CHAPTER III

PHSYCHROMETRY AND THERMAL CONTROL

3.1. INTRODUCTION

Psychrometry studies the air properties. The psychrometric chart provides a visual picture of the changes that take place in the properties of air.

There are seven principal proprieties of the air that are noted on the chart:

1) Dry-bulb temperature: is the air temperature, as indicated by a thermometer

2) Percent of relative humidity: is the weight of water vapor in a given volume of space, compared to the weight of water vapor that the same volume could hold if it were 100% saturated. For example, at normal pressure and 70°F temperature, one cubic foot of air can hold 0.000789 lb of water vapor. This way, the air is 100% saturated when it has 0.000789 pounds of water vapor per cubic foot. If under the same conditions, the quantity of water vapor per cubic foot is 0.00395 lb, the air is 0.000395/0.000789x100% = 50% saturated.

3) Wet-bulb temperature: is the temperature indicated by a thermometer with a wet wick attached to its bulb.

4) Humidity ratio: is the weight of water vapor held in 1 pound of dry air. The weight is frequently measured in grains, where 1 grain = 1/ 7000 lb.

5) Dew point: is the air temperature at which condensation begins.

6) Enthalpy: is the total heat contained in an air mixture, expressed frequently in BTU per pound of dry air.

7) Specific volume: is the number of cubic feet that 1-pound of air occupies.

Figure 3.1 shows the psychrometric chart, where the air characteristics can be appreciated.

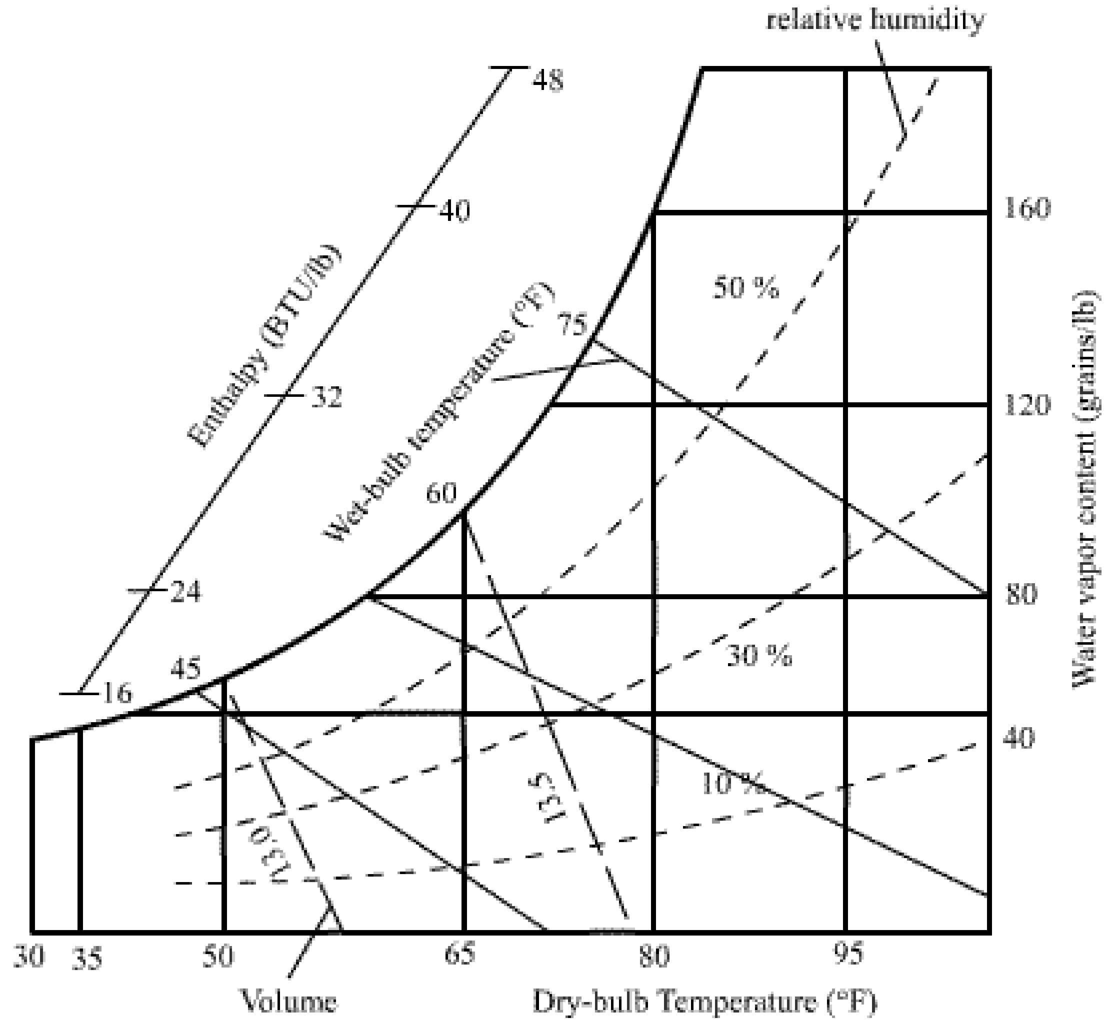

Figure 3.1 Phychrometric chart.

3.2 COMFORT

Is the delicate balance of feelings in the body in relation to its surroundings. Four air properties define comfort in an A/C system:

1) Temperature
2) Humidity
3) Air movement
4) Air cleanliness

The comfort chart shows on the psychrometric chart the different combinations of temperature and humidity for both, summer and winter.

3.3 BASIC OPERATIONS SHOWN ON THE PSYCHROMETRIC CHART

The psychrometric chart is used to graph different processes. This can be appreciated on Figure 3.2.

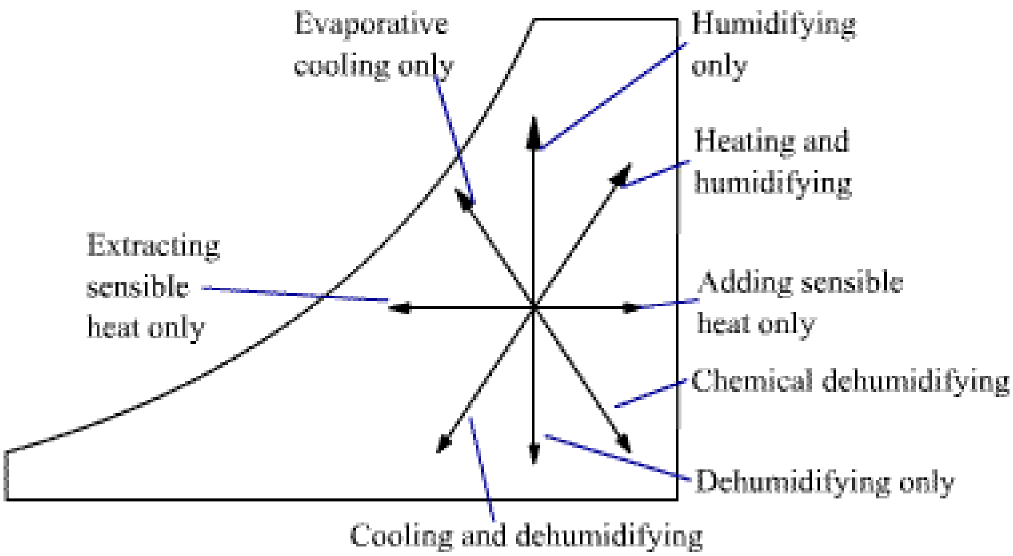

Figure 3.2 Processes Represented on the Psychrometric Chart

The following figures show various air conditioning processes:

1) Cooling: is the process of extracting sensible heat to the air with an evaporator. The wet-bulb temperature and total heat content of the air decrease, and the relative humidity increases. There is no change in dew point or moisture content. (Figure 3.3.)

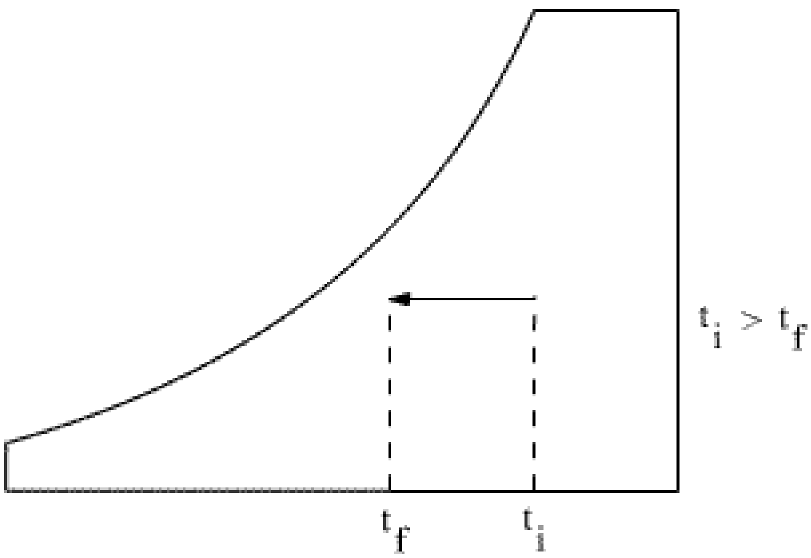

Figure 3.3. Cooling air without humidification

2) Heating: is the process of adding sensible heat. The wet-bulb temperature and total heat content increase and the relative humidity decreases. The dew-point temperature and the moisture contend do not change. (Figure 3.4)

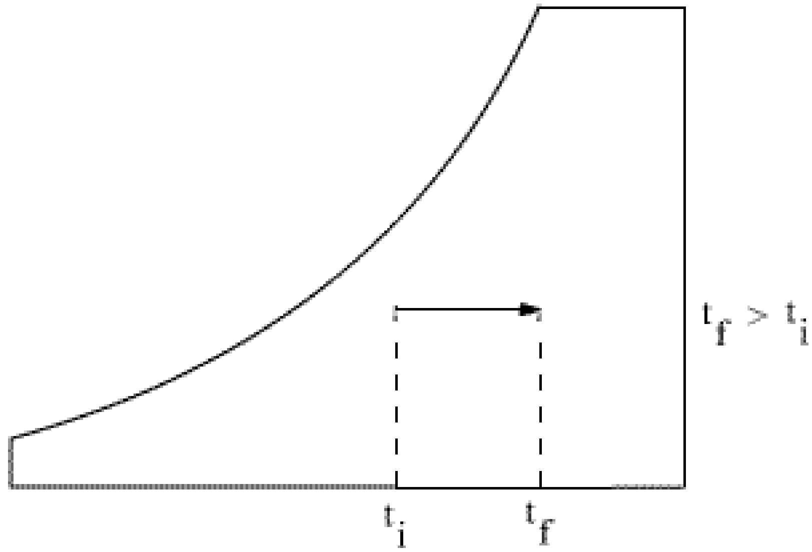

Figure 3.4. Heating air by adding sensible heat.

3. Humidifying: is the addition of moisture to the air. The only property that does not change is the dry-bulb temperature. The added heat is used to evaporate the moisture. The wet-bulb temperature, dew point and relative humidity increase. (Figure 3.5)

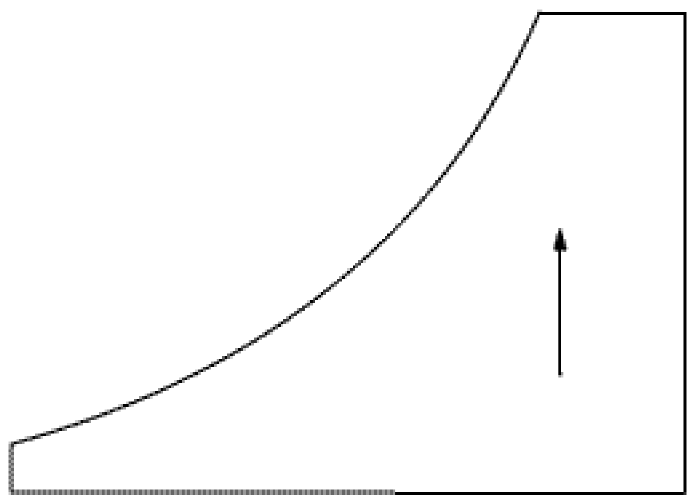

Figure 3.5. Addition of moisture to the air

4. Cooling and Dehumidifying: Is the air-conditioning process that normally takes place during summer. The cooling coil, at the same time cools the air and condenses moisture as the air passes through it. The total heat and wet bulb and dew point temperature all decrease. (Figure 3.6)

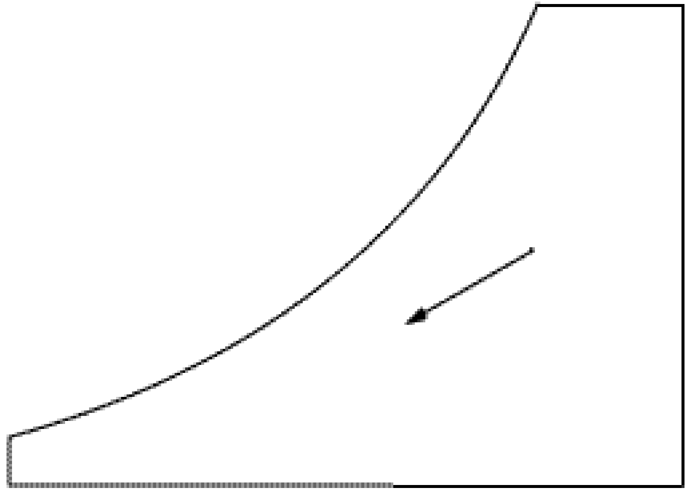

Figure 3.6. Cooling and Dehumidification.

5. Heating and Humidifying: Is the typical process that takes place on winter. The air picks up both heat and moisture as it passes through the heating device. The total heat and wet-bulb and dew-point temperatures all increase. (figure 3.7)

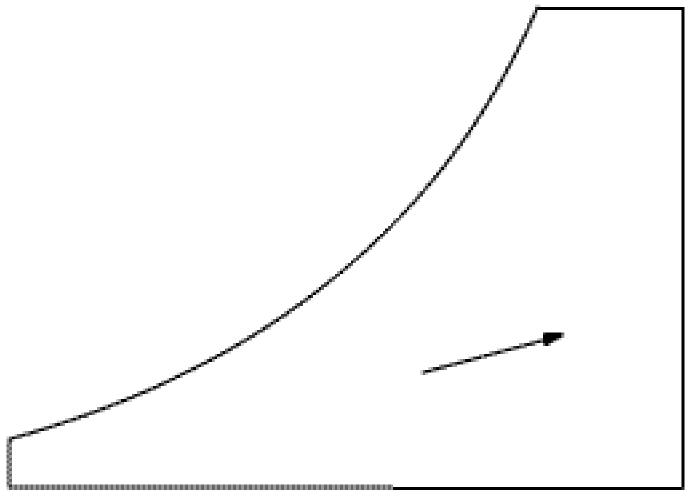

Figure 3.7. Heating and Humidifying.

Example 3.1. Find the relative humidity and the dew-point temperature for the following air mixtures:

a) 80° F (D B), 60° F (W B)

b) 70° F (D B), 55° F (W B)

Answers:

a) 30 % RH; 45° F (dew-point)

b) 39 % RH; 44° F (dew-point)

Example 3.2.

Find the water vapor content in grains per pound for the following air mixtures:

a) 90° F (DB), 50% RH

b) 80° F (DB), 60% RH

Answers:

a) 106 grains/lb

b) 92 grains/lb

Example 3.3.

Find the DB temperature in °F for the following air mixture

50°F (WB), 13.5 ft /lb

Answer: 74°F (DB)

Example 3.4.

Which air/water vapor mixture will occupy the largest volume?

80°F (DB), 70°F (WB) or 65°F(DB), 60°F (WB)

Answer: The first one.

3.4 THE REFRIGERATION CYCLE

The relation to obtain the total heat added or extracted to or from the air when the enthalpy varies is:

BTUh = 4.5 x cfm x $(h_2 - h_1)$ (3.1)

Cooling equipments extract heat from indoor spaces and deliver it on outdoor locations. The opposite process is done with heating equipment.

The compressive refrigeration cycle, which is the base for the cooling equipment, is shown in Figure 3.8.

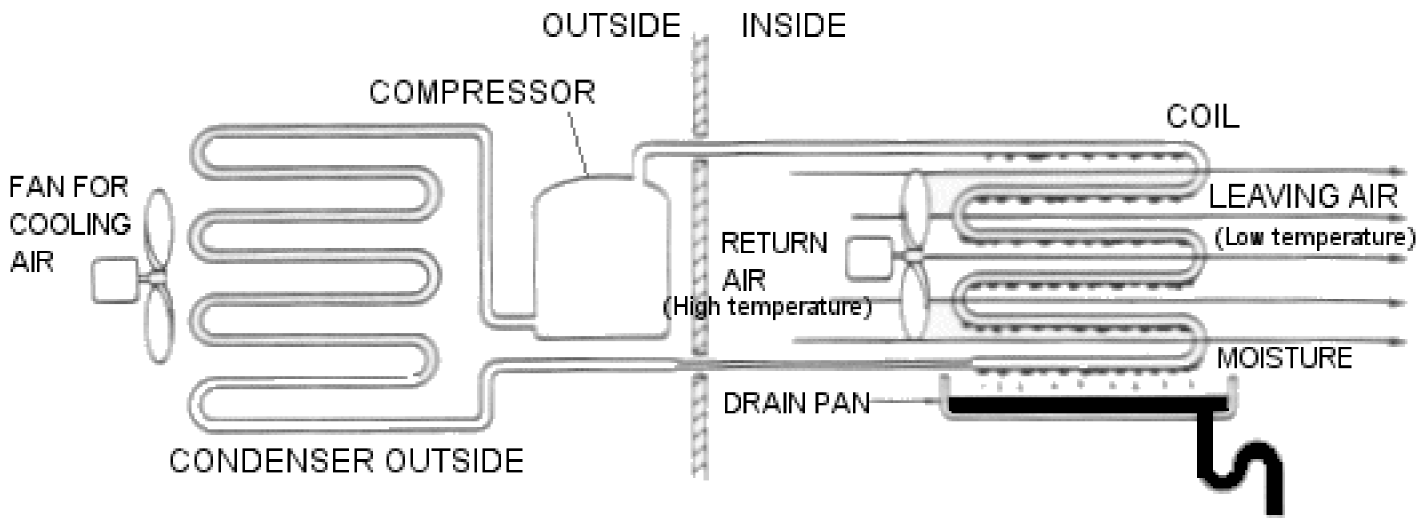

Figure 3.8. The Refrigeration Cycle

Example 3.5.

Suppose a 2000 ft^2 home with an 8-ft ceiling. If the home is to be maintained at 75°F (DB), 50% (RH) in doors when the outdoor temperature is 90°F (DB), 40 % (RH). Calculate the total heat to be extracted per hour, if every hour will be changed 25% of the total air in the room.

Solution: From the psychrometric chart:

Indoor: 75°F (DB), 50% (RH)® h_i = 28 BTU/lb

Outdoor: 94°F (DB), 40% (RH)® h_o = 38 BTH/lb

The cfm that enter the room are:

Cfm = 2000 x 8 x 0.25/60 = 66.7 ¦^{3} /min

Applying ec.(3.1) : BTUh = 4.5 x 66.7 x (38-28)

BTUh = 3000 BTU/hr.

Tons = BTUh/12000 = 0.25 Tons

Example 3.6

Given the outdoor design of 95°F (DB) and 78°F (wB); indoor design 80°F (DB) and 67°F (wb); 20 000 cfm is the required air circulation; and 4000 cfm is the required ventilation air. Find the temperature of the air mixture.

Solution: 4000/20000 = 20% of the total air is ventilation air:

95 x 0.2 = 19

80 x 0.8 = 64

Total = 83

Mixture temperature = 83 °F (DB)

Inside the coil in Figure 3.8 there is some gas, used as refrigerant. The most commonly used refrigerants have been chlorofluorocarbon (CFC) gases such as Freon , but they are a threat to the atmosphere, because of the stratospheric ozone depletion and global warming. Others eventually more efficient are currently substituting these refrigerants.

The refrigerant that enters the compressor, coming from inside the building has absorbed heat from indoors and is a low pressure, high temperature gas. The compressor increases the gas pressure, forcing it to circulate through the condenser coil. The air that passes through the condenser extract heat from the refrigerant, reducing the gas temperature.

As heat is extracted from the refrigerant, it becomes liquid that is forced to circulate again inside the building. The liquid is released through an expansion valve. By physical reasons, the pressure on the outside of the expansion valve is low, and the liquid at high pressure becomes a gas at low pressure and low temperature. This gas circulates through the coil in the evaporator unit, inside the building. The air surrounding this coil is forced to circulate and the low pressure-low temperature gas absorbs the heat from the air, cooling it, and increasing the refrigerant temperature.

The evaporator coil output is connected to the compressor and the low pressure-high temperature refrigerant enters again the compressor to initiate a new cycle.

In bigger systems, on the condenser side, in place of circulating air for extracting the heat from the refrigerant, it is used water, which makes this process more efficient.

The coil in the evaporator not only cools the inside air, but also dehumidifies it. When the warm air becomes in contact with the coil, decreases the air temperature and at the same time reaches the dew point, where the moisture in the air is condensed. The water obtained from this process falls to a pan from where it goes through a pipe to outside the building.

3.5. AIR-CONDITIONING EQUIPMENT

Most air-conditioning installations are composed of the following components:

1.- A fresh air intake to maintain the indoor air quality. In residential installation this air is obtained by infiltration, but commercial installations use mechanical devices to force the air inside the building.

2.- An air handler that controls air quantity, temperature, humidity and quality.

3.- A supply duct system that distributes conditioned air through the building. The air is delivered to each conditioned space and forced to circulate through some return path to the air handler.

4.- An exhaust air path to minimize odors or airborne contaminants from kitchens, laboratories or rest rooms.

The equipment efficiency is measured by an index called SEER (Seasonal Energy Efficiency Ratio). This index measures the number of BTUs removed by 1 watt of electrical energy input. The range of availability goes from 8 to 14 or more. The ways to improve. The SEER is constructing more efficient compressors and better condenser units. As the condenser size increases, the condensing temperature decreases, lowering compressor load and input energy.

Water-cooler refrigeration equipment gives better SEER than air-cooled equipment. For this cooling towers are used. A cooling tower is an outdoor shower that cools water by evaporation.

3.6. APPROXIMATE METHOD FOR CALCULATING COOLING L0AD [1]

The method can be used for residential building and as a first approximation to commercial buildings. The following elements will be taken into account:

1.- Gains Through Roof and Walls

This gain is calculated with the equation $Q = U \times A \times DETD$ (3.2)

Where U – values are for the summer season; A is the area of the roof or wall; and DETD is the design equivalent temperature difference listed in tables from the ASHRAE (American Society of Heating Refrigerating and Air Conditioning Engineers) Handbook of Fundamentals

The DETD values are based on an average indoor temperature of 75°F and the defined outdoor conditions for each location.

2.- Gains Through Glass

Are calculated through the formula

$$Q = A \times DCLF \qquad (3.3)$$

Where A is the glass area and DCLF are the Design Cooling Load Factors, defined in tables from the ASHRAE Handbook of fundamentals. The DCLF include the U-value and depend on the type of glass, the outdoor design temperature, and the glass orientation. The DCLF were based on an inside temperature of 75°F.

3.- Gains from outdoor Air

Depending on the way air enters the building, the sensible heat gain will be calculated by one of the following equations:

Infiltration:

$$Q_{inf} = (A_{exposed})\ (\text{Infiltration Factor}) \qquad (3.4)$$

Ventilation:

$$Q_{mech} = (cfm)\ (\text{ventilation Factor}) \qquad (3.5)$$

The infiltration and ventilation factors are obtained from tables, and the cfm depend on the recommended outdoors air requirements for ventilation that depends on the type of facility.

4.- Gains From People

In this part only sensible gains are tabulated. The latent gains will be included at the end. The following expression is used:

$$Q_{people} = (\text{N° of occupants}) (\text{Sensible gain/occupant}) \quad (3.6)$$

The sensible gain/occupant depends on the type of developed activity, and is found also in tables from the ASHRAE Handbook.

5.- Gains From Lights

The heat gain due to incandescent lights is calculated by means of

$$Q_{inc} = 3.4\ W, \quad (3.7)$$

Where W is the used incandescent wattage in the building

The fluorescent lights develop more heat due to the ballast and it gain is calculated through:

$$Q_{fl} = 1.2\ (3.4\ W) \quad (3.8)$$

The factor 1.2 is included to take into account the ballast heat gain.

6.- Gains From Equipment

In residences it is accepted that 1200 to 1600 BTUh of sensible heat gain is produced by appliances.

For the calculations in other type of facility, the heat gain is obtained for different equipment from specialized tables.

7.- Latent Heat Gains

The simplest way is to assume that between 10% and 30% of the calculated sensible heat gains should be added due to latent heat gains. In general it will depend on the outdoor air infiltration and the type of occupancy. For wet locations, the percent of latent heat increases.

Example 3.7

1.- A 40 ft x 40 ft surface and 10 ft height one story office building is located in a city in South Florida (wet location with mean daily temperature range of 15°F). The office is facing north. The adjoining offices on the east and south sides are conditioned. On the West side of the office there is a non-conditioned and non-covered parking lot.

Roof Construction: Flat masonry with built-up roofing, and a suspend ceiling under naturally vented attic (light). U = 0.112 BTU/h –ft^2 - °F.

North and West Wall Construction: Masonry cavity walls. U = 0.120 BTU/h-ft^2 -°F.

Floor Construction: 4 in. concrete on ground.

Windows: One facing north and one facing west 6 ft x 8 ft windows of regular single glass with Venetian blinds.

Doors: Two 5 ft x 8 ft wood doors, one facing north and one facing west.

$U = 0.2$ BTU/h – ft^2 - °F.

Outdoor Design Conditions: T_{DB} = 90°F

Indoor Design Conditions: T_{DB} = 75°F

Lights: 3 kW; fluorescent.

Equipment: 5 computers (assume 200 BTUh/computer)

Determine the cooling capacity in Tons.

Section	Net Area	U-Value	DT (°F)	Equiv. TD	Cooling Load
Roof	1600	0.112	------	35	6272
N. Wall	312	0.120	------	15.3	572.8
W. Wall	312	0.120	------	15.3	572.8
N. Door	40	0.2	------	13	104
W. Door	40	0.2	------	23	184
N. Window	48	------	------	19	912
W. Window	48	------	------	52	2496
	Building Envelope Subtotal			------	11,113.6 BTUh

Lights:
3000 x 3.4 x 1.2 = 12240 BTUh

Equipment:
5 x 200 = 1000 BTUh

Ventilation:
5 x 20 x 16 = 1600 BTUh

Total Sensible Load: 27,153.6 BTUh

Latent Load: 0.3 x Sensible Load = 8,146.1 BTUh

Total load: 35,299.7 BTUh

Tons = 35,299.7/12 = 2.94 (Approximate 3 Tons)

3.7. REVIEW QUESTIONS

3.1. Name four air characteristics that define comfort.

3.2. What is a comfort chart?

3.3. What means 70% Relative humidity?

3.4. What is the Dew-point Temperature?

3.5. What information is it possible to obtain with the phycrometric chart.

3.6. If the total air circulation in a room is 6,000 cfm at 75º F DB and 50% RH and 1000 cfm of outside air is 91º F DB and 60 % RH, find the mixture RH, DB and WB temperatures.

3.7. If the specific volume of air is 14.2 cu ft/lb. at 77º F WB, the relative humidity will be ________________________.

3.8. Given: Indoor condition of 80º F and 50% RH. Find: WB and DP (dew point) temperatures.

3.9. Given: Condition of 60º F WB and 72º F db. Find: RH

3.10. Given: 68.6º F DB and 60.4º F WB. Find: RH

3.11. Given: Outdoor design of 95º F DB and 78º F WB; indoor design of 80º F DB and 67º F WB; 20,000 cfm required air circulation; and 4,000 cfm required ventilation air. Find DB temperature of mixture.

3.12. Given: Outdoor design of 100º F DB and 77º F WB; indoor design of 85º F DB and 67º F WB; 6,000 cfm required air circulation, and 960 cfm required ventilation air. Find WB temperature of mixture.

3.13. What is the compressor function in an AC system?

3.14. What does the drain line do in an AC?

3.15. What is the expansion valve for?

3.16. A one-story 40ft x 40 ft dining area restaurant is located at Miami (Mean Daily Range 15 degrees Fahrenheight). The kitchen is facing south and separated from the customer space by a partition that goes up to the ceiling (U = 0.32), and its temperature is 85 deg. F. The East wall of the restaurant face to a non-conditioned building. The ceiling height is 10 ft.

Roof Construction: Flat Masonry. U = 0.112

West and east walls construction: 13-in solid brick, no plaster. U = 0.25

North wall construction: Solid masonry. U = 0.27

Floor construction: Concrete slab

Windows: Two 6 ft x 6 ft single glazed windows protected with awnings, not openable, facing north

Front doors: Two, 3 ft x 7 ft, facing north

West door: One, 4 ft x 7 ft

Doors construction: Wood, U = 0.19

Outdoor design conditions: T (DB) = 91 Deg.F; T (WB) = 79 Deg. F

Indoor design conditions: T (DB) = 75 Deg. F; T (WB) = 62.5 Deg. F

Occupancy: 48 customers, one cashier, and 6 waiters

Lights: Fluorescent at 2 Watts per sq. ft.

Determine the necessary cooling capacity in Tons.