2.1. Refrigeration

Refrigeration is the process of maintaining a system at a temperature below the temperature of its surroundings. It can be accomplished by removing heat from the system. For example the household refrigerator absorbs heat from the food products and release this heat into the room where it is kept and thus a constant temperature is maintained inside the refrigerator cabinet. The equipments employed to maintain the system at a lower temperature is termed as refrigerating system and the system which is kept at lower temperature is called refrigerated system. The working fluid used in a refrigerating system is known as refrigerant.

Refrigeration may be obtained by adopting either natural methods or artificial methods. Natural methods include melting of ice. When ice melts, the heat from its surroundings flows into the ice and the surrounding space gets cooled. The natural methods of refrigeration were used in early days. Now, with the development of artificial means of refrigeration (mechanical refrigeration) the application of natural methods becomes insignificant. Hence the term refrigeration is actually used in these days for cooling by mechanical means.

The applications of refrigeration can be broadly classified into three groups as:

(i) Industrial processes which includes processing of food stuffs, farm crops, photographic materials, petroleum and other chemical products, treatment of concrete for dams, processing in textile mills, printing works etc.

(ii) Preservation of perishable goods which includes storage and transportation of food stuffs (eg. Fish, fruits, vegetables, meats, dairy products, poultry products etc).

(iii) Providing comfortable environment which includes comfort air conditioning of residences, hospitals, theatres, offices etc.

2.2. Unit of refrigeration

The rate of heat absorbed from a body or space to be cooled is termed as refrigerating effect. The standard unit of refrigeration is ton refrigeration or simply ton.

The rate of heat absorbed by the system from the body to be cooled, equivalent to the latent heat of fusion of one ton of ice from and at 0°C in 24 hours is called one ton refrigeration. The term ton refrigeration is a carry over from the time ice was used for cooling. This unit of refrigerating capacity is currently used in USA, UK and India. In many countries the standard MKS unit of kcal per hr. is in use. In general, one ton refrigeration always means 3.5167 kJ of heat removal per second.

2.3. Reversed Carnot cycle

A Carnot cycle consists of four reversible processes: two isothermal processes and two adiabatic processes [Refer section 1.4]. Here heat is absorbed from a hot reservoir at constant temperature T_1 and rejected to a cold reservoir at constant temperature T_3. The efficiency of Carnot cycle

$$= \frac{\text{Work done}}{\text{Heat absorbed}} = \frac{\text{Heat absorbed - heat rejected}}{\text{Heat absorbed}}$$

$$= 1 - \frac{\text{Heat rejected}}{\text{Heat absorbed}}$$

$$= 1 - \frac{T_3}{T_1}$$

Since all the four processes in the Carnot cycle are reversible processes, it is possible to have a cycle with all the four processes reversed. This cycle is called reversed Carnot cycle. In this cycle, heat is absorbed from a cold reservoir and is rejected to a hot reservoir with the expenditure of external work. The effectiveness of this cycle is the ratio of heat absorbed to the work required for this heat absorption from the cold reservoir. This effectiveness is expressed by a term known as coefficient of performance, COP.

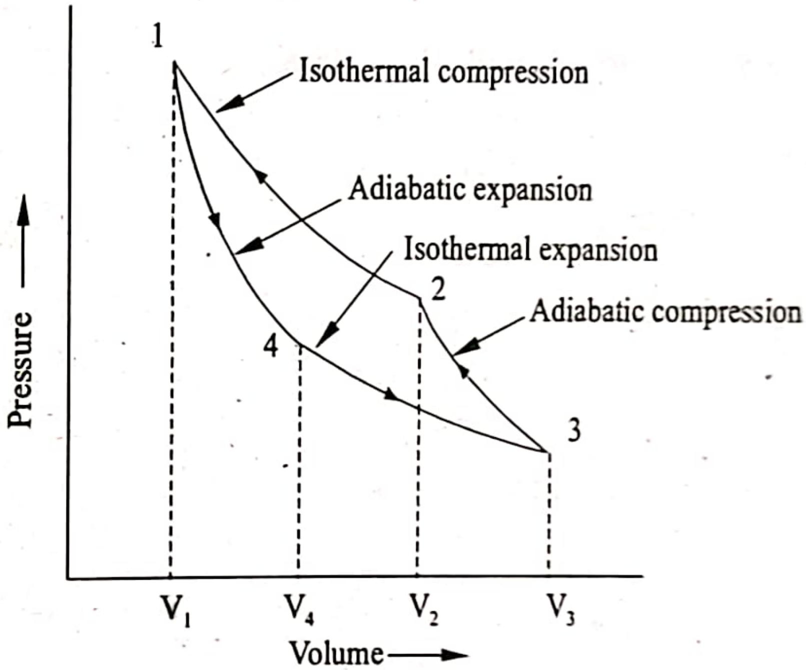


Fig. 2.1. Reversed Carnot cycle

$$\text{COP} = \frac{\text{Heat absorbed}}{\text{Work done}}$$

$$= \frac{\text{Heat absorbed}}{\text{Heat rejected - Heat absorbed}}$$

$$= \frac{1}{\dfrac{\text{Heat rejected}}{\text{Heat absorbed}} - 1}$$

$$=\frac{1}{\frac{T_1}{T_3}-1}$$

Example 2.1.

A Carnot cycle operates between temperatures 400K and 300K. Calculate the efficiency of Carnot cycle and COP of reversed Carnot cycle.

Solution

Given

Temperature of hot reservoir, $T_1 = 400K$

Temperature of cold reservoir, $T_3 = 300K$

$$\eta_{Carnot} = 1 - \frac{T_3}{T_1}$$

$$= 1 - \frac{300}{400} = 0.25$$

$$= 25\%$$

$$COP = \frac{1}{\frac{T_1}{T_3}-1} = \frac{T_3}{T_1 - T_3}$$

$$= \frac{300}{400-300}$$

$$= 3$$

2.4. Coefficient Of Performance (COP)

The effectiveness of a refrigerator is expressed by a term known as coefficient of performance. It is the ratio of desired refrigerating effect to the work spent to produce the refrigerating effect

$$COP = \frac{\text{Desired refrigerating effect}}{\text{Work spent in producing the refrigerating effect}}$$

COP of a refrigerator will be greater than unity.

2.5. Vapour compression system

In a vapour compression refrigerator the working fluid is a vapour which readily evaporates and condenses. During the evaporation process it absorbs heat and gets converted from liquid to vapour. During the condensing process it rejects heat and gets converted from vapour to liquid.

A simple vapour compression system of refrigeration consists of the following basic components:

i) Compressor

ii) Condenser

iii) Expansion valve

iv) Evaporator

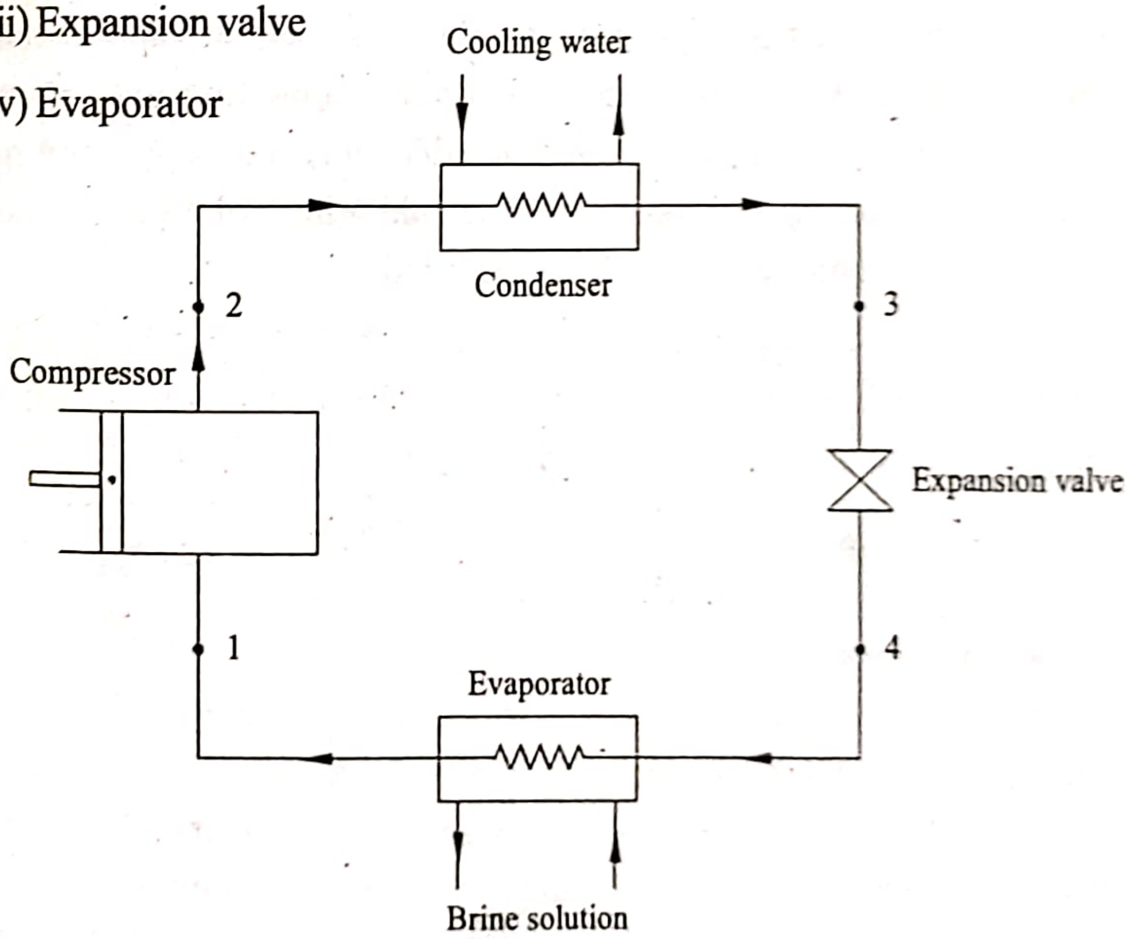


Fig. 2.2. Vapour compression cycle

The line diagram of the arrangement is shown in Fig. 2.2. Let the vapour leaving the evaporator be dry saturated. This dry saturated vapour at pressure p_1 and temperature T_1 is drawn into the compressor cylinder during its suction stroke and during the compression stroke the vapour is compressed isentropically to pressure p_2 and temperature T_2. At the end of compression the vapour is in a superheated state. The vapour at this condition passes to the condenser in which cooling water is circulated to remove heat from the vapour. The vapour is first cooled to the saturation temperature and further removal of latent heat of condensation it condenses to liquid till point 3 is reached. The high pressure liquid is expanded in an expansion valve (throttle valve). The pressure of liquid is lowered to p_1 and the condition obtained after the expansion process is shown by point 4. During throttling the liquid partly evaporates and after throttling we get wet vapour at the low temperature T_1 and low pressure p_1. This wet vapour passes through the evaporator coils immersed in the brine solution. The wet refrigerant vapour absorbs latent heat of vaporisation from the brine solution and evaporates. After evaporation the vapour reaches the condition given by point 1 ie., dry saturated at pressure p_1. This completes one cycle of operation. The cold brine solution is circulated in coils around the space to be refrigerated.

The net refrigerating effect of this system is the heat absorbed by the refrigerant from the brine solution. The work done by the compressor is the work spent to produce this refrigerating effect. Therefore,

$$COP = \frac{\text{Heat extracted in the brine solution}}{\text{Work done by the compressor}}$$

2.6. Refrigerants

The working substance used in a refrigerating system is known as refrigerant. It is actually a carrier of heat from a cold place to a hot place. It changes from liquid to vapour state during the process of absorbing heat and condenses to liquid while liberating heat. The most common refrigerants in use are ammonia, fluorinated hydrocarbons (trade name - Freon), carbon dioxide, sulphur dioxide, air, water etc.

Desirable properties of refrigerants

The important properties to be possessed by an ideal refrigerant are :

1. Condensing and evaporating pressure: Both condensing and evaporating pressure of the refrigerant should be above atmospheric pressure to avoid leakage of air into the system. But the pressure should not be very high as it requires heavy compressor, condenser etc. which increases the cost of the system.

2. Critical temperature : The critical temperature of the refrigerant should be high enough as compared to the condensing temperature, to reduce the power requirements.

3. Freezing temperature : The freezing temperature of the refrigerant should be much below the operating temperature of the plant to prevent the solidification and choking of the flow.

4. Specific heat : The specific heat of the refrigerant liquid should be low to minimise the amount of vapour formed during the throttling process.

5. Latent heat of vapourization: The latent heat of vapourisation of the refrigerant should be high to reduce the quantity of refrigerant to be circulated.

6. Specific volume: The specific volume of the refrigerant vapour should be low to reduce the size of the compressor.

7. Viscosity : Viscosity of the refrigerant should be low to reduce pressure drops, size of pipes, valves etc.

8. Thermal conductivity : The thermal conductivity of the refrigerant should be high to increase the efficiency of the condenser and evaporator..

9. Stability: The refrigerant should be chemically stable throughout the required range of operation.

10. Inflammability : The refrigerant should be non-inflammable (ie, it must not easily catch fire) to avoid fire during overheated conditions.

11. Corrosiveness: The refrigerant should be non-corrosive when comes in contact with metals.

12. Toxicity: The refrigerant should be non-toxic so that it is non-injurious to food stuff and other materials preserved.

13. Leakage detection: The refrigerant should be such that its leakage detection is simple.

14. Oil solubility: The refrigerant must not react with oil, but it must be mixable with the oil for better lubrication of the compressor.

15. Electrical resistance: The refrigerant should have high electrical resistance.

16. Availability: The refrigerant should be cheap and easily available.

2.7. Air conditioning

The science of air conditioning deals with supplying and maintaining a desired internal atmospheric condition irrespective of external conditions. This involves the simultaneous control of air purity, air motion, temperature and humidity of the air inside an enclosed space. The condition to be maintained is dictated by the need for which the conditioned space is intended.

Psychrometric properties

The properties of moist air are called psychrometric properties and the subject which deals with the behaviour of moist air is known as psychrometry. It is the foundation on which most of the air conditioning calculations are based. Several special terms used in the study of psychrometry are defined below:

1. Dry air: Dry air is a mixture of oxygen, nitrogen, carbon - dioxide, hydrogen, argon, neon, helium etc with oxygen and nitrogen as its major constituents. The volumetric composition of air is 79 % nitrogen and 21 % oxygen.

2. Moist air: It is ordinary atmospheric air which is a mixture of dry air and water vapour.

3. Saturated air: It is the air which contains maximum amount of water vapour which the air can hold at a given temperature and pressure. The maximum quantity of water vapour that can be present in the air depends up on the temperature and pressure of air.

4. Specific or absolute humidity or humidity ratio: It is defined as the ratio of the mass of water vapour to the mass of dry air in a given volume of moist air..

5. Relative humidity: It is the ratio of mass of water vapour in a given volume of moist air at a given temperature to the mass of water vapour contained in the same volume of moist air at the same temperature when the air is saturated.

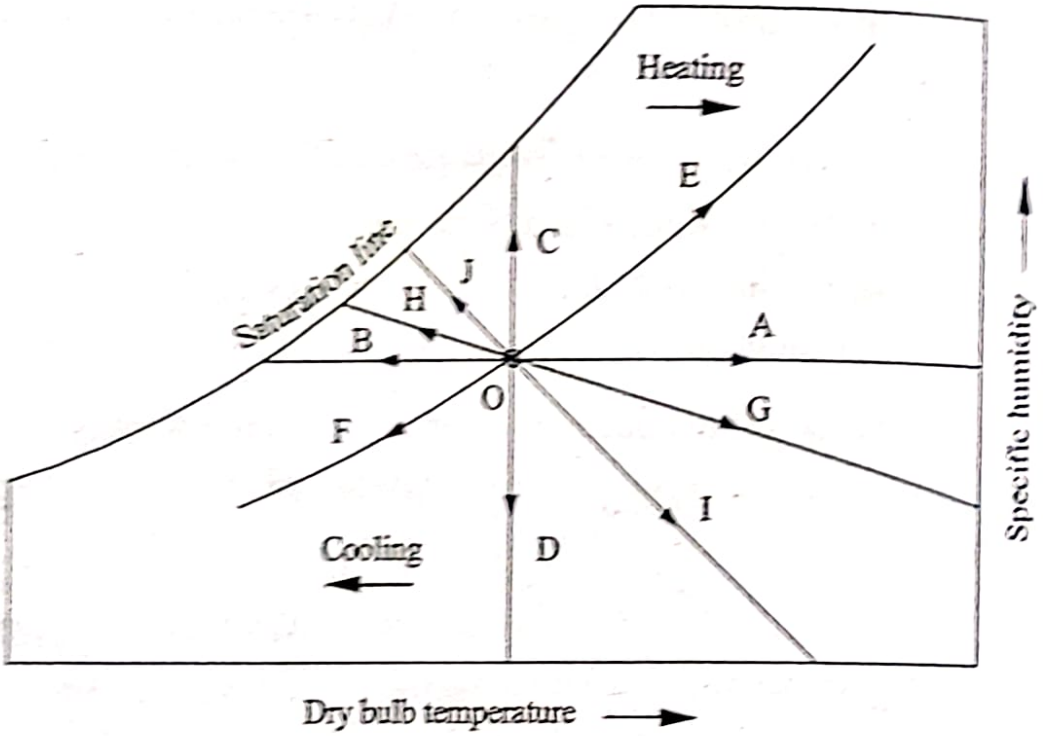
6. Dry bulb temperature: It is the temperature of air measured by an ordinary thermometer.

7. Wet bulb temperature: It is the temperature recorded by a thermometer, when its bulb is covered by a wet cloth and is exposed to a current of moving air. The difference between the dry bulb temperature and wet bulb temperature is known as wet bulb depression and it depends on the relative humidity of air. If relative humidity is high , the rate of evaporation from the wet cloth is low and hence wet bulb depression will be low. When air is dry saturated the DBT and WBT are the same.

8. Dew point temperature: It is the temperature at which the condensation of moisture begins when the air is cooled at constant pressure . The difference between dry bulb temperature and dew point temperature is known as dew point depression.

Psychrometric chart

A psychrometric chart is the graphical representation of the various thermodynamic properties of moist air. The chart enables the properties of moist air to be read off directly.



AOB - Constant dew point temperature line. COD - Constant dry bulb temperature line,

EOF - Constant relative humidity line, GOH - Constant wet bulb temperature line, IOJ - Constant specific volume line.

Fig. 2.3. Psychrometric chart

Fig. 2.3 shows a typical psychrometric chart constructed for a particular value of barometric pressure. The vertical scale of the chart is the specific humidity and the horizontal scale is the dry bulb temperature. In addition, it contains the following lines.

i) Dry bulb temperature lines: These are vertical lines drawn parallel to the ordinate.

ii) Specific humidity lines: These are horizontal lines drawn parallel to the abscissa.

iii) Wet bulb temperature lines: These are straight lines which extend diagonally.

iv) Relative humidity lines: These are curved lines parallel to the saturated line. The saturation line represents 100 % relative humidity

v) Specific volume lines: These are straight inclined lines and uniformly spaced. These lines gives the volume of dry air in m^3/kg

vi) Dew points temperature lines: These are horizontal lines, non uniformly spaced and drawn upto saturation curves.

The various basic process involved in air conditioning are :

i) Sensible heating - Process OA

(ii) Sensible cooling - Process OB

(iii) Humidifying - Process OC

(iv) Dehumidifying - Process OD

(v) Heating and humidifying - Process OE

(vi) Cooling and dehumidifying - Process OF

(vii) Cooling and humidifying - Process OH and OJ

(viii) Heating and dehumidifying - Process OG and OL

Sensible heating and sensible cooling involve a change in dry bulb temperature. The process of humidifying and dehumidifying involve a change in the specific humidity. When the state of air moves from O to A or to B, there is no change in the moisture content of the air. Similarly when the state of air changes from O to C or to D, the DBT remains constant. The last four processes listed above involved both changes in temperature as well as humidity.

2.8. Cooling and dehumidification

Temperature control is a major process in air conditioning system. It is intended to regulate the dry bulb temperature by various psychrometric processes. This is attained by simple heating or cooling, which may be associated with humidification process.

Cooling of air means lowering its dry bulb temperature. It can be attained by passing the air over evaporator coils of a refrigerating system. In a small room air conditioner the intake air is forced to flow over the evaporator coil directly. In such a case the relative humidity aspect is neglected or is of such order that it gets adjusted by itself. In most cases, an indirect evaporator system is used for cooling the air. In such cases chilled water (or chilled brine solution) is used to cool the air. The chilled water after absorbing heat from the air rejects heat to the refrigerant in the evaporator.

Humidity control

Another important process in air conditioning is the control of humidity. This is achieved by the process of humidification (increasing humidity) or dehumidification (decreasing humidity).

Dehumidification

Dehumidification is the process of reducing water vapour content of air. It can be accomplished by the use of an air washer or by the use of absorbents. In the absorption method, air is passed through a chemical (known as drying agent). The moisture in the air enters into chemical combination with the drying agent. The chemicals like H_2SO_4 and NH_3 are normally used as drying agents. Dehumidification can also be achieved by using absorbents. These are materials having capacity to absorb moisture. Common absorbents in use are: activated alumina, calcium chloride and silica gel. Normally, this method of dehumidification is used in small air conditioners.

2.9. Summer Air Conditioning

In summer air conditioning air is cooled and generally dehumidified. The schematic arrangement of a typical summer air conditioning system is shown in Fig. 2.4. The atmospheric air flows through a damper to the air filter where dirt, dust and other impurities are removed. Air now passes through a cooling coil whose temperature is much below the required dry bulb temperature. Water is sprayed to the air. The temperature of water is below the dew point temperature of air. Due to the vapourisation of water the temperature of air further decreases. An eliminator is placed in the path to remove water droplet carried with air. Finally this conditioned air is supplied to the required space using a blower.

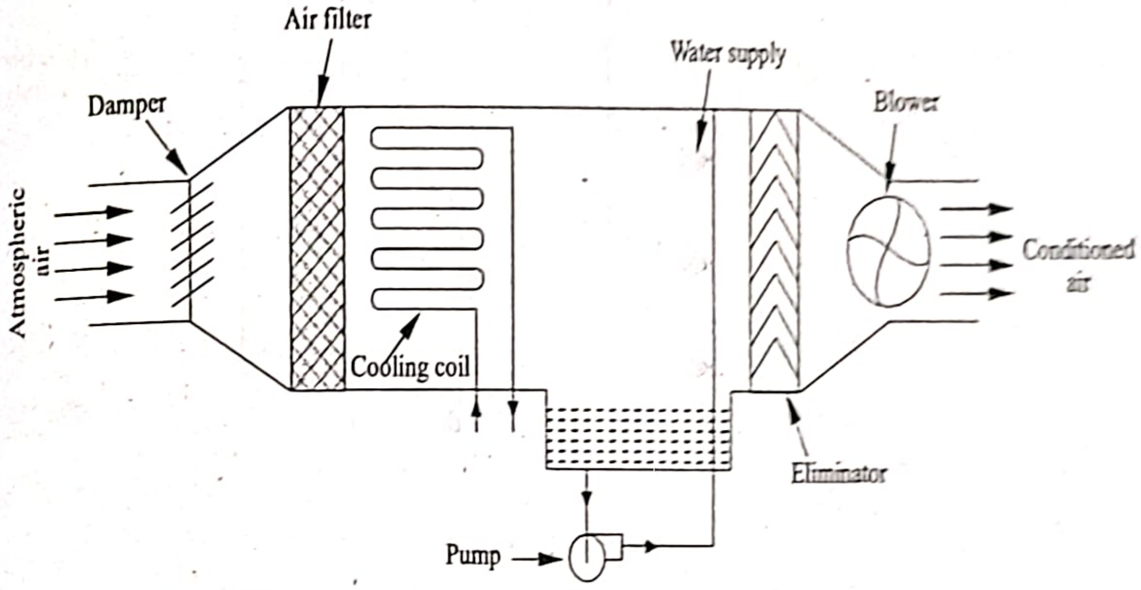
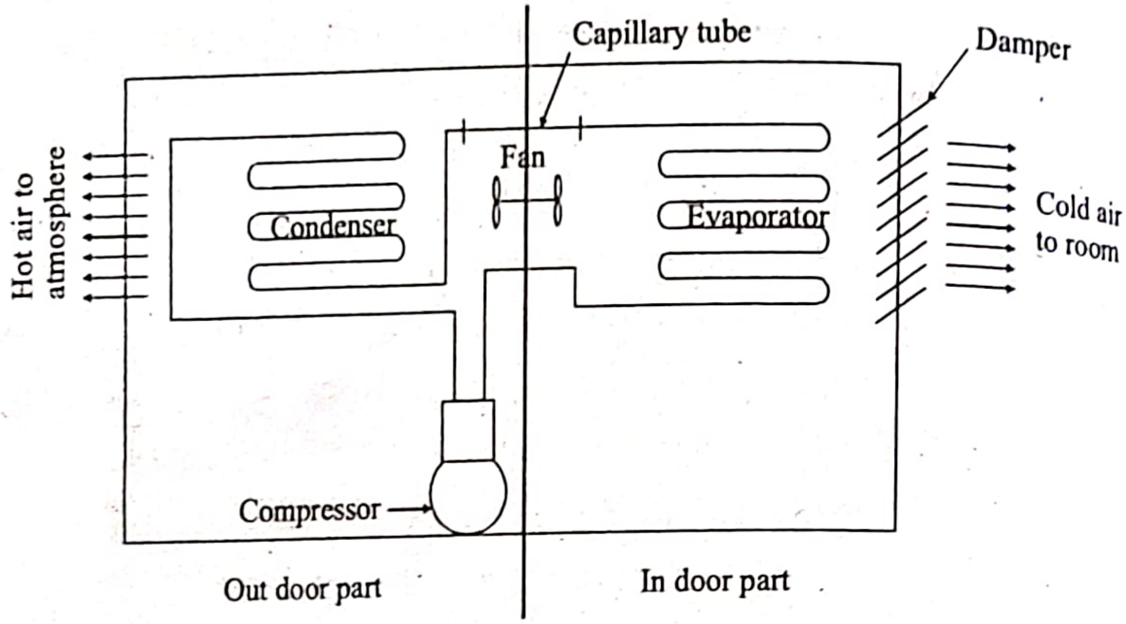


Fig. 2.4. Summer air conditioning

2.10. Unit air conditioner

A window air conditioner which is a unit air conditioner consists of a case divided into two parts, outdoor and indoor parts, by a partition. The outdoor part consists of compressor, condenser and a fan. The indoor part consists of evaporator and a fan. Capillary tube is provided in between the condenser and evaporator. The outdoor portion ramains outside the window. Dampers are provided at the front of indoor portion for changing the direction of airflow.

Low pressure vapour drawn from the evaporator is compressed to a high pressure and is delivered to the condenser. In the condenser the refrigerant vapour is condensed by releasing latent heat oil condensation to the surrounding air. This hot air is driven out using a fan. The high pressure liquid refrigerant enters the capillary tube where the pressure is reduced. This low pressure liquid vapour enters the evaporator.



Unit air conditioner

This liquid re-frigerant evaporates by absorbing latent heat of vaporization from the surrounding air. This cold air is delivered to the room using a fan. The direction of air flow can be changed using a damper. The low pressure refrigerant vapour leaving the evaporator is sucked into the compressor and is compressed to very high pressure. This high pressure vapour is condensed in the condenser. Thus one cycle of operation is completed.

2.11. Central air conditioner

This is the most important type of air conditioner. It is adopted,

(i) When the cooling capacity required is 25tons or more.

(ii) When the air flow is more than 5m³/hr.

(iii) When different zones in a building are to be air conditioned.

In this system all the components of the system are installed in a seperate central room. The conditioned air is distributed through ducts from this central room to various rooms to be air conditioned.

2.12. Reciprocating pump

Pump is a mechanical device used to increase the pressure energy of a liquid. In most of the applications, pump is used for lifting liquids from a