Introduction to refrigeration

Refrigeration is defined as the process of extracting heat from a lower-temperature heat source, substance, or cooling medium and transferring it to a higher-temperature heat sink. A refrigeration system is a combination of components and equipment connected in a sequential order to produce the refrigeration effect.

Refrigeration may also be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature.

Necessity and Applications

Applications of refrigeration:

*Food processing, preservation and distribution

*Chemical and process industries

*Special Applications such as cold treatment of metals, medical, Construction, ice skating etc.

*Comfort air-conditioning

Storage of Raw Fruits and Vegetables

Dairy Products, Meat and poultry, Beverages, Candy

Chemical & process industries

Separation of gases, Condensation of Gases, Dehumidification of Air
Storage as liquid at low pressure, removal of Heat of Reaction,
Cooling for preservation

Industrial applications

Laboratories ,Printing, Manufacture of Precision Parts ,Textile Industry

Pharmaceutical Industries ,Photographic Material ,Farm Animals

Vehicular Air-conditioning

Refrigerators and heat pump and their COPs-

- We all know from experience that heat flows in the direction of decreasing temperature, that is, from high-temperature regions to low-temperature ones. This heat-transfer process occurs in nature without requiring any devices. The reverse process, however, cannot occur by itself. The transfer of heat from a low-temperature region to a high-temperature one requires special devices called **refrigerators.**

- Refrigerators are cyclic devices, and the working fluids used in the refrig-eration cycles are called **refrigerants.** Here Q_L is the magnitude of the heat removed from the refrig-erated space at temperature T_L ,Q_H is the magnitude of the heat rejected to the warm space at temperature T_H , and $W_{net,in}$ is the net work input to the refrigerator. Q_L and Q_H represent magnitudes and thus are positive quantities.

- Another device that transfers heat from a low-temperature medium to a high-temperature one is the **heat pump.** Refrigerators and heat pumps are essentially the same devices; they differ in their objectives only.

- The objec-tive of a refrigerator is to maintain the refrigerated space at a low tempera-ture by removing heat from it. Discharging this heat to a higher-temperature medium is merely a necessary part of the operation, not the purpose. The objective of a heat pump, however, is to maintain a heated space at a high temperature. This is accomplished by absorbing heat from a low-temperature source, such as well water or cold outside air in winter, and supplying this heat to a warmer medium such as a house.

- The performance of refrigerators and heat pumps is expressed in terms of the **coefficient of performance** (COP), defined as

  COP_R = desired output / required input = cooling effect / work input = Q_L / W

  COP_{HP} = desired output / required input = heating effect / work input = Q_H / W

  $COP_{HP} = 1 + COP_R$

Unit of refrigeration-

The standard unit of refrigeration is ton of refrigeration or simply ton denoted by TR. It is defined as the amount of refrigeration effect produced by the uniform melting of one tonne (1000 kg) of ice from and at 0ºC in 24 hours.

Since latent heat of ice is 335kJ/kg, therefore one tone of refrigeration,

1 TR= 1000×335 kJ in 24 hours.

$$= \frac{1000\times335}{24\times60} = 232.6kJ/min$$

In actual practice one tone of refrigeration is taken as equivalent to 210kJ/min or 3.5kW (i.e 3.5kJ/s).

Basic numericals-----

Vapour compression refrigeration –

A vapour compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance, termed as refrigerant, is used. It condenses and evaporates at temperatures and pressures close to the atmospheric conditions. The refrigerants, usually, used for this purpose are ammonia (NH3), carbon dioxide (CO2) and sulphur dioxide (SO2). The refrigerant used, does not leave the system, but is circulated throughout the system alternately condensing and evaporating. In evaporating, the refrigerant absorbs its latent heat from the brine (salt water) which is used for circulating it around the cold chamber. While condensing, it gives out its latent heat to the circulating water of the cooler. The vapour compression refrigeration system is, therefore a latent heat pump, as it pumps its latent heat from the brine and delivers it to the cooler.

**The vapour compression refrigeration system is now-a-days used for all purpose refrigeration. It is generally used for all industrial purposes from a small domestic refrigerator to a big air conditioning plant.

Advantages and Disadvantages of vapour Compression Refrigeration System over Air Refrigeration System

Following are the advantages and disadvantages of the vapour compression refrigeration system over air refrigeration system:

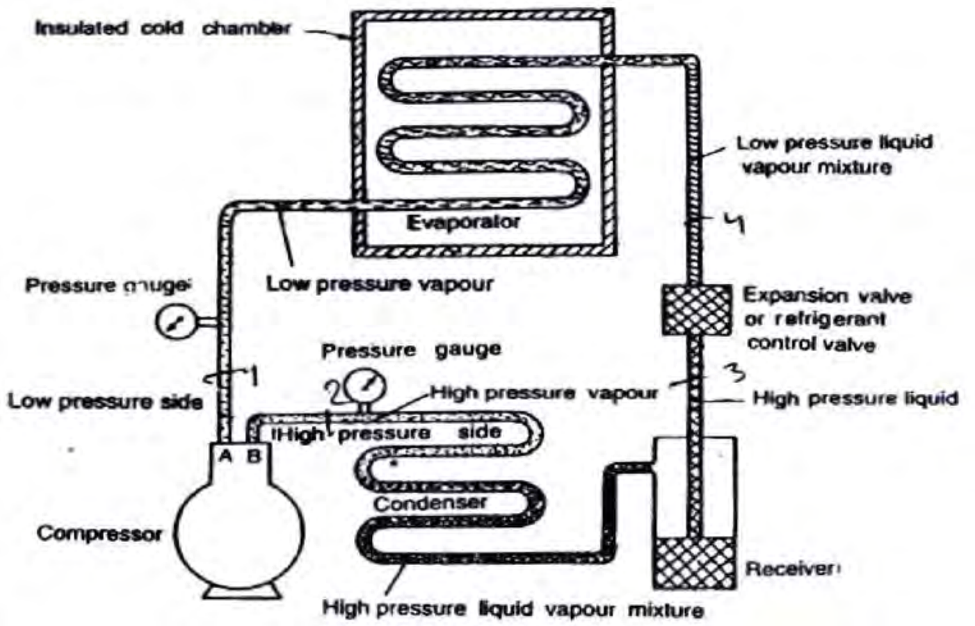
Advantages-

1. It has smaller size for the given capacity of
2. It has less running cost.
3. It can be employed over a large range of temperatures.
4. The coefficient of performance is quite high.

Disadvantage –

1. The initial cost is high
2. The prevention of leakage of the refrigerant is the major problem in vapour compression system

Mechanism of simple VCRS –



Refrigeration system. It consists of the following five essential parts :

1. *Compressor*. The low pressure and temperature vapou refrigerant from evaporator is drawn into the compressor through the inlet or suction valve A, where it is compresses to a high pressure and temperature. This high pressure and temperature vapour refrigerant is discharge the condenser through the delivery or discharge valve B.

2. *Condenser*. The condenser or cooler consists of coils of pipe in which the high pressure and temperature vapour refrigerant is cooled and condensed. The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.

3. *Receiver*. The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve.

4. *Expansion valve*. It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporised in the evaporator at the low pressure and temperature.

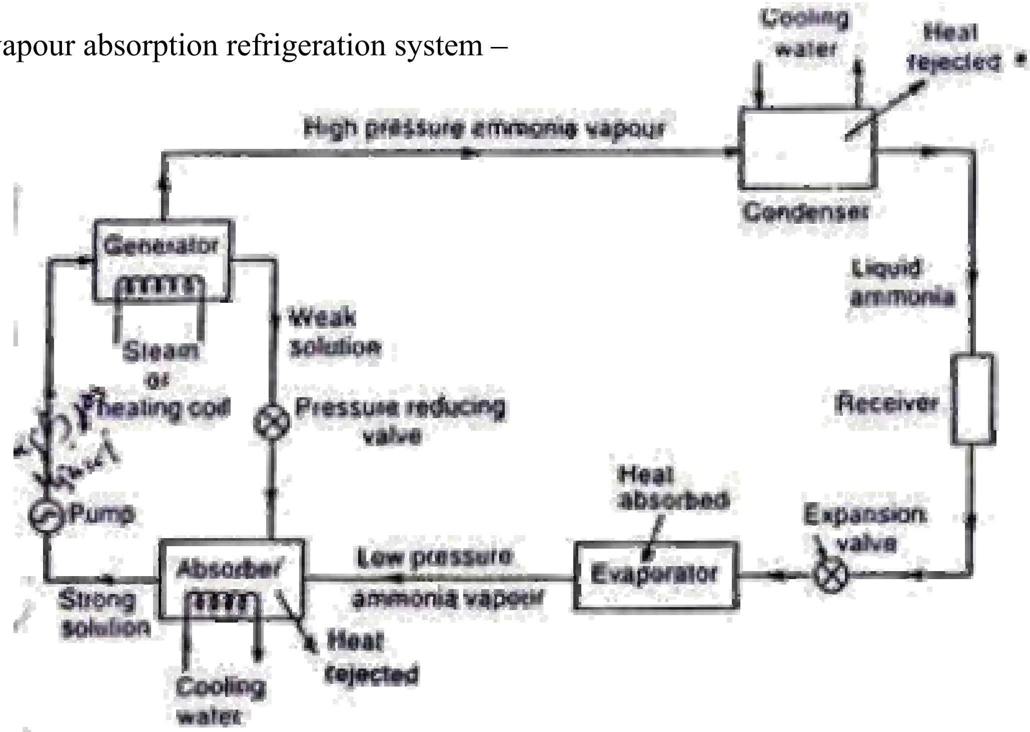
5. *Evaporator*. An evaporator consists of coils of pipe in which the liquid-vapour refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, water or brine) which is to be cooled.

Note : In any compression refrigeration system, there are two different pressure conditions. One is called the high pressure side and other is known as low pressure side. The high pressure side includes the discharge line (i.e. piping from the evaporator to the suction valve A).

Vapour absorption refrigeration system-

- The vapour absorption refrigeration system is one of the oldest method of Producing refrigerating effect. The principle of vapour absorption was first Discovered by Michael Faraday in 1824.
- The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle. We have discussed in the previous chapters that the function of a compressor, in a vapour compression system, is to withdraw the vapour refrigerant from the evaporator. It then raises its temperature and pressure higher than the cooling agent in the condenser so that the higher pressure vapours can reject heat in the condenser. The liquid refrigerant leaving the condenser is now ready to expand to the evaporator conditions again.
- In the vapour absorption system, the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve. These components in vapour absorption system perform the same function as that of a compressor in vapour compression system. In this system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by the weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by some external source. During the heating process, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquefied. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

Simple vapour absorption refrigeration system –



. In this system, the low pressure ammonia vapour leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber. The water has the ability to absorb very large quantities of ammonia vapour and the solution thus formed, is known as aqua-ammonia. The absorption of ammonia vapour in water lowers the pressure in the absorber which in turn draws more ammonia vapour from the evaporator and thus raises the temperature of solution. Some form of cooling arrangement (usually water cooling) is employed in the absorber to remove the heat of solution evolved there. This is necessary in order to increase the absorption capacity of water, because at higher temperature water absorbs less ammonia vapour. The strong solution thus formed in the absorber is pumped to the generator by the liquid pump. The pump increases the pressure of the solution upto 10 bar.

The *strong solution of ammonia in the generator is heated by some external source such as gas or steam. During the heating process, the ammonia vapour is driven off the solution at high pressure leaving behind the hot weak ammonia solution in the generator. This weak ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to a high pressure liquid ammonia. This liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator. This completes the simple vapour absorption cycle.

Introduction to Air Conditioning

- Atmospheric air makes up the environment in almost every type of air conditioning system. Hence a thorough understanding of the properties of atmospheric air and the ability to analyse various processes involving air is fundamental to air conditioning design.

- Psychrometry is the study of the properties of mixtures of air and water vapour.

- Atmospheric air is a mixture of many gases plus water vapour and a number of pollutants. The amount of water vapour and pollutants vary from place to place. The concentration of water vapour and pollutants decrease with altitude, and above an altitude of about 10 km, atmospheric air consists of only dry air. The pollutants have to be filtered out before processing the air. Hence, what we process is essentially a mixture of various gases that constitute air and water vapour. This mixture is known as moist air.

- Composition the molecular weight of dry air is found to be 28.966 and the gas constant R is 287.035 J/kg.K.

- The air to be processed in air conditioning systems is a mixture of dry air and water vapour. While the composition of dry air is constant, the amount of water vapour present in the air may vary from zero to a maximum depending upon the temperature and pressure of the mixture (dry air + water vapour).

- At a given temperature and pressure the dry air can only hold a certain maximum amount of moisture. When the moisture content is maximum, then the air is known as saturated air, which is established by a neutral equilibrium between the moist air and the liquid or solid phases of water.

- For calculation purposes, the molecular weight of water vapour is taken as 18.015 and its gas constant is 461.52 J/kg.K.

- Dry bulb temperature (DBT) is the temperature of the moist air as measured by a standard thermometer or other temperature measuring instruments.

- Saturated vapour pressure (p_{sat}) is the saturated partial pressure of water vapour at the dry bulb temperature. This is readily available in thermodynamic tables and charts

- Relative humidity is defined as the ratio of the mole fraction of water vapour in moist air to mole fraction of water vapour in saturated air at the same temperature and pressure.

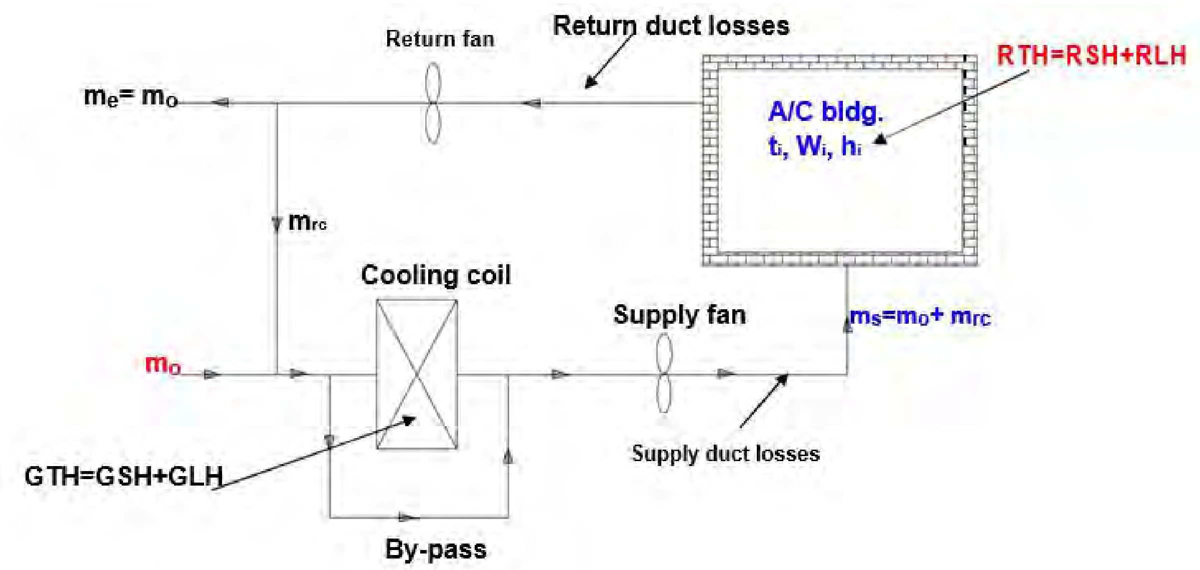
- Relative humidity is normally expressed as a percentage. When is 100 percent, the air is saturated.

- Humidity ratio (W): The humidity ratio (or specific humidity) W is the mass of water associated with each kilogram of dry air[1]. Assuming both water vapour and dry air to be perfect gases
- For a given barometric pressure p_t, given the DBT, we can find the saturated vapour pressure p_{sat} from the thermodynamic property tables on steam. Then using the above equation, we can find the humidity ratio at saturated conditions, W_{sat}.
- Dew-point temperature: If unsaturated moist air is cooled at constant pressure, then the temperature at which the moisture in the air begins to condense is known as dew-point
- Degree of saturation: The degree of saturation is the ratio of the humidity ratio W to the humidity ratio of a saturated mixture W_s at the same temperature and pressure,
- Enthalpy: The enthalpy of moist air is the sum of the enthalpy of the dry air and the enthalpy of the water vapour. Enthalpy values are always based on some reference value. For moist air, the enthalpy of dry air is given a zero value at 0^oC, and for water vapour the enthalpy of saturated water is taken as zero at 0^oC.
- Specific volume: The specific volume is defined as the number of cubic meters of moist air per kilogram of dry air. From perfect gas equation since the volumes occupied by the individual substances are the same, the specific volume is also equal to the number of cubic meters of dry air per kilogram of dry air.

Psychrometric chart

A Psychometric chart graphically represents the thermodynamic properties of moist air. Standard psychometric charts are bounded by the dry-bulb temperature line (abscissa) and the vapour pressure or humidity ratio (ordinate). The Left Hand Side of the psychometric chart is bounded by the saturation line. Psychometric charts are readily available for standard barometric pressure of 101.325 kPa at sea level and for normal temperatures (0-50^oC). ASHRAE has also developed psychometric charts for other temperatures and barometric pressures (for low temperatures: - 40 to 10^oC, high temperatures 10 to 120^oC and very high temperatures 100 to 120^oC)

Basic summer air conditioning system-



Design and analysis of air conditioning systems involves selection of suitable inside and outside design conditions, estimation of the required capacity of cooling or heating equipment, selection of suitable cooling/heating system, selecting supply conditions, design of air transmission and distribution systems etc. Generally, the inputs are the building specifications and its usage pattern and any other special requirements. The schematic of a basic summer air conditioning system, As shown in the figure, under a typical summer condition, the building gains sensible and latent heats from the surroundings and also due to internal heat sources (RSH and RLH). The supply air to the building extracts the building heat gains from the conditioned space.

These heat gains along with other heat gains due to ventilation, return ducts etc. have to be extracted from the air stream by the cooling coil, so that air at required cold and dry condition can be supplied to the building to complete the cycle. In general, the sensible and latent heat transfer rates (GSH and GLH) on the cooling coil are larger than the building heat gains due to the need for ventilation and return duct losses. To estimate the required cooling capacity of the cooling coil (GTH), it is essential to estimate the building and other heat gains. The building heat gains depend on the type of the building, outside conditions and the required inside conditions. Hence selection of suitable inside and outside design conditions is an important step in the design and analysis of air conditioning systems.

Thermal Comfort:-

Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment". This condition is also sometimes called as "neutral condition", though in a strict sense, they are not necessarily same. A living human body may be likened to a heat engine in which the chemical energy contained in the food it consumes is continuously converted into work and heat. The process of conversion of chemical energy contained in food into heat and work is called as "metabolism".

The rate at which the chemical energy is converted into heat and work is called as "metabolic rate". Knowledge of metabolic rate of the occupants is required as this forms a part of the cooling load of the air conditioned building. Similar to a heat engine, one can define thermal efficiency of a human being as the ratio of useful work output to the energy input.

The thermal efficiency of a human being can vary from 0% to as high as 15-20% for a short duration. By the manner in which the work is defined, for most of the light activities the useful work output of human beings is zero, indicating a thermal efficiency of 0%. Irrespective of the work output, a human body continuously generates heat at a rate varying from about 100 W (e.g. for a sedentary person) to as high as 2000 W (e.g. a person doing strenuous exercise).

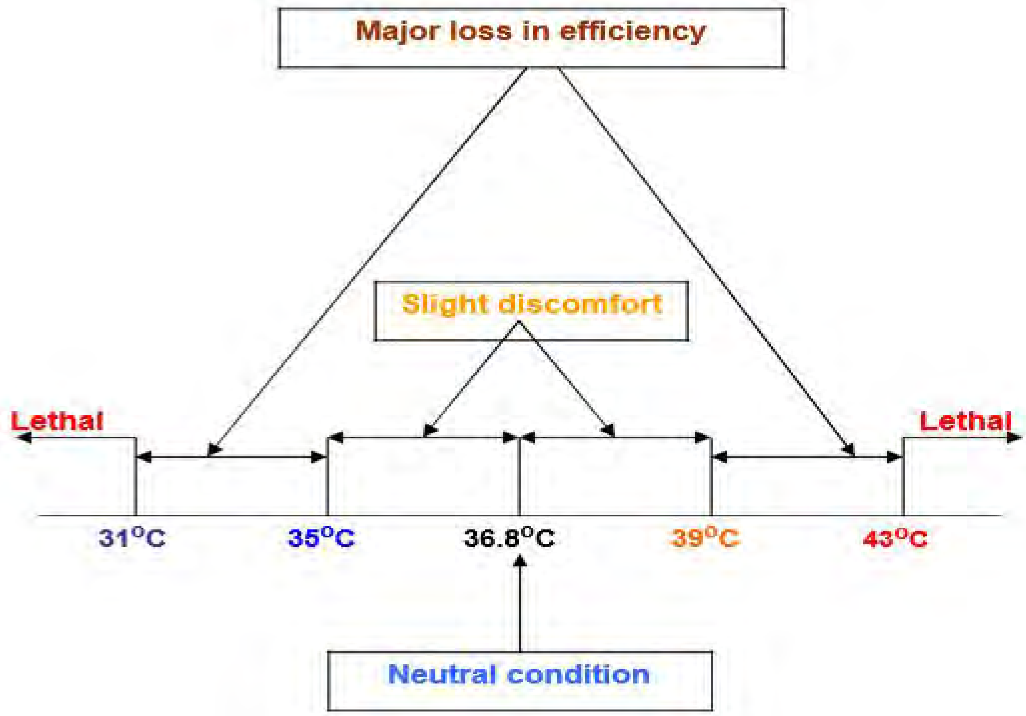
Continuous heat generation is essential, as the temperature of the human body has to be maintained within a narrow range of temperature, irrespective of the external surroundings.

A human body is very sensitive to temperature. The body temperature must be maintained within a narrow range to avoid discomfort, and within a somewhat wider range, to avoid danger from heat or cold stress. Studies show that at neutral condition, the temperatures should be:

$$\text{Skin temperature, } t_{skin} \approx \mathbf{33.7^{o}C}$$

$$\text{Core temperature, } t_{core} \approx \mathbf{36.8^{o}C}$$

At other temperatures, the body will feel discomfort or it may even become lethal. It is observed that when the core temperature is between 35 to 39ºC, the body experiences only a mild discomfort. When the temperature is lower than 35ºC or higher than 39ºC, then people suffer major loss in efficiency. It becomes lethal when the temperature falls below 31ºC or rises above 43ºC, shows in figure



Thermal comfort is affected by several factors. These are:

Physiological factors such as age, activity, sex and health. These factors influence the metabolic rate. It is observed that of these factors, the most important is activity. Other factors are found to have negligible effect on thermal comfort.

Insulating factor due to clothing. The type of clothing has strong influence on the rate of heat transfer from the human body. The unit for measuring the resistance offered by clothes is called as "**clo**". 1 clo is equal to a resistance of about 0.155 m^2.K/W. Typical clo values for different types of clothing have been estimated and are available in the form of tables. For example, a typical business suit has a clo value of 1.0, while a pair of shorts has a clo value of about 0.05.

Environmental factors. Important factors are the dry bulb temperature, relative humidity, air motion and surrounding surface temperature. Of these the dry bulb temperature affects heat transfer by convection and evaporation, the relative humidity affects heat loss by evaporation, air velocity influences both convective and evaporative heat transfer and the surrounding surface temperature affects the radiative heat transfer.