W_1 and W_2 = humidity ratio at points 1 and 2 respectively.
h_{w3} = enthalpy of saturated liquid at the final temperature, t_3.

If a breakdown into *latent* and *sensible heat* components is desired, the following relations may be used:

The *latent heat* may be found from

$$q_e = (W_1 - W_2)h_{fg4} \tag{7}$$

where

h_{fg4} = enthalpy at the condensing temperature, t_4.

The *sensible heat* may be shown to be

$$q_s + q_w = (h_1 - h_2) - (W_1 - W_2)h_{g4} + (W_1 - W_2)\,(h_{w4} - h_{w3}) \tag{8}$$

where

h_{g4} = 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_3. Then,

$$q_w = (W_1 - W_2)\,(h_{w4} - h_{w3}) \tag{9}$$

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_{w3} = 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

$$q_s + q_w = (38.42 - 25.10) - (0.00565 \times 1091.34) + 0.00565\,(37.11 - 22.12)$$
$$= 13.32 - 6.16 + 0.00565 \times 14.99$$
$$= 13.32 - 6.16 + 0.08 = 7.24 \text{ Btu per lb of dry air.}$$

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 36

REFRIGERATION

Refrigeration Theory: Definitions and Basic Concepts, Refrigerants, Vapor Compression Refrigeration Cycles, Suction and Discharge Pressure Effect, Complex Refrigeration Cycles, Air Cycle, Steam Jet, Absorption System, Heat Pump; Basic Refrigeration Equipment: Compression Machines and Controls, Condensers, Evaporators and Coolers; Refrigeration Control, 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 × 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:

$$H_t = (\text{Btu per hour heat gain}) \div 12{,}000 \tag{1}$$

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