The total refrigeration load, q_t, of a cooling and dehumidifying coil (or air washer) per lb of dry air 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_4, of the entering air.
3. The heat of *subcooling*, q_w, removed from the condensate in cooling it from the condensing temperature, t_4, to the leaving condensate temperature, t_3.

Items 1, 2, and 3 may be related by

$$q_t = q_s + q_e + q_w \qquad (5)$$

If only the *total heat* value is desired, it may be computed by

$$q_t = (h_1 - h_2) - (w_1 - w_2)h_{w3} \qquad (6)$$

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_{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

$$q_e = (w_1 - w_2)h_{fg4} \qquad (7)$$

where

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

The *sensible heat* may be shown to be

$$q_s + q_w = (h_1 - h_2) - (w_1 - w_2)h_{g4} + (w_1 - w_2)(h_{w4} - h_{w3}) \qquad (8)$$

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,

$$q_w = (w_1 - w_2)(h_{w4} - h_{w3}) \qquad (9)$$

The final condensate temperature, t_3, leaving the system is subject to substantial variations, depending upon the method of coil installation, as affected by coil face orientation, air flow direction, air duct insulation, etc. In practice, frequently t_3 is the same as the leaving wet-bulb temperature. Within the normal air-conditioning range, precise values of t_3 are not necessary since heat of the sub-cooled condensate represents about 0.5 to 1.5 percent of the total refrigeration load.

All values for solving the foregoing equations may be found on the ASHRAE PSYCHROMETRIC CHART (Chart 1) 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 of 54 F which is between the leaving air dew point and coil surface temperature. Find the total, latent, and sensible cooling loads on the coil.

Solution: From the ASHRAE PSYCHROMETRIC CHART, find the following:

h_1 = 38.42 Btu per lb of dry air.
h_2 = 25.10 Btu per lb of dry air.
t_4 = 69 F dew point of entering air.
w_1 = 0.01525 lb per lb of dry air.
w_2 = 0.00960 lb per lb of dry air.

From Table 3, find:

h_{w4} = 37.07 Btu per lb.
h_{w3} = 22.08 Btu per lb.
h_{fg4} = 1054.27 Btu per lb.
h_{g4} = 1091.34 Btu per lb.

The total heat from Equation 6 is

$$q_t = (38.42 - 25.10) - (0.01525 - 0.00960) \times 22.08$$
$$= 13.32 - (0.00565 \times 22.08)$$
$$= 13.32 - 0.12 = 13.20 \text{ Btu per lb dry air.}$$

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

$$q_s + q_w = (38.42 - 25.10) - (0.00565 \times 1091.34) + 0.00565\,(37.07 - 22.08)$$
$$= 13.32 - 6.16 + 0.00565 \times 14.99$$
$$= 13.32 - 6.16 + 0.08 = 7.24 \text{ Btu per lb of dry air.}$$

The *subcooling* 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 35

AIR-HEATING COILS

Uses for Coils; Coil Construction and Design: Steam Coils, Water Coils, Flow Arrangement, Applications; Coil Selection: Coil Ratings; Heat Transfer; Heating Coil Performance: Overall Heat Transfer Coefficients

COILS described in this chapter are used for heating air under forced convection. The total coil surface may consist of a single coil section or a number of individual coil sections assembled into a bank. The application of the coils described in this chapter is limited to comfort heating and air conditioning employing steam or hot water (250 F maximum) as the heating medium.

USES FOR COILS

Heating coils are used for tempering, preheating, reheating, or booster heating. The coils serve air-heating purposes only, but the apparatus assembly may include means for humidification and air cleaning. Steam or hot water are the usual heating media, although other media are used in special cases, e.g., glycols or the discharge gas from a refrigerating system.

COIL CONSTRUCTION AND DESIGN

The coils described in this chapter are *extended-surface* coils. The heat transfer surface consists of (1) the primary surface and (2) the secondary surface.

The primary surface is the surface of the round tubes or pipes, which are arranged in a repetitive pattern with respect to the air flow.

The secondary surface (fins) consists of thin metal plates or a spiral ribbon uniformly spaced or wound along the length of the primary surface, and in intimate contact with it for good heat transfer from primary to secondary surface.

The bond between secondary and primary surface is a most important factor in the performance of extended-surface coils. This bond must be maintained permanently to assure continuation of rated performance.

The heat transfer bond may be achieved in numerous ways among which bonding the fins to the tubes mechanically is employed most frequently. The bonding is generally accomplished by expanding the tubes into the tube holes in the fins to obtain a permanent mechanical bond. The tube holes are frequently provided with a formed fin collar, which provides the area of thermal contact and may serve as a means of spacing the fins uniformly along the length of the tubes.

The fins of spiral or ribbon-type fin coils are tension-wound onto the tubes. In addition, an alloy with low melting point, such as solder, may be used to provide a metallic bond between fins and tube. Some types of spiral fins are knurled into a shallow groove on the exterior of the tube. Sometimes the fins are formed out of the material of the tube itself.

The fin designs most frequently used for heating coils are flat plate fins, plate fins of special shape, and spiral or ribbon fins, all shown in Fig. 1 of Chapter 34.

Copper and aluminum are the materials most commonly used in the fabrication of extended-surface coils. Tubing made of steel or various copper alloys is used in applications where corrosive forces might attack the coils from either inside or outside. The most common combination is aluminum fins on copper tubes.

Lightweight extended-surface heating coils most commonly have tubes with outside diameters of $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$ and 1 in., and have fins spaced from 3 per inch up to 14 per inch. The tube spacing varies from approximately 1 to 3 in. on centers, depending on tube diameter, fin dimensions, and other considerations.

Steam Coils

For proper performance of steam heating coils, condensate and air or other noncondensables must be rapidly eliminated and the steam must be uniformly distributed to the individual tubes. Noncondensable gases, such as carbon dioxide, remaining in a coil, cause chemical corrosion and result in early coil failure.

Uniform steam distribution is accomplished by different methods such as:

1. Individual orifices in the tubes.
2. Distributing plates in the steam headers.
3. Special perforated small diameter inner steam distributing tubes extending into the larger diameter tubes of the primary surface.

Coils of the perforated inner tube type are constructed with different arrangements such as:

a. Supply and return on one end, with the incoming steam used to heat the leaving condensate.
b. Supply and return on opposite ends.
c. Supply and return on one end and a supply on the opposite end.

Coils arranged as described in Item 3a are sometimes referred to as *non-freeze type*.

Particular care in piping, controls, and installation is necessary to protect the coils from freeze-up due to incomplete draining of condensate.

Properly designed and selected steam distribution tube coils distribute the steam throughout the entire length of all primary tubes, even when the leaving air temperature is controlled by modulating the steam supply through a steam-metering valve. Thus more uniform leaving air temperatures are produced over the entire length and face of the coil than would result when using a single-tube coil.

When the entering air temperature is 32 F or lower, uniform leaving air temperature is the first prerequisite for protecting the condensate from freezing. For positive freeze protection, the modulating valve must be so controlled, that the inside heat transfer surface temperature is always above the freezing temperature.

Water Coils

The performance of water coils for heating depends on the elimination of air from the system and the proper distribution

The general responsibility for this chapter is assigned to TC 9.1 Coils, Fan-Coil Units, Air-Cooled Condensers.