[12] Harry Buchberg: Cooling load from thermal network solutions (ASHAE TRANSACTIONS, Vol. 64, 1958, p. 111).

[13] Harry Buchberg: Cooling load from pretabulated impedances (ASHAE TRANSACTIONS, Vol. 64, 1958, p. 503).

[14] W. B. Drake, Harry Buchberg, and D. Lebell: Load calculations using pretabulated admittance functions (ASHAE TRANSACTIONS, Vol. 65, 1959, p. 515).

[15] W. B. Drake, Harry Buchberg, and D. Lebell: Transfer admittance functions for typical composite wall sections (ASHAE TRANSACTIONS, Vol. 65, 1959, p. 523).

[16] Walter Koch, B. H. Jennings and C. M. Humphreys: ASHRAE RESEARCH REPORT No. 1715—Environmental Study II—Sensation responses to temperature and humidity under still air conditions in the comfort range (ASHRAE TRANSACTIONS, Vol. 66, 1960, p. 264).

[17] *Evaluated Weather Data for Cooling Equipment Design* (Fluor Products Co., Santa Rosa, Calif., 1st edition, 1958).

[18] *Engineering Weather Data* (Army, Navy, and Air Force *Manual*, TM5–785, 1963).

[19] L. W. Crow: Study of Weather Design Conditions (*Bulletin*, ASHRAE Research Project No. 23, 1964).

[20] C. C. Boughner: *Canadian Meterological Memoirs No. 5* (Meterological Branch, Department of Transport, Ottawa, Ontario, Canada, 1960).

[21] W. V. Consolazio and L. J. Pecora: Minimal replenishment air required for living spaces (ASHVE TRANSACTIONS, Vol. 53, 1947, p. 127).

[22] *Recommended Safe Practice of the NBFU for Hospital Operating Rooms* (*National Board of Fire Underwriters Pamphlet* No. 56).

[23] P. Moon: Proposed standard solar radiation curves for engineering use (*Journal of the Franklin Institute*, Vol. 230, November 1940, p. 583).

[24] C. O. Mackey: ASHVE RESEARCH REPORT No. 1268—Summer weather data and sol-air temperature—Study of data for Lincoln, Nebr. (ASHVE TRANSACTIONS, Vol. 51, 1945, p. 93).

[25] C. O. Mackey and E. B. Watson: Summer weather data and sol-air temperature—Study of data for New York City (ASHVE TRANSACTIONS, Vol. 51, 1945, p. 75).

[26] G. A. Hendrikson and J. H. Walker: Summer cooling for comfort as affected by solar radiation (*Heating and Ventilating*, Vol. 29, November 1932, p. 14).

[27] *Tables of Computed Altitude and Azimuth* (U. S. Navy Dept. *Hydrographic Office Bulletin* No. 214, Vol. 1–9, 1940).

[28] *The American Nautical Almanac* (U. S. Naval Observatory, annual).

[29] F. C. Houghten, J. L. Blackshaw, E. M. Pugh, and Paul McDermott: ASHVE RESEARCH REPORT No. 923—Heat transmission as influenced by heat capacity and solar radiation (ASHVE TRANSACTIONS, Vol. 38, 1932, p. 231). J. S. Alford, J. E. Ryan, and F. O. Urban: Effect of heat storage and variation in outdoor temperature and solar intensity on heat transfer through walls (ASHVE TRANSACTIONS, Vol. 45, 1939, p. 369). Victor Paschkis: Periodic heat flow in building walls determined by electrical analogy method (ASHVE TRANSACTIONS, Vol. 48, 1942, p. 75). C. O. Mackey and L. T. Wright, Jr.: Periodic heat flow—Homogeneous walls or roofs (ASHVE TRANSACTIONS, Vol. 50, 1944, p. 293). C. O. Mackey and L. T. Wright, Jr.: Periodic heat flow—Composite walls or roofs (ASHVE TRANSACTIONS, Vol. 52, 1946, p. 283). H. A. Johnson: Periodic heat transfer at the inner surface of a homogeneous wall (ASHVE TRANSACTIONS, Vol. 54, 1948, p. 143).

[30] F. C. Houghten, Carl Gutberlet, and A. A. Rosenburg: The effect of solar radiation on the heat transmission through walls (*American Society of Testing Materials Symposium on Thermal Insulating Materials*, 1939).

[31] F. C. Houghten, H. T. Olson, and Carl Gutberlet: ASHVE RESEARCH REPORT No. 1157—Summer cooling load as affected by heat gain through dry, sprinkled and water covered roofs (ASHVE TRANSACTIONS, Vol. 46, 1940, p. 231).

[32] F. C. Houghten, Carl Gutberlet, and A. J. Wahl: ASHVE RESEARCH REPORT No. 1001—Cooling requirements of single rooms in a modern office building (ASHVE TRANSACTIONS, Vol. 41, 1935, p. 53).

[33] J. N. Livermore: Study of actual vs. predicted cooling load on an air conditioning system (ASHVE TRANSACTIONS, Vol. 49, 1943, p. 287).

[34] F. C. Houghten, E. C. Hach, S. L. Taimuty, and Carl Gutberlet: ASHVE RESEARCH REPORT No. 1195—Heat gain through walls and roofs as affected by solar radiation (ASHVE TRANSACTIONS, Vol. 48, 1942, p. 91).

[35] J. P. Stewart: Solar heat gain through walls and roofs for cooling load calculations (ASHVE TRANSACTIONS, Vol. 54, 1948, p. 361).

[36] G. V. Parmelee and W. W. Aubele: ASHVE RESEARCH REPORT No. 1442—Radiant energy emission of atmosphere and ground (ASHVE TRANSACTIONS, Vol. 58, 1952, p. 85).

[37] D. Brunt: Radiation in the atmosphere (*Supplement to the Quarterly Journal of the Royal Meteorological Society*, Vol. 66, 1940).

[38] N. Ozisik and L. F. Schutrum: Solar heat gains through slat-type between-glass shading devices (ASHRAE TRANSACTIONS, Vol. 66, 1960, p. 359).

[39] G. V. Parmelee and D. J. Vild: ASHVE RESEARCH REPORT, No. 1485—Design data for slat-type sun shades for use in load estimating (ASHVE TRANSACTIONS, Vol. 59, 1953, p. 403).

[40] Personal communication from C. W. Pennington related to work in progress on ASHRAE Research Project RP-30, for which papers will be published.

[41] C. W. Pennington and W. A. Smith: Shading coefficients for glass block panels (ASHRAE TRANSACTIONS, Vol. 70, 1964).

[42] N. Ozisik and L. F. Schutrum: Heat gain through windows shaded by canvas awnings (ASHRAE TRANSACTIONS, Vol. 64, 1958, p. 463). N. Ozisik and L. F. Schutrum: Heat gain through windows shaded by metal awnings (ASHRAE TRANSACTIONS, Vol. 65, 1959, p. 311).

[43] C. S. Leopold: The mechanism of heat transfer, panel cooling, heat storage (REFRIGERATING ENGINEERING, July 1947, p. 33). C. S. Leopold: Hydraulic analogue for the solution of problems of thermal storage, radiation, convection and conduction (ASHVE TRANSACTIONS, Vol. 54, 1948, p. 389).

[44] C. O. Mackey and N. R. Gay: Heat gains are not cooling loads (ASHVE TRANSACTIONS, Vol. 55, 1949, p. 413).

[45] C. O. Mackey and N. R. Gay: Cooling load from sunlit glass (ASHVE TRANSACTIONS, Vol. 58, 1952, p. 321).

[46] *Application Engineering Standards for Air Conditioning for Comfort* (Air Conditioning and Refrigerating Machinery Association, Inc., 1947, p. 8).

[47] C. M. Ashley: Psychrometric factors in the air conditioning estimate (ASHVE TRANSACTIONS, Vol. 55, 1949, p. 91).

[48] W. G. Darley: Cooler footcandles for air conditioning (ASHVE TRANSACTIONS, Vol. 46, 1940, p. 367). IES-ASHVE Joint Committee on Lighting and Air Conditioning: Lighting and air conditioning design factors (ASHVE JOURNAL SECTION, *Heating, Piping and Air Conditioning*, September 1941, p. 605). H. M. Sharp: Lighting and air conditioning (*Heating and Ventilating*, November 1942, p. 35).

[49] W. L. Marn: *Commercial Gas Kitchen Ventilation Studies* (American Gas Association Laboratories, *Research Bulletin* No. 90, March 1962).

[50] *Gas and Electric Consumption in Two College Cafeterias* (American Gas Association, October 1950).

[51] *A Comparison of Gas and Electric Usage for Commercial Cooking* (American Gas Association, 1949).

[52] E. A. Jahn: *Commercial Kitchen Ventilation* (American Gas Association, April 1960, p. 24) and other sources.

[53] Compiled by J. P. Stewart and E. A. Jahn from various sources.

[54] H. T. Gilkey, D. R. Bahnfleth and R. W. Roose: Cooling a small residence with a two-horsepower mechanical condensing unit (ASHVE TRANSACTIONS, Vol. 59, 1953, p. 283). D. R. Bahnfleth, C. F. Chen and H. T. Gilkey: Cooling a small residence using a perimeter-loop duct system (ASHVE TRANSACTIONS, Vol. 60, 1954, p. 271). W. S. Harris and P. J. Waibler: Cooling studies in a research home (ASHVE TRANSACTIONS, Vol. 60, 1954, p. 487). H. T. Gilkey, W. S. Stoecker, and S. Konzo: Effects of weather conditions on cooling unit operation in a residence (ASHAE TRANSACTIONS, Vol. 61, 1955, p. 255).

[55] *Load Calculation for Residential Winter and Summer Air Conditioning* (National Warm Air Heating and Air Conditioning Association, *Manual J*). *Standard for Application of Year-Round Residential Air Conditioning* (Air Conditioning and Refrigeration Institute, *Standard* 230–62). *Cooling Load Calculation Guide* (The Institute of Boiler and Radiator Manufacturers, *Guide C-30*, 3rd edition).

[56] *The All-Industry Procedure for Heat Gain Calculation and Equipment Selection* (Technical Information Feature, *The Bulletin*, National Warm Air Heating and Air Conditioning Association, May 1961).

[57] *Standard* 210–62: *Standard for Unitary Air-Conditioning Equipment; Standard 240: Standard for Unitary Heat Pump Equipment; Standard* 250–62: *Standard for Unitary Heat-Operated Air-Conditioning Equipment* (Air Conditioning and Refrigeration Institute). *American Standard ASA Z21.40.1: Approval Requirements for Gas-Fired Absorption Air Conditioning Appliances; American Standard ASA Z21.40.2: Approval Requirements for Gas Engine-Powered Air Conditioning Appliances* (American Gas Association, Inc.).

CHAPTER 28

REFRIGERATION LOAD

Heat Gains from Walls, Roofs, and Floors; Air Change Load; Product Load; Heat Gains from People, Lights and Other Sources; Short Method Calculations

TO SELECT refrigeration equipment which will result in a balanced system it is first necessary to calculate the heat load of the refrigerated space. There are four general sources of heat: (1) wall heat gain, (2) air changes, (3) product load, and (4) miscellaneous loads, such as the heat gain from men working in the room, lights, electric motors and other heat producing equipment. For a complete calculation, each of the four sources should be evaluated separately to determine the total.

WALL HEAT GAIN

The heat gain through walls, floor, and ceiling will vary with the following factors: type of insulation, thickness of insulation, construction, outside wall area, and temperature difference between refrigerated space and ambient air.

The heat transfer factors at various temperature differences are listed in Table 1. The thickness of cork referred to in this table is actual cork or equivalent insulation thickness, not the overall wall thickness. The comparative values of various insulation materials can be found in Chapter 24, Table 4.

The overall coefficient of heat transmission, U, of the wall can be found by the following equation:

$$U = \frac{1}{\frac{1}{f_i} + \frac{x}{k} + \frac{1}{f_o}} \qquad (1)$$

where

U = coefficient of heat transmission, Btu per (hour) (square foot) (Fahrenheit degree).
x = thickness of the wall, inches.
k = conductivity of material in wall, Btu per (hour) (square foot) (Fahrenheit degree per inch thickness).
f_i = inside film or surface conductance, Btu per (hour) (square foot) (Fahrenheit degree).
f_o = outside film or surface conductance, Btu per (hour) (square foot) (Fahrenheit degree).
f_i and f_o are frequently used as 1.65 for still air. If the outer surface is exposed to weather, f_o is increased to 6.

With thick walls and low conductivity, the resistance x/k makes U so small that $1/f_i$ and $1/f_o$ have little effect and can be omitted from the calculation. As walls are seldom made of one material, the value x/k represents the composite resistance value of the several materials used in series to the heat flow, and for a wall with flat parallel surfaces of materials 1, 2, 3, etc.,

$$U = \frac{1}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3}} \qquad (2)$$

where x_1, x_2, x_3, etc., are the thicknesses and k_1, k_2, k_3, etc., are the conductivities of the several materials used.

After establishing the coefficient of transmittance U the heat gain is given by the basic equation:

$$Q = UA\Delta t \qquad (3)$$

where

Q = heat leakage, Btu per hour.
A = outside area of section, square feet.
Δt = difference between average outside temperature and average refrigerated space temperature, Fahrenheit degrees.

The refrigeration industry has tended to standardize the minimum insulation of a refrigerator. Table 2 is a list of recommended minimum insulation thicknesses. Installations have been made with no insulation in the floor, but this type of installation will not be discussed due to the lack of authentic data.

The outdoor design temperatures for the major cities in the United States can be found in Table 1, Chapter 27.

If the refrigerator is exposed to the sun, additional heat will be added to the heat load. For practical purposes, the temperature difference can be adjusted to compensate for the sun effect. The values given in Table 3 are applicable throughout the 24 hr period and are added to the ambient temperature in calculating wall heat gain.

AIR CHANGES

Each time the door is opened some outside air enters the storage room. The temperature of this warm outside air must be reduced to the storage temperature, thus adding to the refrigeration load. It is difficult to determine the load with any degree of accuracy. The traffic in a refrigerator usually varies with its size or volume. The number of times doors are opened is dependent upon the volume rather than the number of doors. The air changes listed in Table 4 are based on practical experience.

The heat removed to reduce one cubic foot of air from outside conditions to the refrigerator temperature is listed in Table 5. Inlet air temperature listed in Table 5 refers to the air which enters the refrigerator when the doors open.

Table 4 does not apply if outdoor air is provided. The ventilating load under these conditions will replace the door opening load, if greater. To calculate the load due to ventilation, change the ventilating cubic feet per minute to cubic feet per 24 hours (cfm×60×24) and use Table 5 for the heat load per cubic foot of air.

PRODUCT LOAD

A product placed in a refrigerator at a temperature higher than the storage temperature will lose heat until it reaches the storage temperature. The quantity of heat to be removed may be calculated from a knowledge of the product, including its state upon entering the refrigerator, its final state, its

The general responsibility for this chapter is assigned to TC 2.1, Load Calculation Data and Procedures.