CHAPTER I

ELEMENTS OF APPLIED THERMODYNAMICS

1.1. INTRODUCTION.

The Air Conditioning systems extract heat from some closed location and deliver it to other places. To better understanding the principles under which these systems work, it is useful to introduce some concepts and definitions that will be used in the future. These concepts are close related to variations in the physical characteristics of gases and liquids with the temperature variation.

1.2. HEAT AND TEMPERATURE.

Heat is a form of mechanical energy associated with random motions of atoms and molecules.

When heat is added to or extracted from a body, its temperature increases or decreases. So the temperature is a parameter related to the internal energy in a body.

For measuring the body's temperature special devices are used. These are thermometers, which measure the body's temperature, using the variation of some parameter when it is located in intimate contact with the body.

Examples of such parameters may serve the body expansion, the gas pressure, etc.

Several scales are used for measuring temperature. The more commonly used are Celsius and Fahrenheit scales. They define two points:

1. The lower fixed point, which is the temperature at which the water becomes ice, at normal pressure, defined as 0° C for the Celsius scale, and 32° F for the Fahrenheit scale.

2. The upper fixed point, which is the temperature at which water becomes vapor at normal pressure, defined as 100° C for the Celsius scale, and 212° F for the Fahrenheit scale.

The relation between these two scales is obtained easily from simple geometrical considerations shown in Figure1.1.

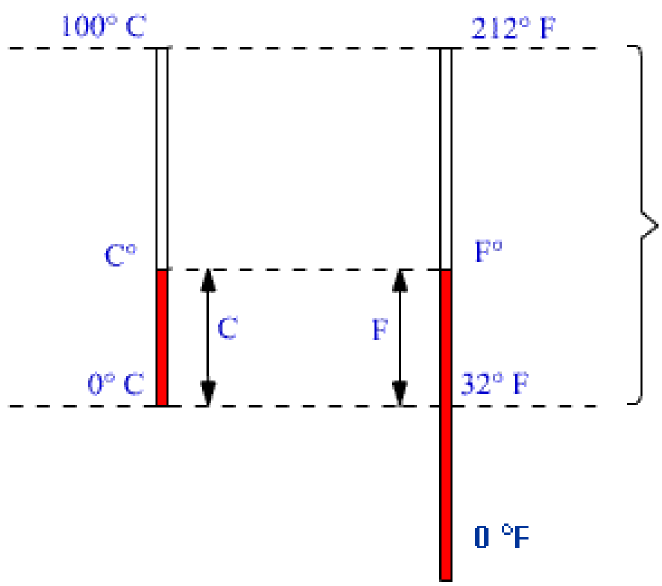

Figure 1.1. Relation between Celsius and Fahrenheit scales.

From Figure 1.1.

$$\frac{C^\circ}{F^\circ - 32} = \frac{100}{180} = \frac{5}{9} \qquad (1.1)$$

$$C° = \frac{5}{9}(F° - 32)$$

Solving for F° in relation (1.1), can be obtained:

$$F° = \frac{9}{5}(C° + 32) \qquad (1.2)$$

Example 1.1.

Calculate the temperature in °C for 75° F.

$$C = \frac{5}{9}(75 - 32) = \frac{5}{9}(43) = 23.9°C$$

There exist also the absolute temperature scales, defined as the temperature of a body that is incapable of giving up any thermal energy.

The absolute temperature scales are used in scientific works. The most popular is the used in the international system of units: the Kelvin scale.

The temperature of a body in degrees Kelvin is related to the Celsius scale by the relation:

°K = 273 + ° C   (1.3)

Example 1.2.

A body has temperature of 20° C. What is its temperature in Kevin degrees (°K)?

From relation (1.3), the temperature will be: (273+20)° K = 293° K.

A very important property of any object related with its temperature is that different objects in contact tend to vary it temperatures, until the final temperature is the same for all. This can be expressed in the following way: If objects having different temperatures are placed in an insulated enclosure, all the objects eventually come to the same temperature.

1.3 HEAT AND THERMAL ENERGY

The quantity of heat or thermal energy that an object possesses depends among other factors on its temperature and state.

When adding heat to a substance, its temperature increases if there is not change of state. This is known as sensible heat. The British Thermal Unit (BTU) is the quantity of heat required to raise the temperature of 1lb of water from 58.5° F to 59.5° F. The International system of Units uses the kilocalorie as unit of heat, defined as the quantity of heat required to raise the temperature of one kilogram of water from 14.5° C to 15.5° C.

The relation between BTU and kcal is given by:

1 BTU = 0.2520 kcal

The heat capacity of a body is the quantity of heat required to raise the temperature of the body by one degree, and is expressed in BTU/°F or in Kcal/°C.

The specific heat capacity of a substance is the quantity of heat required to raise the temperature of 1 lb of the substance by one degree, and is expressed in $\frac{BTU}{°F \cdot lb}$.

Besides the sensible heat, it also exist the latent heat. It is the heat needed to change the state of a substance.

The latent heat of fusion of a substance is the heat that must be added to unit of mass of the solid at its melting point to change it to liquid at the same temperature and pressure.

The latent heat of vaporization is the heat that must be added to unit mass of the liquid at its boiling point to change it to vapor at the same temperature and pressure.

For the water, the change from one state to the other can be represented using Figure 1.2.

$$\left[1\ lb.\ \ ICE\right] + 144\ \ BTU \rightarrow \left[1\ \ lb.\ \ H_2O\right] + 180\ \ BTU \rightarrow \left[1\ \ lb.\ \ H_2O\right] + 970\ \ BTU \rightarrow \left[1 lb.\ \ STEAM\right]$$

	Latent heat of fusion		sensible heat		Latent heat of vaporizati on	
Temperature 32°F	----------→	32°F	----------→	212°F	----------→	212°F

The sensible heat is calculated through

Q_S = mCDT (1.4)

and the latent heat through

Q_L = mL (1.5)

Figure 1.2. Process of adding heat to one pound of water.

Example 1.3. Calculate the quantity of heat required to change 2 lb of ice at 20° F into water at 50° F. The specific heat of water is 1.0 and that of ice 0.48.

Total quantity of heat = Sensible heat of ice + Latent heat of fusion + sensible heat of water.

$$BTU = m_{ice} \cdot c_{ice} \cdot (32 - 20) + L_{fusion} + m_{H_2O} c_{H_2O} (50 - 32)$$
$$= 2 \times 0.48 \times 12 + 144 + 2 \times 1 \times 18$$

1.4. HEAT TRANSFER

The basic law for heat transfer, which comes from the principle of energy conservation, is that in any closed system the heat lost by hot bodies is equal to the heat gained by cold bodies.

The process of heat transfer from a body to other may be by conduction when both bodies are in intimate contact, by convection when the air carries the heat from one to the other or by radiation when the heat is radiated in the form of waves.

The quantity of heat that flows though a body depends on several factors: the type of material, the temperature difference, and the body dimensions. This effect is shown in Figure 1.3. for a wall separating two rooms with different temperature.

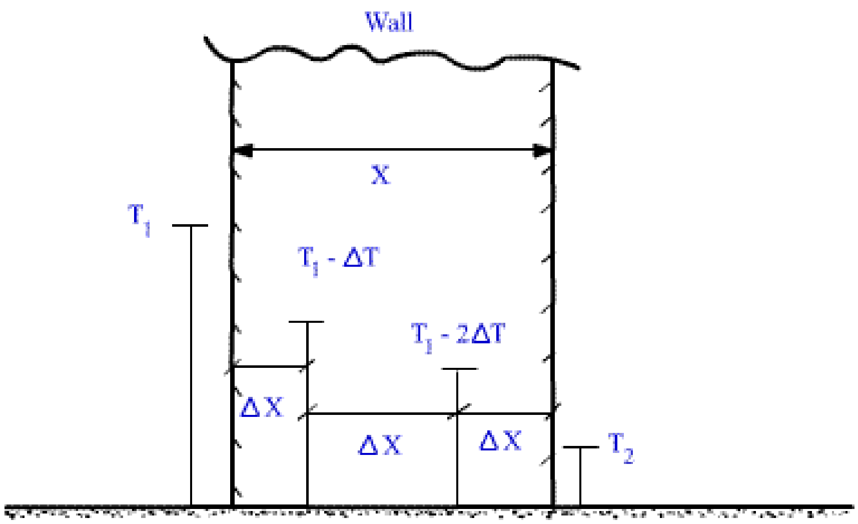

Figure 1.3. Variation of temperature between T_1 and T_2.

The rate at which the heat flows can be calculated by the expression 1.6.

$$\frac{Q}{t} = CA(\Delta T) \qquad (1.6)$$

Where Q/t is the quantity of heat that flows per unit of time, which in air conditioning calculations is usually expressed in BTU per hour (BTUh); DT is the temperature variation in °F; A is the area of the surface perpendicular to the flow, and C is the thermal conductance, defined as the rate of heat flow by conduction per unit area per unit temperature gradient.

If the thermal conductance of a material is specified for a width of 1 inch of material, then the conductivity (k) of the material have been obtained. In practical works is frequently desirable the thermal resistance (R) as the reciprocal of the conductance.

$$R = \frac{1}{C} \qquad (1.7)$$

Example 1.4.

A piece of glass fiber insulation board has the dimensions shown in Figure 1.4 and the temperature difference between its both sides is 1° F. Under these conditions the quantity of heat that flows from one side of the board to the other is 0.25 BTUh. What are the conductance, the conductivity and the resistance of this board?

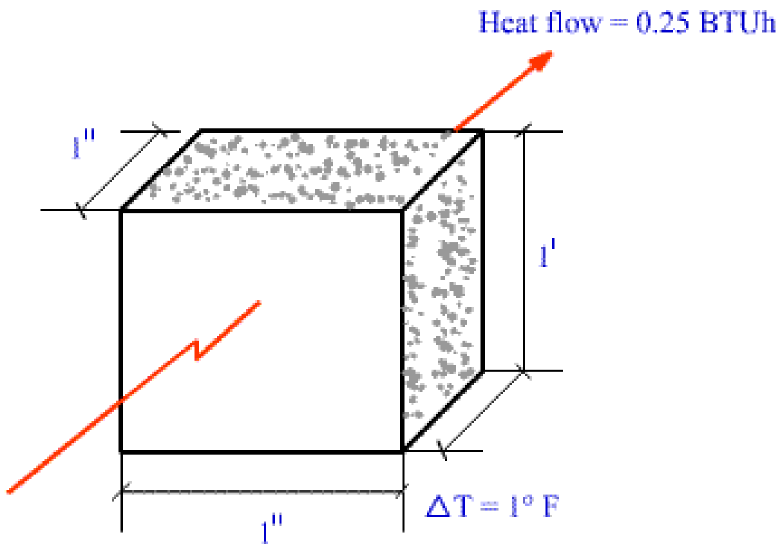

Figure 1.4. Piece of glass fiber insulation board.

According to the definitions, the conductance and the conductivity are both 0.25 BTUh, and from relation 1.5, the resistance is:

$$R = \frac{1}{0.25} = 4.0$$

Example 1.5.

If the width of the board of Example 1.4 is increased to 4 inches, what are the new values of conductivity, conductance and resistance?

The conductivity remains the same, because it is a property of the substance that does not depend on the dimensions of the object.

Conductance:

$$C = \frac{k}{x} = \frac{0.25}{4} = 0.063 \quad BTUh$$

Resistance:

$$R = \frac{x}{k} = \frac{4}{0.25} = 16$$

1.5 REVIEW QUESTIONS

1.1. - For the Celsius temperature scale, the lower fixed point is ______and the upper fixed point is _____

1.2. - For the Fahrenheit temperature scale, the lower fixed point is______ and the upper fixed point is _____

1.3. - Calculate the temperature in degrees Celsius for – 62º F.

1.4. - Calculate the temperature in degrees Fahrenheit for 45º C.

1.5. - At what temperature two thermometers graduated in degrees Celsius and Fahrenheit respectively, show the same number?

1.6. - One kilocalorie is equal to ________________________BTU.

1.7. - The quantity of heat required to increase the temperature of 4lb. of water by 40º F is _________ BTU.

1.8 - A copper container of 0.25-kg mass contains 0.4 kg of water. Container and water are initially at room temperature of 20º C as measured by a thermometer. A block of copper of 1-kg mass is heated to 100º C by placing in a steam from water boiling at normal atmospheric pressure. It is then removed from the steam and quickly placed in the water of the calorimeter. The copper block cools, the water container becomes warmer, and the final temperature as read on the thermometer, is found to be 34.5º C. From these data determine the specific heat capacity of the copper.

1.9. - The heat can be transferred by ____________________,__________________, and ______________

1.10. - The rate of heat flow by conduction per unit area per unit temperature gradient is called

1.11. - The rate of heat flow for a piece of corkboard 20 ft^2 area and 4 inches width, where the inside temperature is 60º F and the outside temperature is 95º F is