.1	15.5	15
Methyl alcohol	6.0	36.5	54
Methyl bromide	13.5	14.5	....
Methyl butyl ketone	1.2	8.0	....
Methyl chloride	8.0	19.7	....
Methyl cyclohexane	1.1	....	25
Methyl ethyl ether	2.0	10.1	−35
Methyl ethyl ketone	1.8	11.5	30
Methyl formate	5.0	22.7	−2
Methyl propyl ketone	1.5	8.2	....
Natural gas	4.8	13.5	....
Naphtha (benzine)	1.1	6.0	20–45
Naphthalene	0.9	....	174
Nonane	0.74	2.9	88
Octane	0.84	3.2	56
Paraldehyde	1.3	....	....
Pentane	1.4	8.0	....
Propane	2.4	9.5	....
Propyl acetate	1.8	8.0	58
Propyl alcohol	2.5	....	59
Propylene	2.0	11.1	....
Propylene dichloride	3.4	14.5	59
Propylene oxide	2.1	21.5	....
Pyridine (70 C)	1.8	12.4	68
Toluene (toluol)	1.3	7.0	40
Turpentine	0.8	....	95
Vinyl ether	1.7	27.0	....
Vinyl chloride	4.0	22.0	....
Water gas (variable)	6.0	70	....
Xylene (xylol)	1.0	6.0	63

FLAMMABLE GASES AND VAPORS

Adequate ventilation is a primary requirement for eliminating or 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 overventilation 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 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 ¼ or ⅕ 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.

The ability of a flammable liquid to form explosive mixtures is determined largely by its vapor pressure, volatility, or rate of evaporation. *Flash 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 of flame 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.

The 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[12, 13].

Design of equipment for the control of combustible anesthetics is outlined in Chapter 13. Construction of equipment for handling air containing 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 per cent by volume, or *volume per cent.* Comparison with concentrations on the *part per million* scale used in chemical, medical or industrial hygiene literature is readily made by the conversion: 1 per cent = 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 per cent, while the *maximum allowable concentrations* for gases and vapors in Table 3 are below 1000 ppm or 0.1 per cent in most cases. Therefore, control of toxic or injurious vapors in workrooms 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 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).

The intensity of a dust explosion depends upon: the chemical and thermal properties of the dust; the particle size and shape; the concentration in air; the proportion of inert dust in the air; the moisture content and composition of the air; the size and temperature of the ignition source; and the degree of dispersion of the dust cloud. Investigations on the explosibility of dusts require a determination of the maximum pressure developed during an explosion of a known air concentration, as well as determination of the rate of pressure rise. Investigators frequently experience difficulty in obtaining dust suspensions of uniform dispersion, and this should be kept in mind when comparing results from several sources [14].

The 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 [15-21].

ATMOSPHERIC POLLEN

The properties of pollen grains discharged by weeds, grasses and trees and responsible for hay fever are of special interest to engineers who design equipment for their removal from indoor air (see Allergic Disorders in Chapter 13, and Air Cleaning Devices, Chapter 33). 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 and found near dusty industrial 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 [22, 23, 24]. The geographical distribution of plants known to produce hay fever is also recorded [25, 26].

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 [25, 27, 28] 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 still uncertain 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 [29, 30, 31].

AIRBORNE BACTERIA

Study of the occurrence and significance of micro-organisms in the atmospheres of the indoor world is currently 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 occupied and unoccupied 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 [32]. Many are attached to the dust particles which are also 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 13), 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 commercially feasible for the protection or preservation of pharmaceuticals, cosmetics, and food products.

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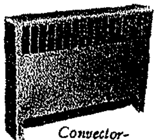

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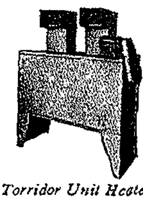

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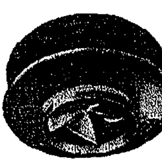

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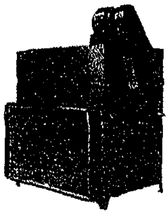

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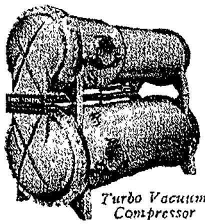

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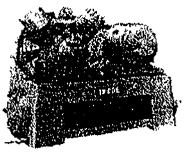

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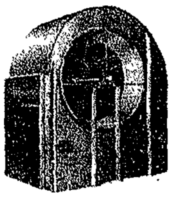

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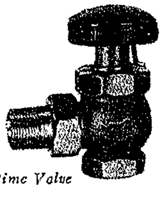

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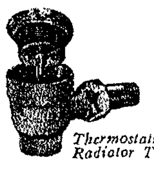

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