

AIR CONDITIONING TECHNOLOGY

PART 2

MORE BASIC DEFINITIONS & PRINCIPLES

In Part 2 we continue with the study of the fundamentals essential for a clear understanding of air conditioning and refrigeration technology. This data is equally applicable to heating and ventilation. The following is expressed in simple terms for clarity.

Energy

Energy is normally defined as the ability to perform work and is consists of:

- i) *Energy* stored in a body

Forms of *Energy* in storage:

Kinetic -	Due to motion or velocity
Potential -	Due to position or elevation
Chemical -	Due to reaction
Enthalpy -	Due to heat
Electrical -	Due to potential difference
Pressure -	Due to pressure difference

- ii) *Energy* in a flow between bodies

Forms of *Energy* in flow:

Work -	Due to force & distance
Heat -	Due to temperature (other) difference

The above are illustrated in Figure 1. Heat energy can flow from one body to another by conduction, convection or radiation. Radiation is either visible or invisible light energy.

FIGURE 1 Energy forms in storage and in transfer.

Heat & Temperature

Heat is a form of energy in flow from one body to another and can be expressed as follows:

Heat is a form of energy transferred from one body to another body as a result of a temperature difference.

Heat energy will always flow from a high temperature body to a body at a lower temperature.

The rate of *heat* energy flow is directly related to the difference in temperature. If no temperature difference exists, there is no *heat* energy flow. *Heat* energy is often expressed as Q . The unit of heat energy most commonly used is the Joule (J) or kilojoule (kJ).

Figure 2 shows two examples of *heat* energy flow. In the case of the office with the radiator, *heat* energy flows from the radiator with a mean temperature of 76.5 Deg C to room air at 20 Deg C as a result of the temperature difference of 56.5 K. (K = Kelvin and should always be used to express a temperature difference).

Heat is also lost from the room air at 20 Deg C to the outdoor ambient air at -1 Deg C as a result of the temperature difference of 21.0 K.

The coldroom in Figure 2 is maintained at -21 Deg C whilst the ambient temperature surrounding the coldroom is 25 Deg C. The temperature difference of 46.0 K causes *heat* energy to flow into the coldroom. The use of very effective insulation will limit the flow of heat energy to reasonable levels, which would otherwise be high with such a large temperature difference.

FIGURE 2 Directions and Rate of Heat Transfer

A further example of heat energy flow is shown in Figure 3. It is common practice in heat flow calculations to refer to the two temperatures as T_1 and T_2 . If a body were to change in temperature, T_1 would refer to the initial temperature and T_2 would represent the final temperature.

FIGURE 3 Heat Flow from a high temperature body to a body at lower temperature.

Temperature is a measure of the level of thermal activity in a body. The greater the velocity of molecules within a body, the higher the *energy* level. This results in a higher *temperature*.

The measurement of *heat energy* is normally obtained with a thermometer. The thermometer can utilise the expansion of a liquid within a tube or can utilise thermocouple technology to provide a digital reading. The unit of temperature measurement is the degree Celsius (Deg C). The Celsius scale uses 0 Deg C as a point of reference at which water freezes and 100 Deg C as the boiling point (Saturation Temperature) of water. (At an atmospheric pressure of 1.01325 bar).

There is also an Absolute Temperature Scale, which is referenced to a temperature of absolute zero. Absolute temperatures are expressed in K (Kelvin). The relationship between S.I. normal temperature and absolute temperature scales is illustrated in Figure 4.

FIGURE 4 - Temperature and Absolute Temperature Scales (S.I.)

Imperial Temperature Measurement: As the Imperial measure of temperature (Fahrenheit Scale - Deg F) still remains widely used, the relationship between Imperial normal temperature and absolute temperature scales are illustrated in Figure 4. Imperial absolute temperature is expressed in R (Rankine).

Conversion from one scale to the other is achieved as follows:

$$\text{Deg F} = (\text{Deg C} \times 1.8) + 32$$

$$\text{Deg C} = \frac{\text{Deg F} - 32}{1.8}$$

Conversion from normal temperature to absolute is achieved as follows:

$$K = \text{Deg C} + 273.15$$

$$R = \text{Deg F} + 460$$

Methods of Heat Transfer

Conduction, convection & radiation are the means, which heat transfers energy from one body to another.

Conduction

Heat energy is transferred by *conduction* when the molecules within a body are in direct contact or when the molecules of two or more bodies are in direct contact. If, for example, a copper tube were heated at one end, the movement and velocity of molecules would increase, striking adjacent molecules and imparting energy to them. This would continue throughout the length of the tube causing the energy level and temperature to rise at the far end.

Air within and surrounding the tube in direct contact with the surface of the tube would also receive heat energy as molecules at the surface of the tube strike molecules within the air.

The rate of heat energy transfer by conduction is directly proportional to the temperature difference between high and low temperature bodies. Some materials conduct heat more effectively than others. For a fixed temperature difference, the amount of heat energy transferred will vary with the material. The relative capacity of a material to conduct heat is referred to as *Thermal Conductivity*.

Solids are the best conductors, followed by liquids and gases. Materials with high *thermal conductivity* are used as heat conductors and those with low *thermal conductivity* as insulating materials.

FIGURE 6 - Transfer of heat energy by conduction

Convection

Heat energy is transferred by *convection* when heat is conveyed from one part of a gas or fluid to another by virtue of *convection* currents. Heating of a gas or fluid causes expansion due to the increased molecular activity, which causes the *density* (mass per unit volume) to decrease. This portion of the gas or fluid becomes lighter than the unheated or lower temperature regions and rises, setting up the *convection* current. As the gas or fluid cools, the increase in *density* causes this portion to fall.

Convection currents cause the heat energy applied at one point to become fairly evenly distributed throughout the entire mass of gas or fluid. Equally, if a cooling effect were applied to air in a room or cold store at the correct point, preferably at high level, the air temperature can effectively be reduced throughout the entire volume of the room or coldstore.

FIGURE 7 - Transfer of heat energy by convection

Heat energy is transferred from one body to another by *radiation*. In order to occur, the body emitting radiation energy must be at a higher temperature than the body receiving radiation energy. A typical example would be the Sun at 6000 Deg C emitting enormous amounts of radiation energy to the Earth with a GMT (Global Mean Temperature) of 15 Deg C. This energy travels through 93 million miles of space, in a perfect vacuum. *Radiation* energy also travels unaffected through air from one body to another cooler body. The amount of energy transferred is very little affected by the temperature of the air.

Radiation is a waveform motion similar to that of light, but at other frequencies and length. The high molecular activity within a hot body is believed to generate radiation waves, which can travel effectively through vacuum or gases. When received by a cooler body, these waves are converted into internal energy within the cooler body.

If the receiving body is dark in colour, a higher level of radiation energy is absorbed. If the receiving body is light in colour, a portion of the radiant energy will be deflected or reflected. A mirror will deflect a very high amount of radiant energy. Clearly, rough surfaces will also absorb higher levels of radiant energy than smooth surfaces.

FIGURE 8 - Transfer of heat energy by radiation

Effects of Pressure on Fluids & Vapours

Matter or substances can exist in three “states” or “phases”. These are solid, liquid and vapour. The state or phase of a substance varies according to the temperature of the substance and the pressure it is exposed to.

The change of state of a substance, heat energy and temperatures involved will be studied next, using water as an example. Referring to Figure 9 (a), water in a vessel open to atmospheric pressure (1.01325 bar) is at an initial temperature of 20 Deg C. The boiling point of the water at this pressure is 100.0 Deg C. This should really be referred to as the *Saturation Temperature*.

As the water is at a temperature of 20 Deg C, it is currently 80 degrees below the Saturation Temperature and is said to *Sub-Cool* by 80.0 K. *Sub-Cooling* is an important element in air conditioning and refrigeration and is covered later in the series.

If sufficient heat energy is added to the water, the temperature will rise until the *Saturation Temperature* is reached as in Figure 9 (b). *Sub-Cooling* has now been reduced to 0.0 K.

The addition of further heat energy will cause part of the water to vapourise (evaporation) and the vapour produced (steam in the case of water) is termed *Saturated Vapour*. The body of water and the vapour will both remain at the *Saturation Temperature* of 100.0 Deg C as shown in Figure 9 (c). This temperature will remain constant until all the liquid has been vapourised.

When sufficient heat energy has been applied to vapourise all the liquid, *Saturated Vapour* only is present at 100 Deg C *Saturation Temperature* as in Figure 9 (d). The *Saturation Temperature* of the vapour remains at 100 Deg C.

If more heat energy is now applied to the *Saturated Vapour*, the temperature of the vapour will increase beyond the *Saturation Temperature* of 100 Deg C, This is termed *Superheat*.

Sensible Heat, Latent Heat & Total Enthalpy

Heat energy is measured in Joules (J) or kilojoules (kJ).

Heat energy added to a substance (solid, liquid or gas), which causes the temperature to rise, is termed *Sensible Heat*. Heat energy removed from a substance, which causes the temperature to fall, is also termed *Sensible Heat*.

Heat energy added to a liquid at *Saturation Temperature*, which causes the liquid to evaporate to a Saturated Vapour condition, is termed the *Latent Heat of Vaporisation*. Heat energy removed from a vapour at *Saturated Vapour* condition is termed the *Latent Heat of Condensation*.

The amount of Sensible Heat energy added to raise the temperature of a substance through a given temperature rise (K) is equal to the amount of Sensible Heat energy that must be removed from the substance to reduce the temperature to the original level.

The amount of *Latent Heat* energy required to vapourise a given mass of *Saturated Liquid* to a *Saturated Vapour* is equal to the amount of *Latent Heat* energy that must be removed from the *Saturated Vapour* to return the vapour to a *Saturated Liquid* condition.

The sum of all *Sensible* and *Latent* heat energy added to or removed from a substance is termed *Total Enthalpy*. Other terms used include *Total Heat* and *Specific Enthalpy*.

Latent Heat of Fusion

If sufficient heat energy is removed from water at 0.0 Deg C, the water will freeze and change state from liquid to a solid termed ice. The temperature of the substance will not change during the process. The heat energy (J or kJ) removed during this process is referred to as the *Latent Heat of Fusion*. Only when further heat energy (*Sensible*) is removed, will the ice drop in temperature.

The amount of *Latent Heat* energy that must be added to 1 kg ice at 0.0 Deg C to melt the ice to water at 0.0 Deg C is 335.0 kJ. The amount of *Latent Heat* energy that must be removed from 1 kg ice at 0.0 Deg C to freeze the water into ice at 0.0 Deg C is also 335.0 kJ. The *Latent Heat of Fusion* is therefore expressed as 335.0 kJ/kg.

Specific Heat

The amount of energy required to raise 1 kg (1 litre) of water 1.0 K = 4.19 kJ. This value is termed Specific Heat and is expressed as kJ/kg K. The specific heat varies from one substance to another and is applied to solids, liquids and gases (vapour). The specific heat values of ice, water and superheated vapour are different, yet they are all essentially H₂O. Specific Heat is referred to as *c*.

Calculation of Heat Energy

The following formula is used to calculate the quantity of *Sensible Heat* energy required to change the temperature of a substance:

$$\text{Heat Energy kJ} = m \times c \times (T_2 - T_1)$$

Where:

- m = mass (kg)
- c = specific heat (kJ/kg K)
- T_1 = initial temperature (Deg C)
- T_2 = final temperature (Deg C)

Example:

How much heat energy must be added to 1 kg of water at 0 Deg C to raise the temperature to 100 Deg C?

$$\begin{aligned} \text{Heat Energy kJ} &= m \times c \times (T_2 - T_1) \\ &= 1.0 \text{ kg} \times 4.19 \text{ kJ/kg K} \times (100 \\ \text{Deg C} - 0.0 \text{ Deg C}) & \\ &= 419.0 \text{ kJ} \end{aligned}$$

The following formula is used to calculate the quantity of *Latent Heat* energy required to change the state of a substance:

$$\text{Heat Energy kJ} = m \times l_{hv}$$

(Latent heat of vaporisation)

or $m \times l_{hc}$ (latent heat of condensation)
or $m \times l_{hf}$ (latent heat of fusion)

Where: $m = \text{mass (kg)}$
 $l_{hv}, l_{hc} \text{ or } l_{hf} = \text{kJ/kg}$

The Latent Heat of Vaporisation or Condensation for water is 2257 kJ/kg.

Example:

How much latent heat energy must be added to 2 kg water at a Saturated Liquid condition of 100.0 Deg to cause complete vaporisation to 2 kg of Saturated Vapour?

$$\begin{aligned} \text{Heat Energy kJ} &= m \times l_{hv} \\ &\text{(Latent heat of vaporisation)} \\ &= 2 \text{ kg} \times 2257 \text{ kJ/kg} \\ &= 4514 \text{ kJ.} \end{aligned}$$

The values given above are based on water at an atmospheric pressure of 1.01325 bar. If the pressure is increased, to say 2.7 bar, considerable changes occur including the *Saturation Temperature* and *Specific Heat* values. In order to conduct calculations at pressures other than 1.01325 bar, it is necessary to use the values that apply at other pressures and these are derived from Steam Tables.

NEXT MONTH:

Refrigeration cycles.