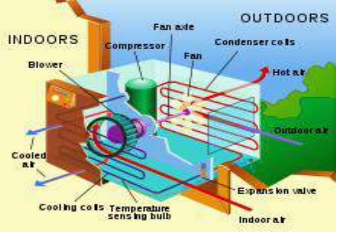
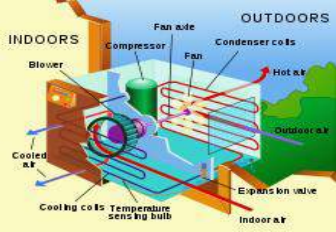


LECTURE NOTES

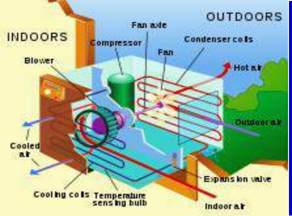


REFRIGERATION
AND
AIR CONDITIONING

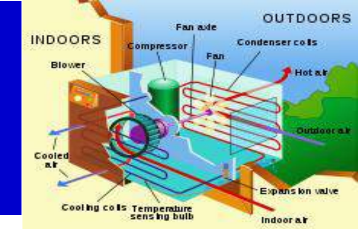
Mr . SHARANA KUMARA K

Department of Mechanical Engineering
Faculty of Government polytechnic Kampli

STANDARD PRINCIPLES
OF
REFRIGERATION
AND
AIR CONDITIONING SYSTEMS



A REFRIGERATOR



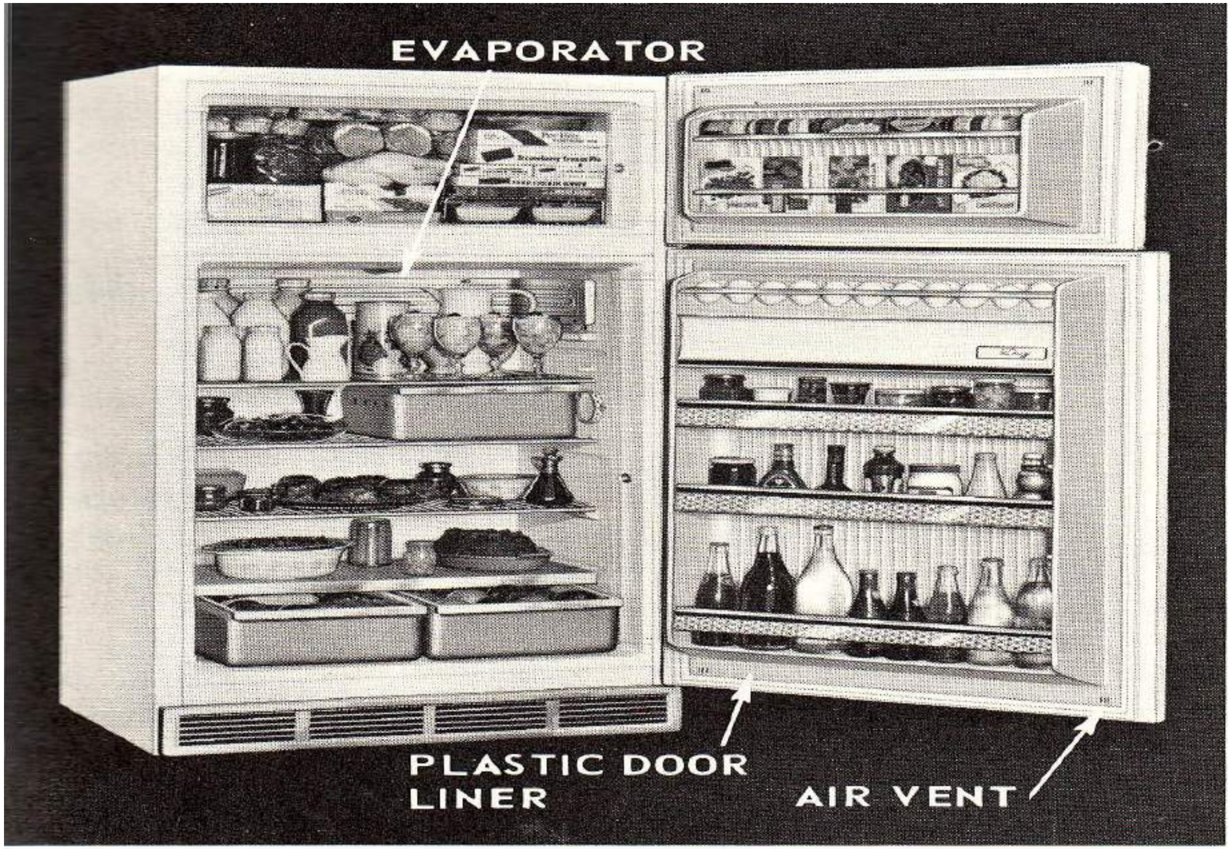
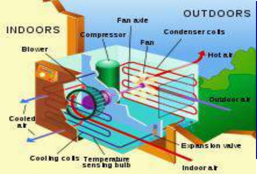
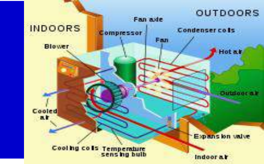
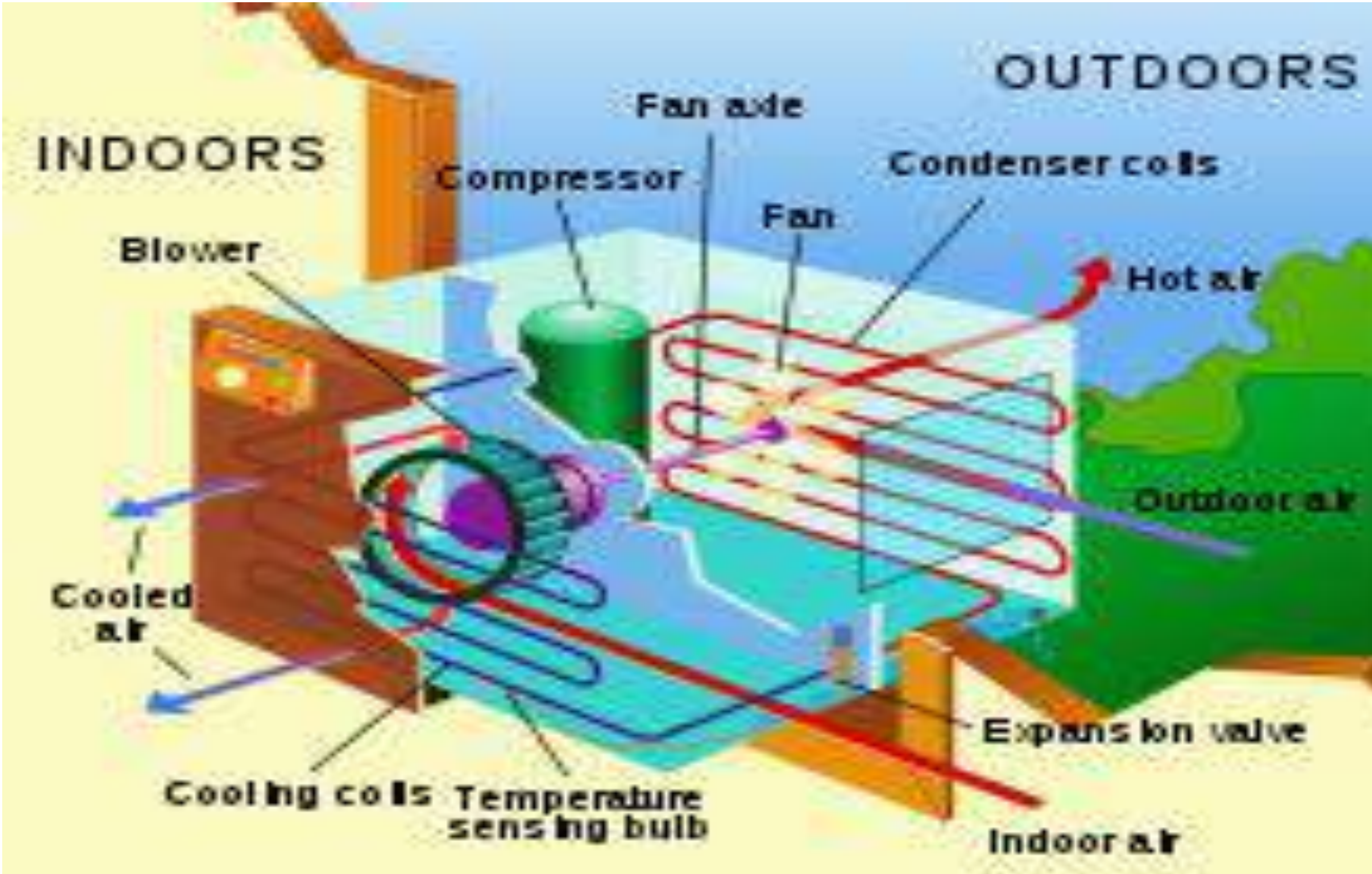


Fig. 10-6. Two-door model refrigerator-freezer with freezer at top. Note evaporator in upper part of lower compartment. (Kelvinator, Inc.)

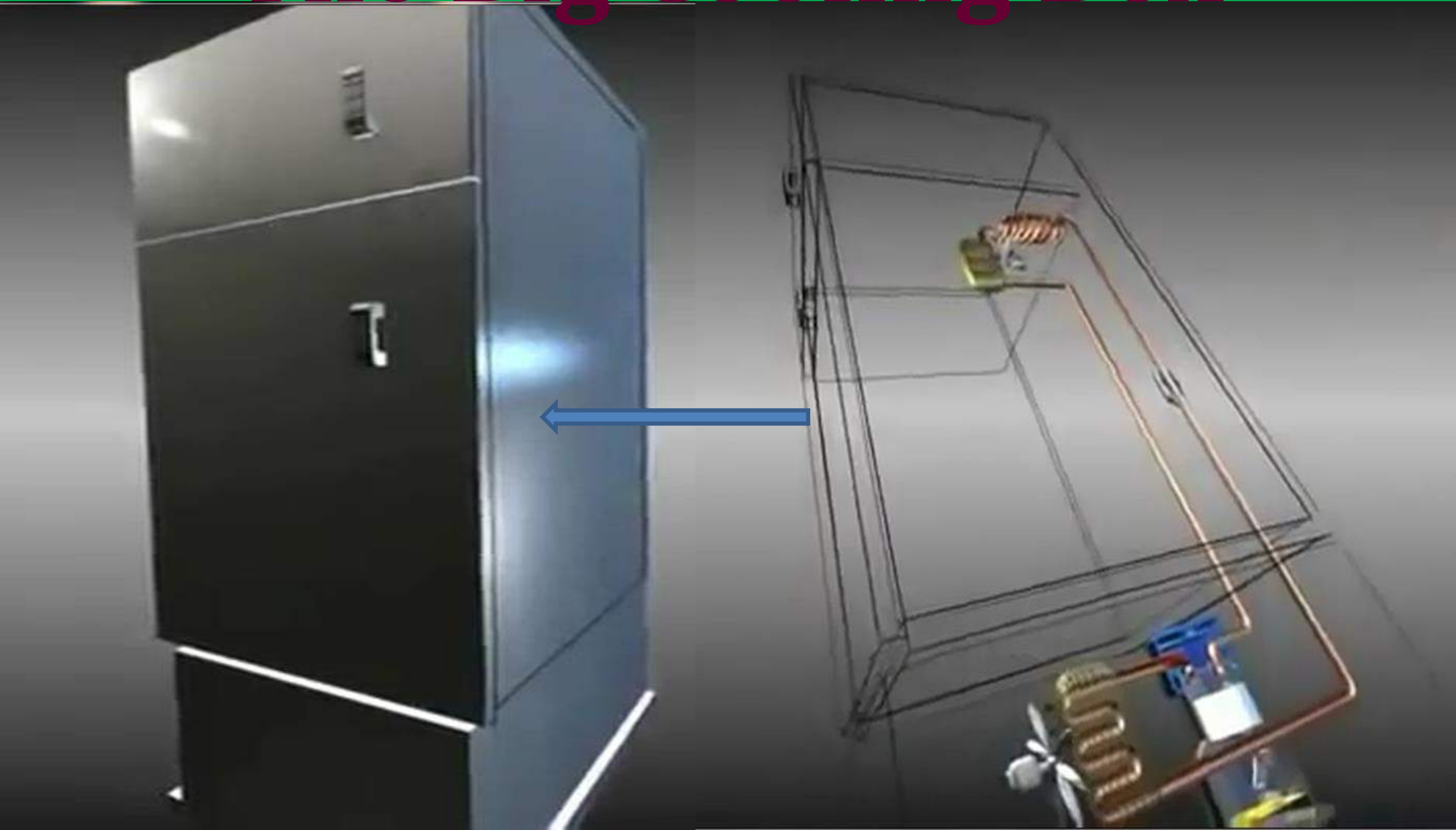


AIR CONDITIONING SYSTEM

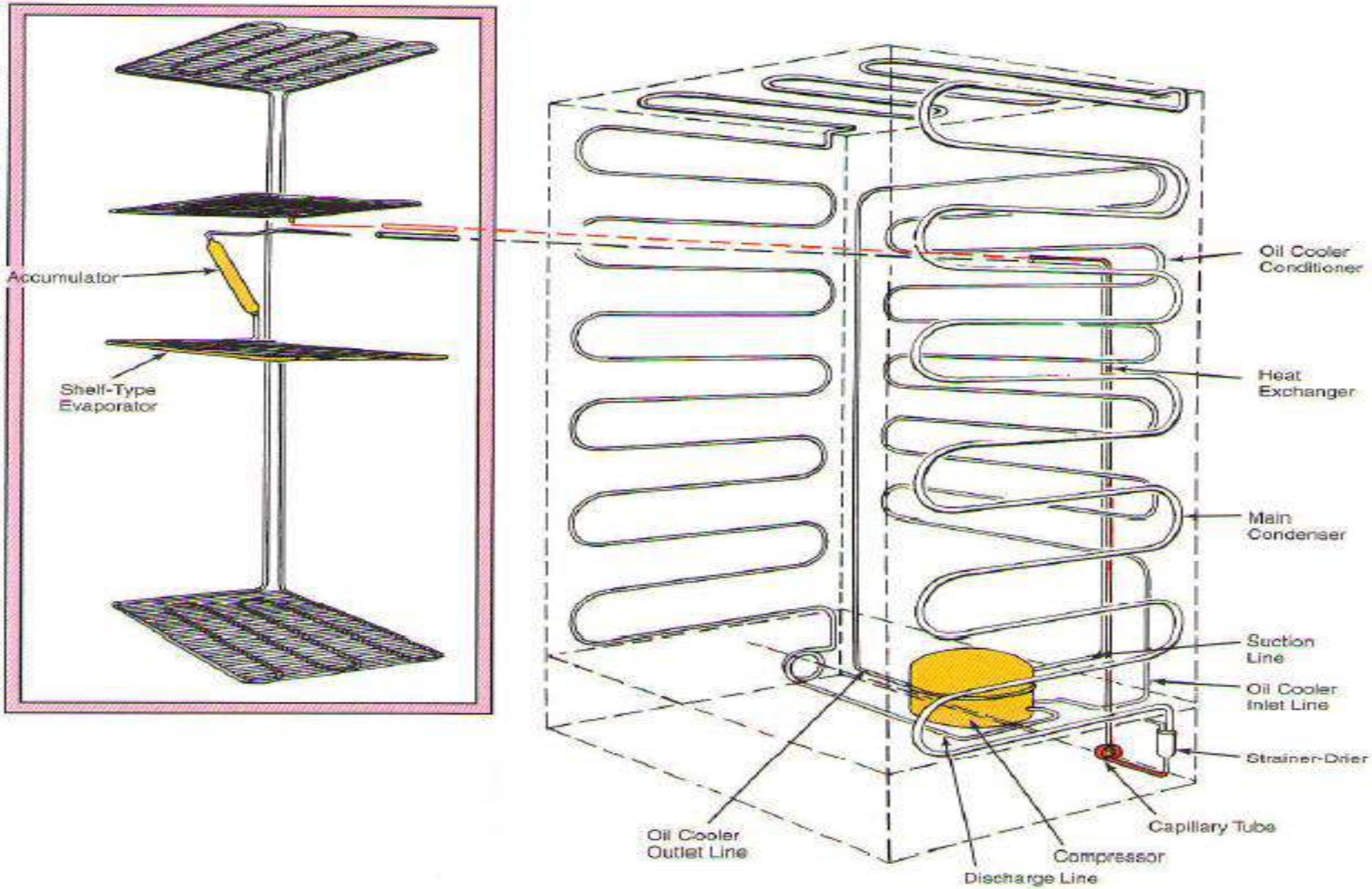


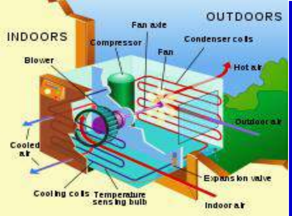


The Big Cooling Box

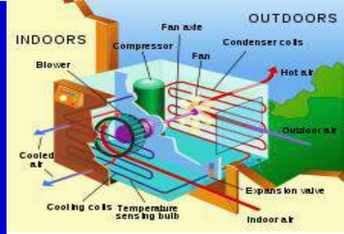


What is inside?





INTRODUCTION TO REFRIGERATION



Refrigeration may be defined as the process of removing heat from a substance under controlled conditions.

It also includes the process of reducing and maintaining the temperature of a body below the general temperature of its surroundings.

In other words, the refrigeration means a continued extraction of heat from a body whose temperature already below the temperature of its surrounding.

POPULAR MISCONCEPTIONS ABOUT REFRIGERATION

- Refrigeration and air conditioning cool without creating heat.
- There are no other methods of cooling.
- Boiling water only emits heat.

ACTUAL FACTS ABOUT REFRIGERATION

- Refrigeration and air conditioning actually transfer heat. The cool in one area and heat another!
- Water evaporators can actually cool dry air.
- Certain solid state materials can cool on one side and heat on the other.
- Boiling water absorbs heat when it becomes a gas (water vapor).
- Rubbing alcohol cools the skin when it evaporates.

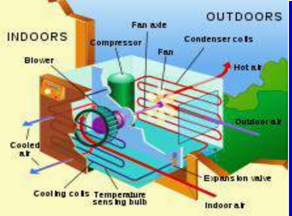
BASIC PRINCIPLES OF REFRIGERATION

- The two main principles for refrigeration and air conditioning operation are:
- Liquids absorb heat, when changing from liquid into gas.
- Gases emit heat, when changing from gas into liquid.
- In a refrigeration system, liquid refrigerant absorbs heat from the air when changing to a gas (boiling).

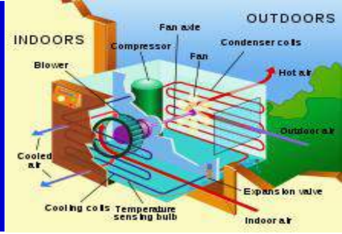
BASIC COOLING PRINCIPLES

Refrigerators and air conditioners:

- Remove heat from the air faster than warming sources.
- The removed heat is dissipated to the atmosphere.



REFRIGERATOR

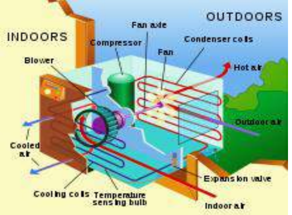


REFRIGERATOR

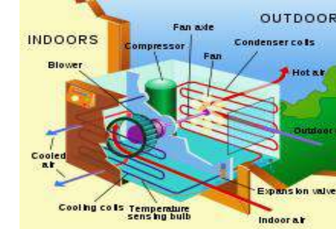
In a refrigerator, heat is virtually being removed from a lower temperature to a higher temperature.

According to the second law of thermodynamic (it is impossible to construct a device which, operating in a cycle, will produce no effect other than the transfer of heat from a cooler to a hotter body), this process can only be performed with the aid of some external work.

It is thus obvious that supply of power (say electric motor) is regularly required to drive refrigerator.

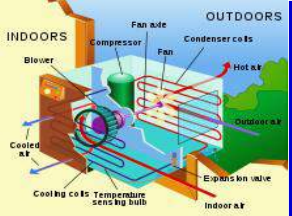


REVERSED HEAT ENGINE CYCLE

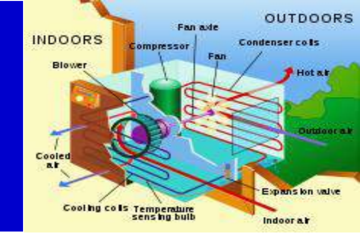


REVERSED HEAT ENGINE CYCLE

A reversed heat engine cycle is an engine operating in the reverse way, i.e. receiving heat from a low temperature region, discharging heat to a higher temperature region, and receiving a net inflow of work. Under such condition the cycle is called a heat pump or a refrigeration cycle.

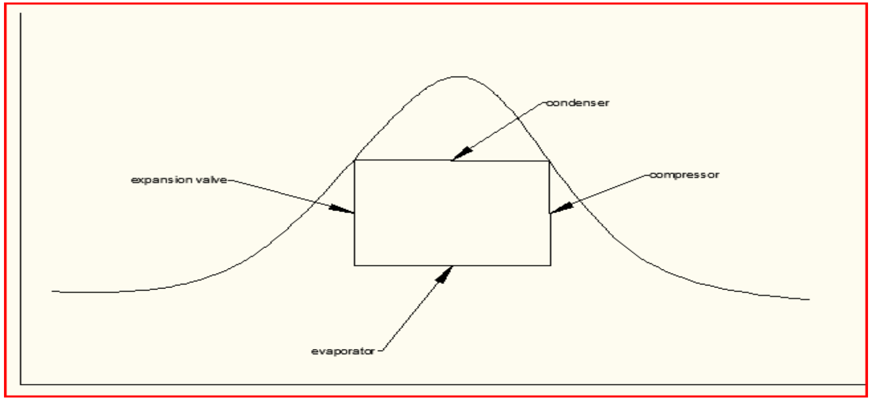


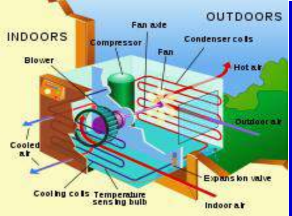
REVERSED CARNOT CYCLE



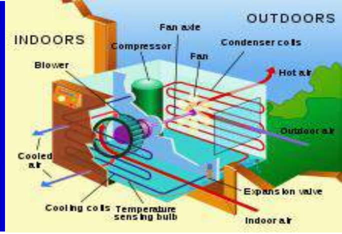
REVERSED CARNOT CYCLE

In the Reversed Carnot cycle, the refrigerant is first compressed reversibly and adiabatically in process 1-2 where the work input per kg refrigerant is W_0, then it is condensed reversibly in process 2-3 where the heat of rejection is Q_1, the refrigerant then expands reversibly and adiabatically in process 3-4 where the work output is W_E, and finally it absorbs heat Q_2 reversibly by evaporation from the surroundings in process 4 – 1.





THE IDEAL REFRIGERATION CYCLE : THE CARNOT CYCLE

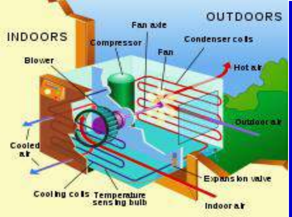


- The Carnot refrigeration cycle Carnot refrigeration cycle is a completely reversible cycle, hence is used as a model of perfection for a refrigeration cycle operating between a constant temperature heat source and sink. It is used as reference against which the real cycles are compared

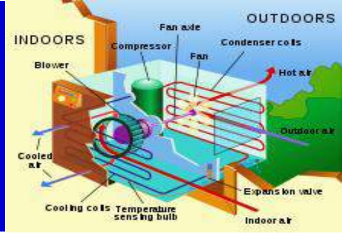
Practical difficulties with Carnot refrigeration system:

It is difficult to build and operate a Carnot refrigeration system due to *wet compression due to the presence of liquid. In practice, wet compression is very difficult especially with reciprocating compressors. This problem is particularly severe in case of high speed reciprocating compressors, which get damaged due to the presence of liquid droplets in the vapour.*

ii. The second practical difficulty with Carnot cycle is that using a turbine and extracting work from the system during the isentropic expansion of liquid refrigerant is not economically feasible, particularly in case of small capacity systems.



PRINCIPLE
OF
VAPOUR COMPRESSION REFRIGERATION SYSTEM



- The Carnot cycle cannot be achieved for the vapour cycle in actual practice because liquid slugging would occur during compression of the two-phase refrigerant. In addition, the mixture, mostly liquid, does very little work when it expands after condensation in the heat engine. Therefore, a single- stage ideal vapour compression cycle is used instead of the Carnot cycle. In an ideal single-stage vapour compression cycle compression occurs in the superheated region. A throttling device, such as an expansion valve, is used instead of the heat engine. Single-stage means that there is only one stage of compression. An ideal cycle is one in which the compression process is isentropic and the pressure losses in the pipeline, valves, and other components are negligible.

Vapour compression means that the vapour refrigerant is compressed to a higher pressure, and then the condensed liquid is throttled to a lower pressure to produce the refrigerating effect by evaporation. It is different from the absorption or air expansion refrigeration cycle.

PRINCIPLE OF VAPOUR COMPRESSION REFRIGERATION SYSTEM

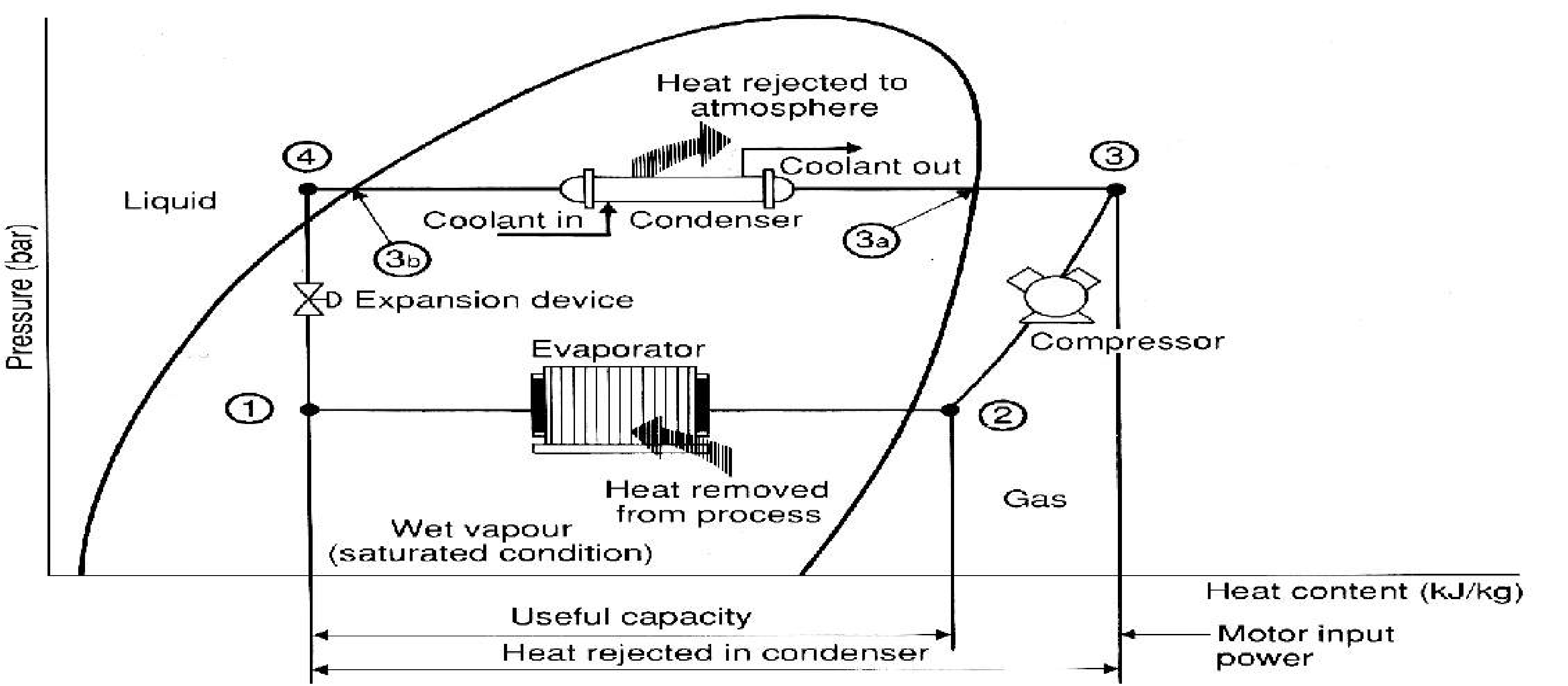
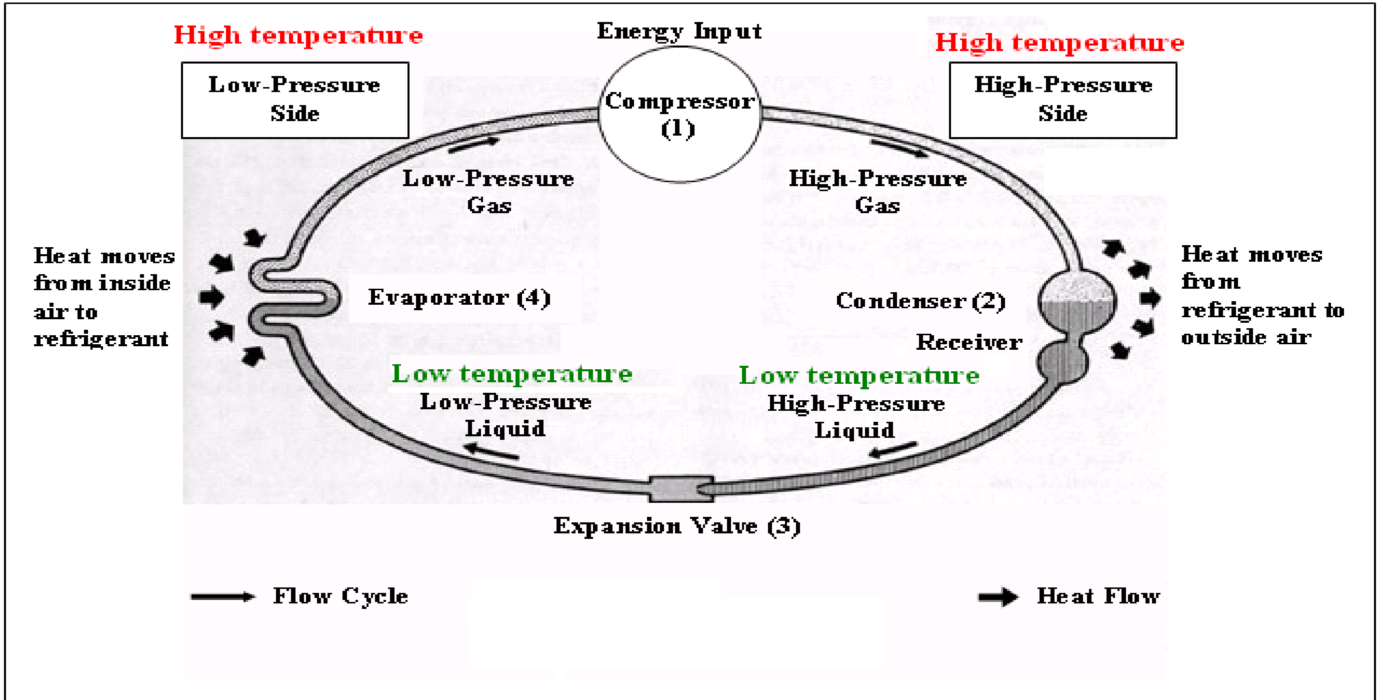


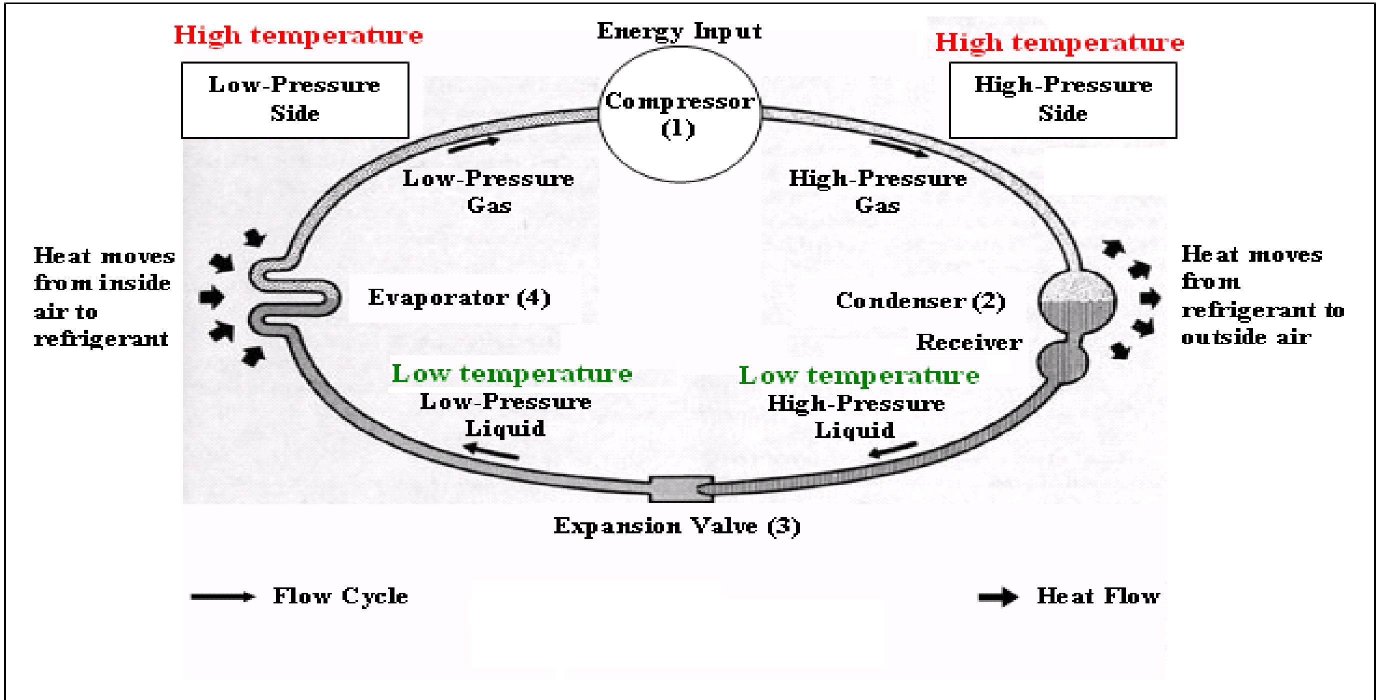
Fig 1 Single stage vapour compressor circuit and pressure enthalpy diagram

REFRIGERANT CYCLE



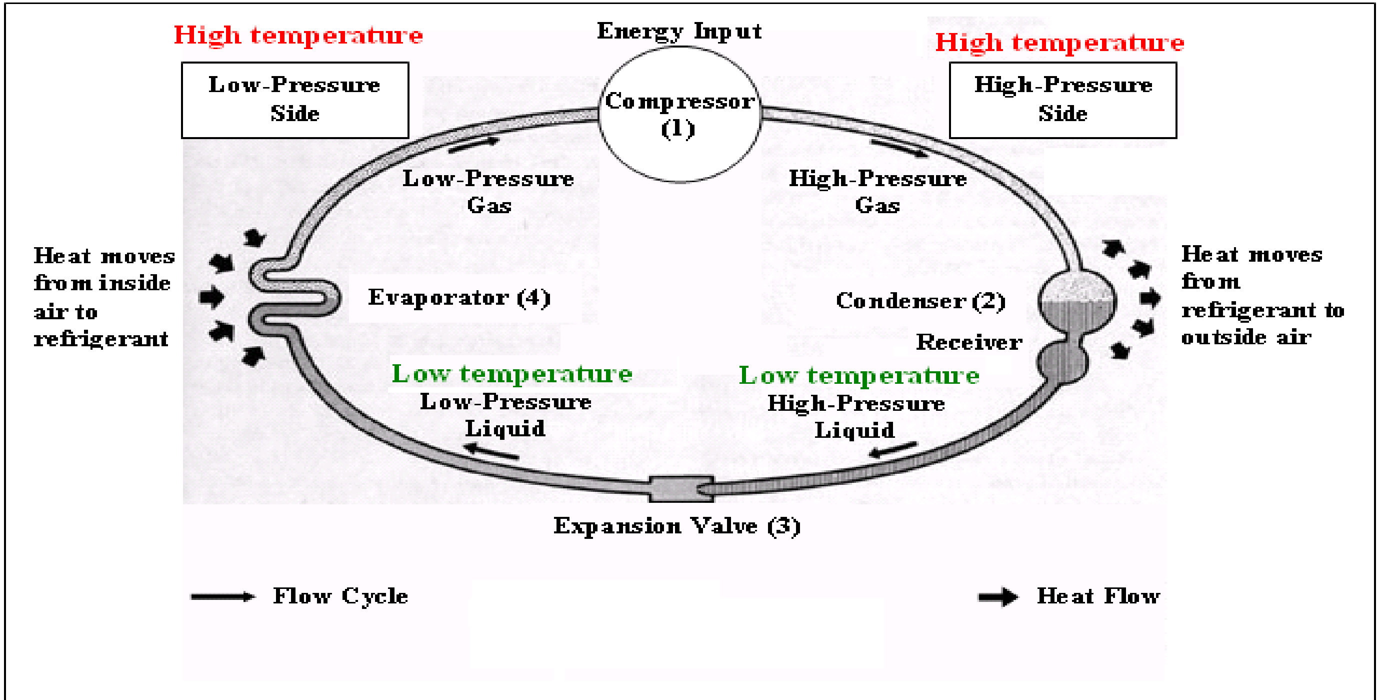
Low pressure gas enters the compressor (1) and leaves the compressor as a high pressure, high temperature gas.

REFRIGERANT CYCLE



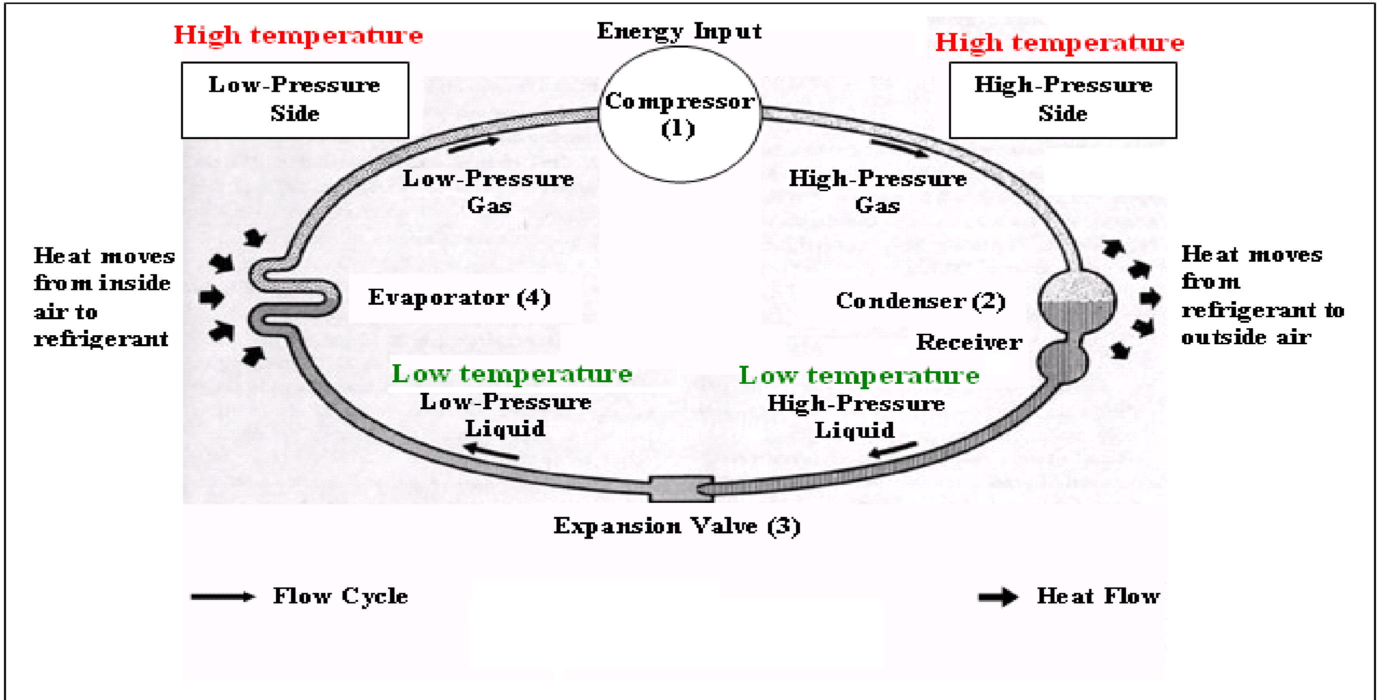
The high temperature, high pressure gas flows into the condenser (2) and becomes a liquid and gives off heat to the outside air.

REFRIGERANT CYCLE



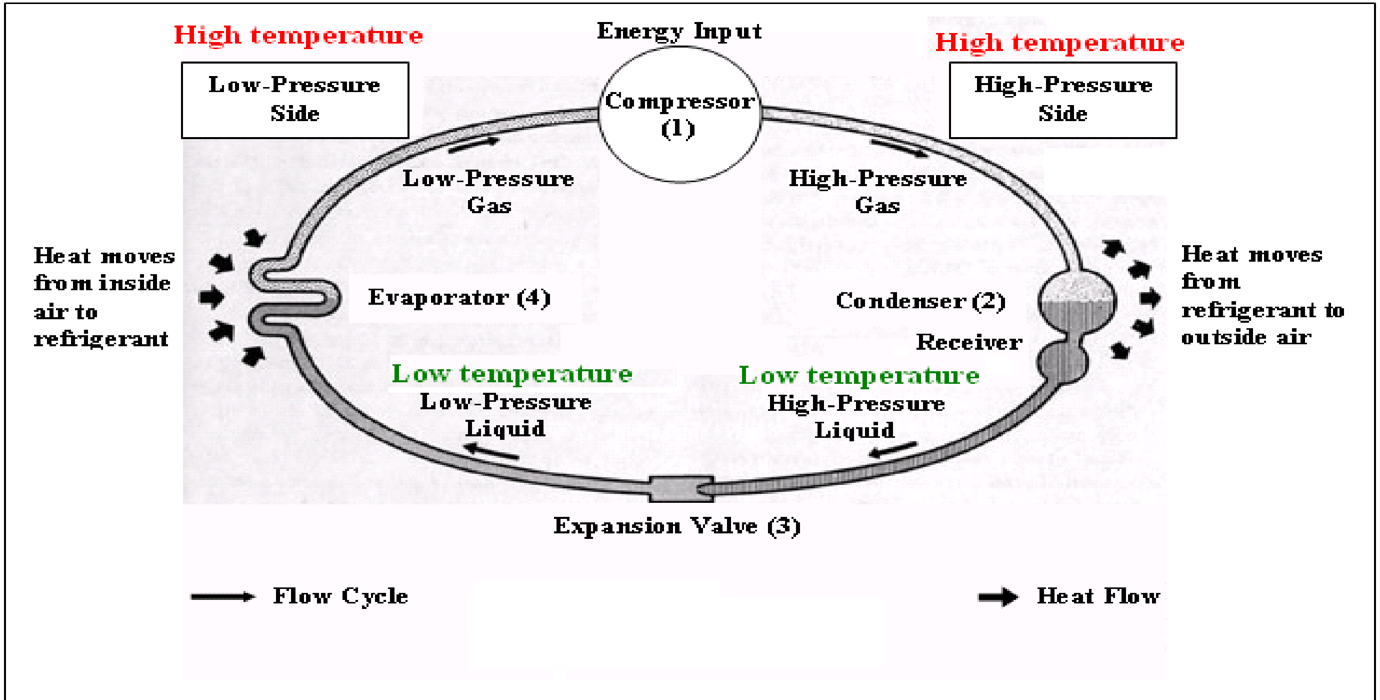
The liquid then flows under high pressure, to the expansion valve (3). This valve restricts the flow of the liquid to lower its pressure as

REFRIGERANT CYCLE

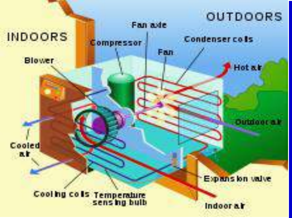


The low pressure liquid then moves to the evaporator (4), where heat from the inside air is absorbed by the liquid changing its state from liquid into gas (boils).

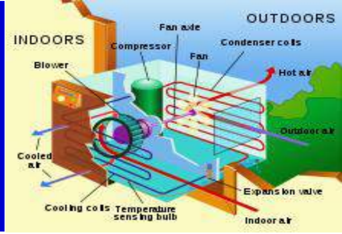
REFRIGERANT CYCLE



The refrigerant, now a hot low-pressure gas, moves back to the compressor (1) where the entire cycle is repeated over and over again.

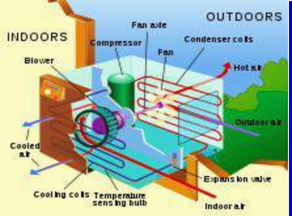


PRINCIPLE
OF
VAPOUR COMPRESSION REFRIGERATION SYSTEM

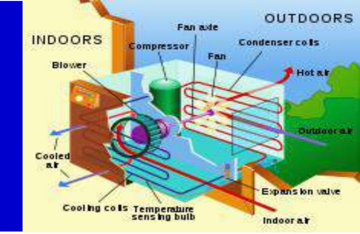


PRINCIPLE OF VAPOUR COMPRESSION REFRIGERATION SYSTEM

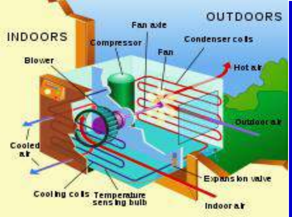
Heat is put into the fluid at the lower temperature and pressure in the evaporator which provides the latent heat to make it boil and change to a vapour. This vapour is then mechanically compressed (by the compressor) to a higher pressure and a corresponding saturation temperature at which its latent heat can be rejected in the condenser so that it changes back to a liquid. The total cooling effect will be the heat transferred to the working fluid in the boiling or evaporating vessel (evaporator), i.e. the change in enthalpies between the fluid entering and the vapour leaving the evaporator.



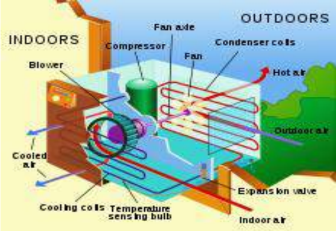
PRINCIPLE OF VAPOUR COMPRESSION REFRIGERATION SYSTEM



A working system will require a connection between the *condenser* and the inlet to the *evaporator* to complete the circuit. Since these are at different pressures this connection will require a pressure reducing and metering valve. Since the reduction in pressure at this valve must cause a corresponding drop in temperature, some of the fluid will flash off into vapour to remove the energy for this cooling. The volume of the working fluid therefore increases at the valve by this amount of flash gas, and gives rise to its name, the *expansion valve.*



PRINCIPLE
OF
VAPOUR COMPRESSION REFRIGERATION SYSTEM



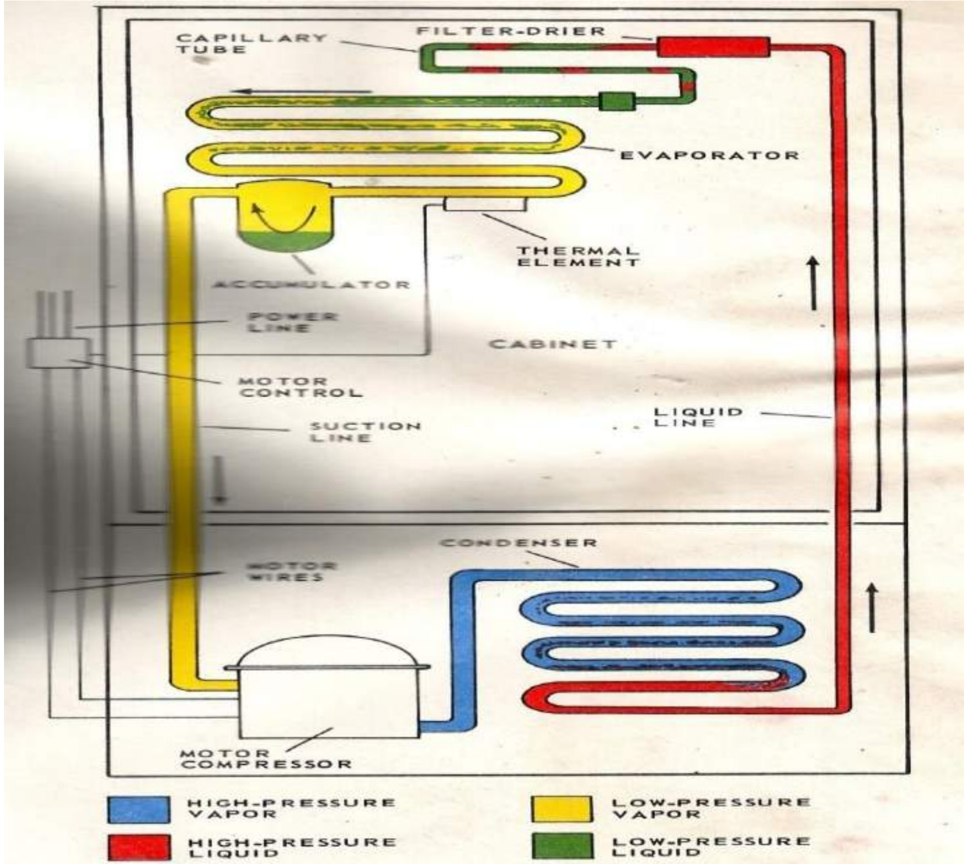
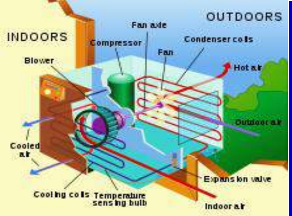
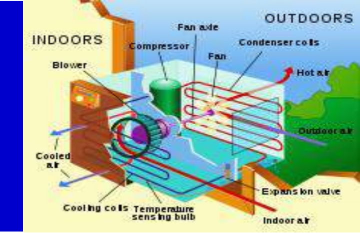


Fig. 3-9. Compression system using capillary tube type refrigerant control.

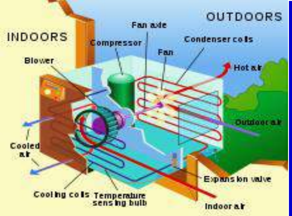


PRINCIPLE
OF
VAPOUR COMPRESSION REFRIGERATION SYSTEM

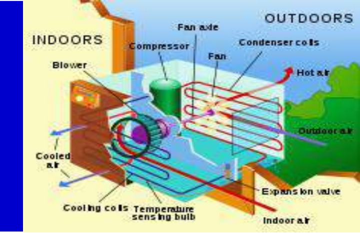


The refrigeration cycle is shown by the process lines *ABCD* (Figure 2). Compression is assumed to be adiabatic, but this will alter according to the type of compressor. Since there is no energy input or loss within the expansion valve, these two points lie on a line of equal enthalpy. The pressure–enthalpy chart can give a direct measure of the energy transferred in the process.

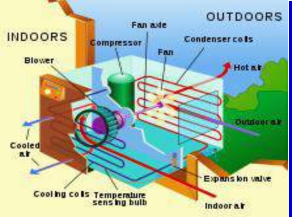
In a working circuit, the vapour leaving the evaporator will probably be slightly superheated and the liquid leaving the condenser subcooled. The gas leaving the evaporator is superheated to point *A*1 and the liquid subcooled to *C*1.

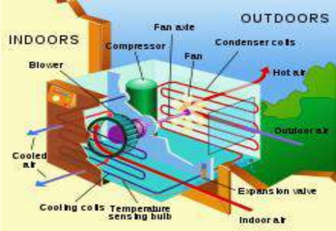


PRINCIPLE OF VAPOUR COMPRESSION REFRIGERATION SYSTEM



Also, pressure losses will occur across the gas inlet and outlet, and there will be pressure drops through the heat exchangers and piping. The final temperature at the end of compression will depend on the working limits and the refrigerant. Taking these many factors into account, the refrigerating effect ($A1 - D1$) and the compressor energy ($B1 - A1$) may be read off directly in terms of enthalpy of the fluid. The distance of $D1$ between the two parts of the curve indicates the proportion of flash gas at that point. The condenser receives the high-pressure superheated gas, cools it down to saturation temperature, condenses it to liquid, and finally subcools it slightly. The energy removed in the condenser is seen to be the refrigerating effect plus the heat of compression.

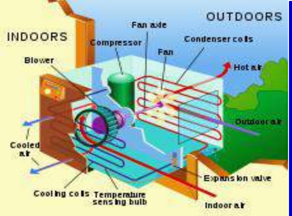


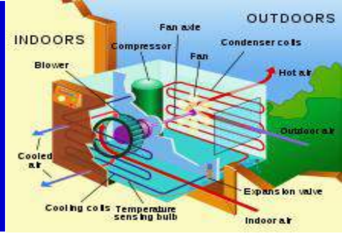


COEFFICIENT OF PERFORMANCE

Since the vapour compression cycle uses energy to move energy, the ratio of these two quantities can be used directly as a measure of the performance of the system. This ratio, the coefficient of performance, was first expressed by Sadi Carnot in 1824 ideal reversible cycle, and based on the two temperatures of the system, assuming that all heat is transferred at constant temperature. Since there are mechanical and thermal losses in a real circuit, the coefficient of performance (COP) will always be less than the ideal Carnot figure. For practical purposes in working systems, it is the ratio of the cooling effect to the input compressor power.

The coefficient of performance which is an index of performance of a thermodynamic cycle or a thermal system. Because it can be greater than 1, “COP” is used instead of thermal efficiency.



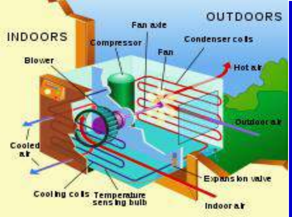


Subcooling

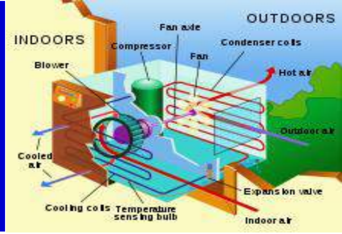
Condensed liquid refrigerant is usually subcooled to a temperature lower than the saturated temperature corresponding to the condensing pressure of the refrigerant. This is done to increase the refrigerating effect. The degree of subcooling depends mainly on the temperature of the coolant (e.g., atmospheric air, surface water, or well water) during condensation, and the construction and capacity of the condenser.

Superheating

the purpose of superheating is to avoid compressor slugging damage. *The degree of superheat depends mainly on the type of refrigerant* feed and compressor as well as the construction of the evaporator



PRINCIPLE OF VAPOUR COMPRESSION REFRIGERATION SYSTEM



- Vapour compression refrigeration systems are the most commonly used among all refrigeration systems. As the name implies, these systems belong to the general class of vapour cycles, wherein the working fluid (refrigerant) undergoes phase change at least during one process. In a vapour compression refrigeration system, refrigeration is obtained as the refrigerant evaporates at low temperatures. The input to the system is in the form of mechanical energy required to run the compressor. Hence these systems are also called as mechanical refrigeration systems. Vapour compression refrigeration systems are available to suit almost all applications with the refrigeration capacities ranging from few Watts to few megawatts. A wide variety of refrigerants can be used in these systems to suit different applications, capacities etc. The actual vapour compression cycle is based on Evans-Perkins cycle, which is also called as reverse Rankine cycle. Before the actual cycle is discussed and analysed, it is essential to find the upper limit of performance of vapour compression cycles. This limit is set by a completely reversible cycle.

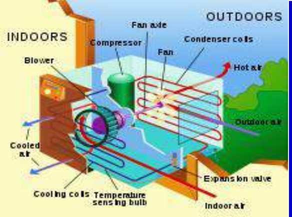
TYPES OF REFRIGERATION SYSTEM

1. VAPOUR COMPRESSION RERIGERATION SYSTEM
2. VAPOUR ABSOPTION RERIGERATION SYSTEM
3. VAPOUR ADSOPTION RERIGERATION SYSTEM
4. ELECTROLUX REFRIGERATION SYSTEM
5. THERMOELECTRIC REFRIGERATION SYSTEM
6. EJECTOR REFRIGERATION SYSTEM

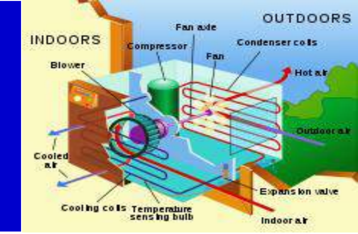
TYPES OF REFRIGERATION CYCLES

Refrigeration Methods

- **Steady State Refrigeration cycles**
  - **Compression refrigeration cycles**
    - **Vapor Compression (Subcritical)**
      - Basic (single stage)
      - Cascade (multi stage)
      - Mixed Gas (single/multi stage)
    - **Vapor Compression (Transcritical)**
      - Joule Thomson
      - Carbon dioxide based
    - **Turbo expander cycles**
      - Carnot (Expander)
      - Brayton (Expander)
      - Claude (Expander & J-T Valve)
  - **Vapor absorption cycles**
    - Single effect
    - Double effect
  - **Thermoelectric**
- **Periodic Refrigeration Cycles**
  - **Regenerative cycles**
    - Stirling
    - Pulse Tube
    - Gifford McMahon
    - Vuilleumier
  - **Magnetic refrigeration cycles**
  - **Adsorption refrigeration cycles**

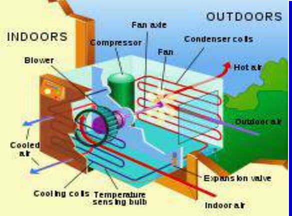


VAPOUR COMRESSION REFRIGERATION SYSTEM

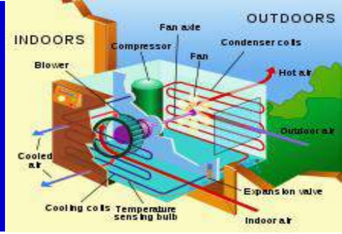


VAPOUR COMPRESSION REFRIGERATION SYSTEM

In an vapour refrigeration cycle, an exanpder or expansion engine is not used, since power recovering is small and does not justify the cost of the engine. A throttle valve or capillary tube is used for expansion in reducing the pressure from P_1 to P_2.



ACTUAL VAPOUR COMPRESSION REFRIGERATION CYCLE

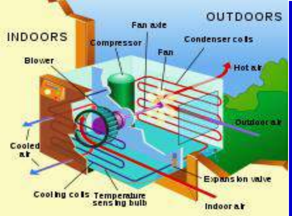


ACTUAL VAPOUR COMPRESSION REFRIGERATION CYCLE

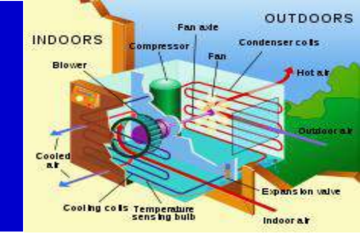
In order to ascertain that there is no droplet of liquid refrigerant being carried over into the compressor, some superheating of vapour is used after the evaporator.

A small degree of subcooling of the liquid refrigerant after the condenser is also used to reduce the mass of vapour formed during expansion, so that too many vapour bubbles do not impede the flow and the liquid refrigerant through the expansion valve.

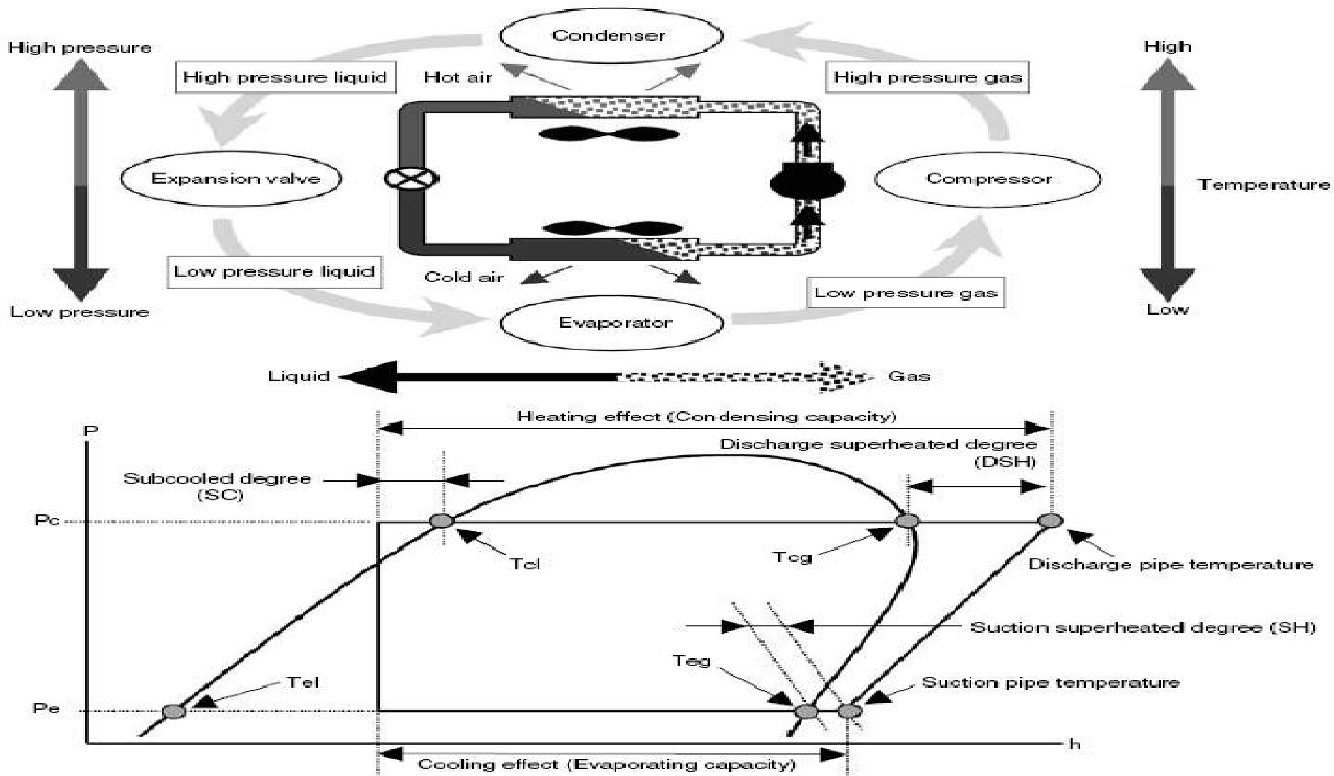
Both the superheating of vapour at the evaporator outlet and subcooling of liquid at the condenser outlet contributed to an increase in the refrigerating effect.



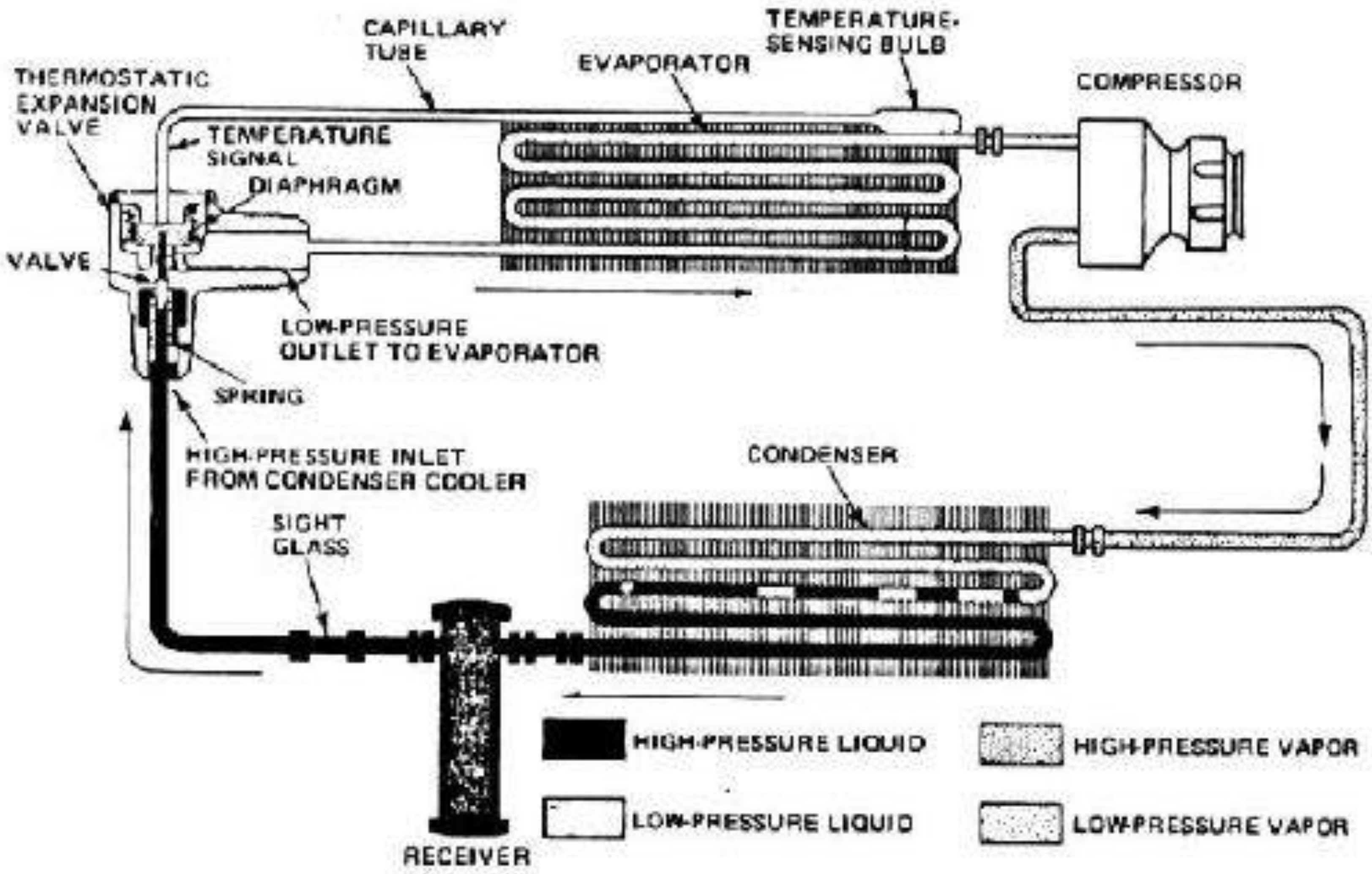
THE FLOW SYSTEM OF VAPOUR COMRESSION REFRIGERATION CYCLE

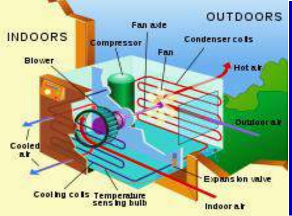


INDOORS
OUTDOORS
Fan axle
Compressor
Condenser coils
Fan
Blower
Hot air
Outdoor air
Cooled air
Expansion valve
Cooling coils
Temperature sensing bulb
Indoor air

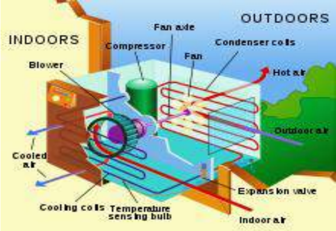


A Refrigeration System





A REFRIGERATOR



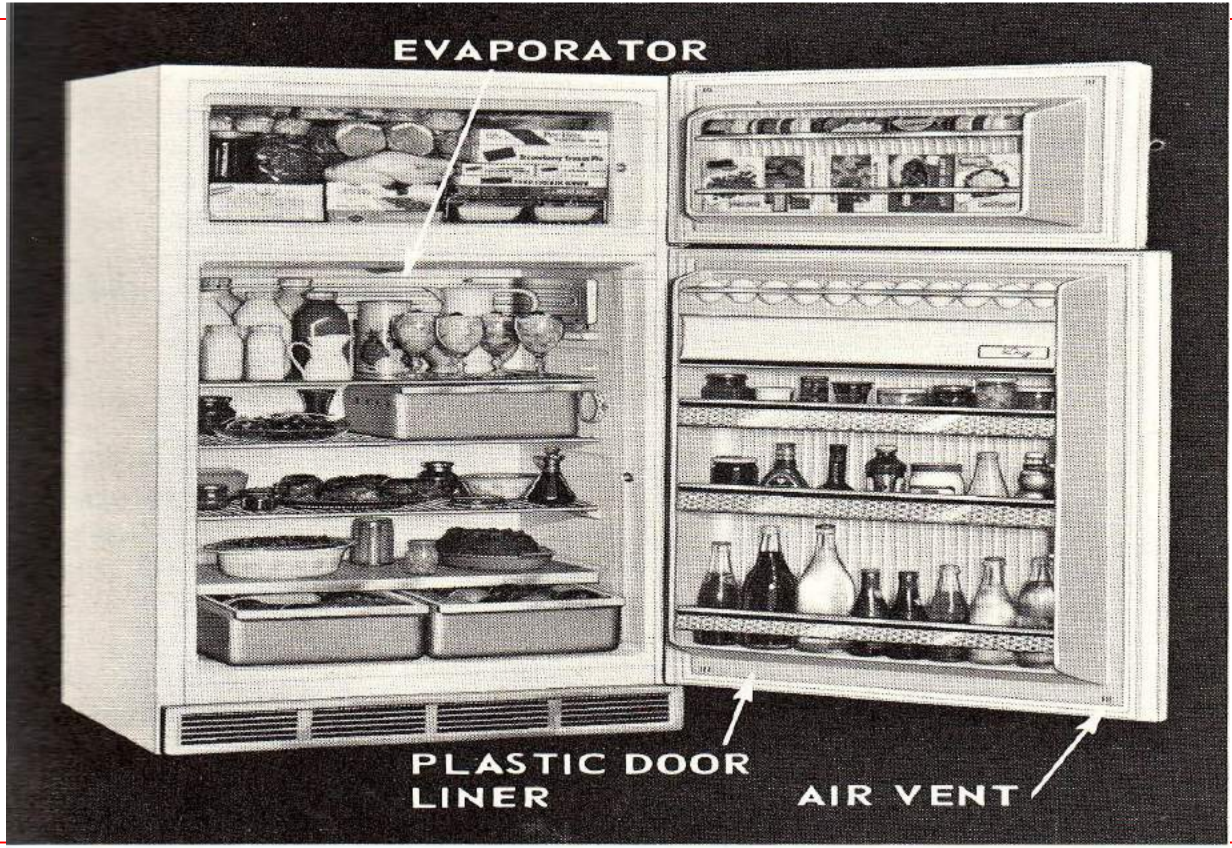
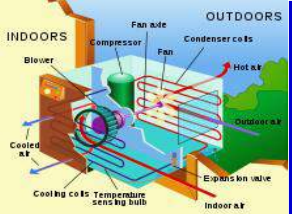
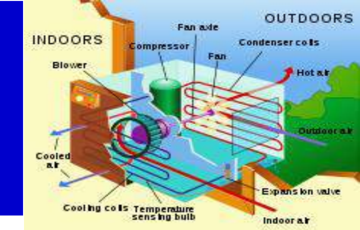


Fig. 10-6. Two-door model refrigerator-freezer with freezer at top. Note evaporator in upper part of lower compartment. (Kelvinator, Inc.)



A CYCLE DIAGRAM OF A REFRIGERATOR



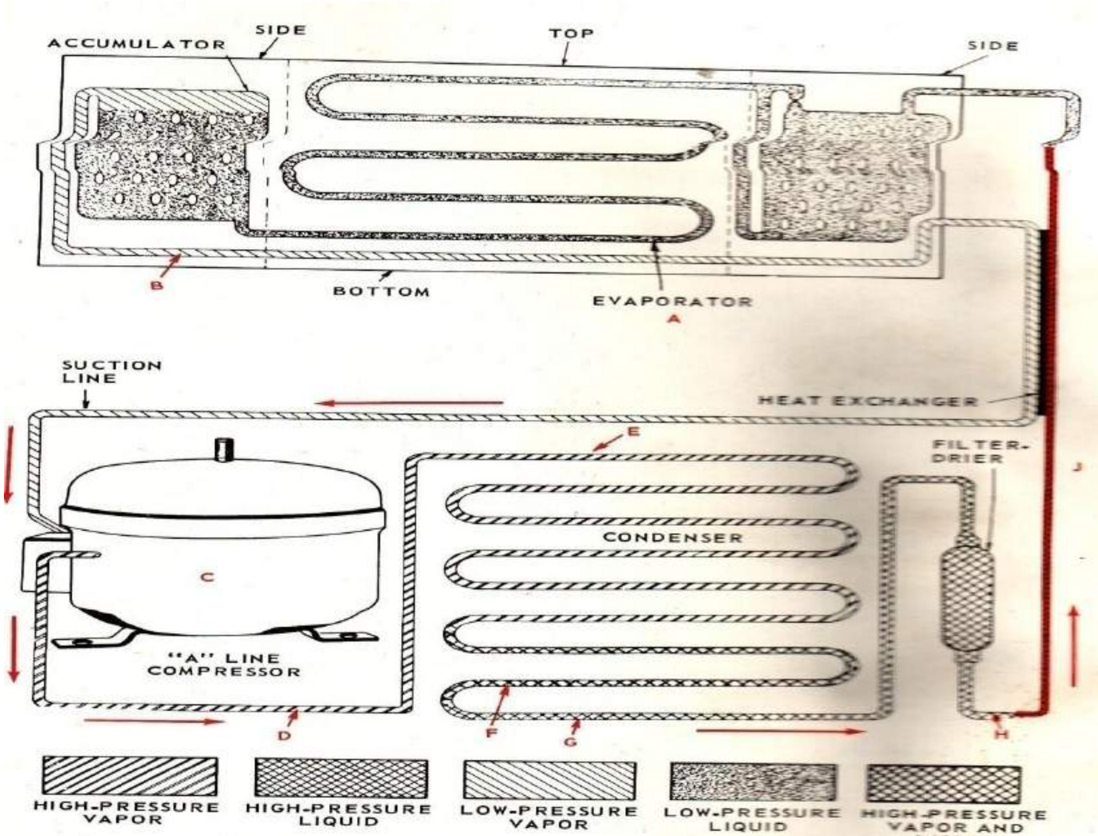
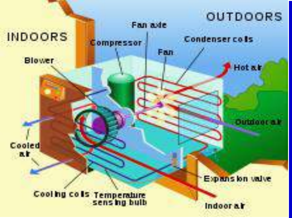
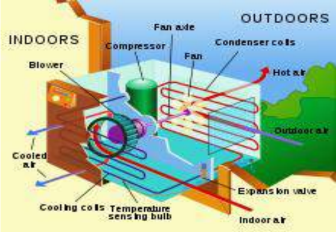


Fig. 10-2. Cycle diagram for a fresh food refrigerator.

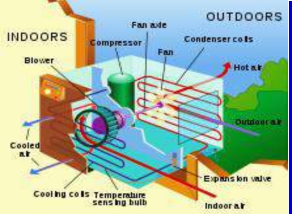


REFRIGERATOR COMPONENT FUNCTIONS

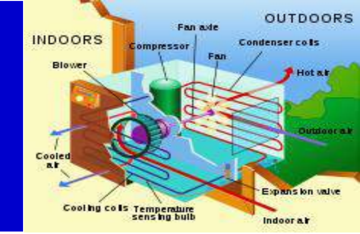


1. **Compressor:** The low pressure and temperature vapour refrigerant from evaporator is drawn into the compressor through the inlet or suction valve, where it is compressed to high pressure and temperature. This high pressure and temperature vapour refrigerant is discharged into the condenser through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

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.



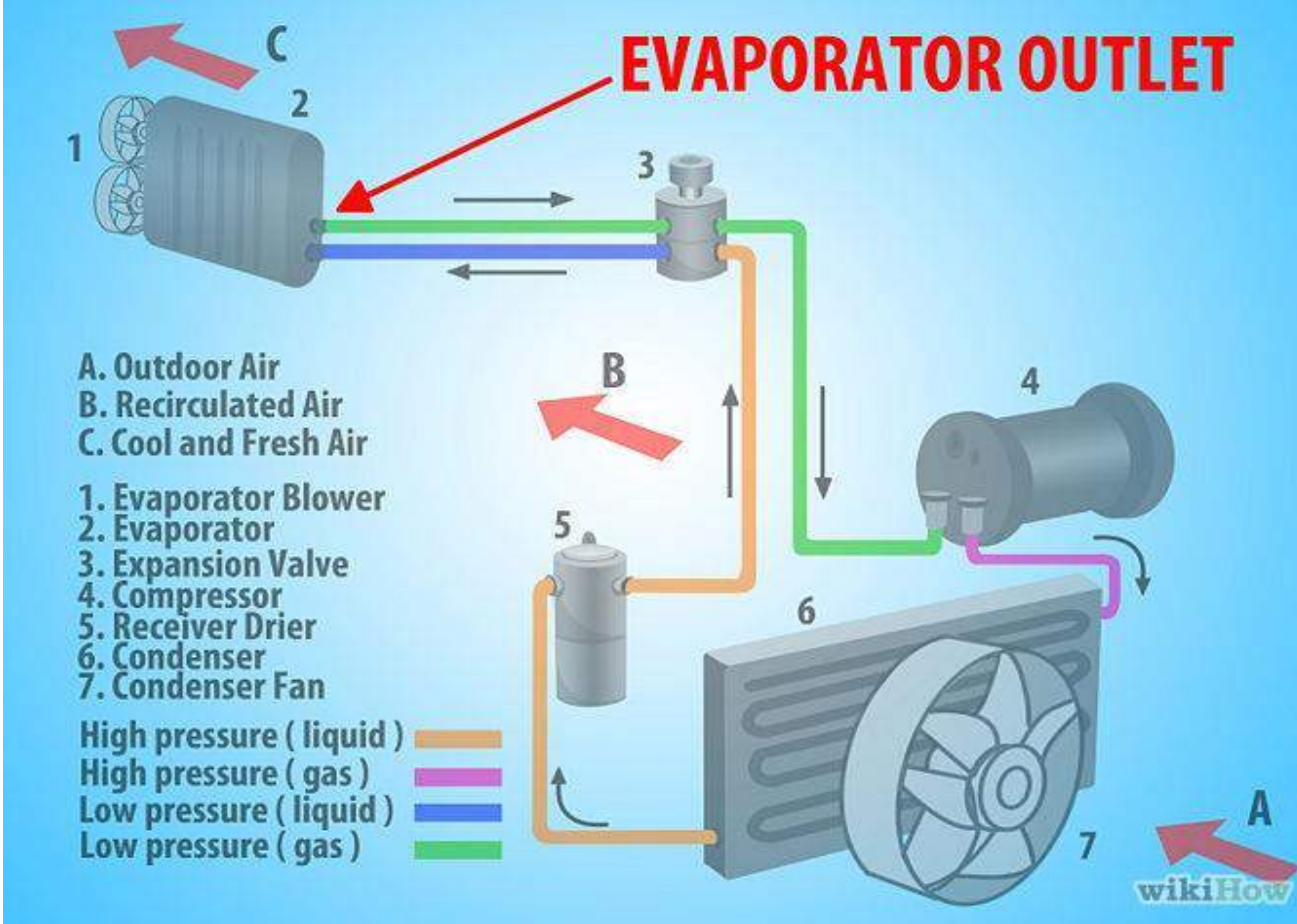
Refrigerator Component Functions



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 vapourised In the evaporator at the low pressure and pressure.

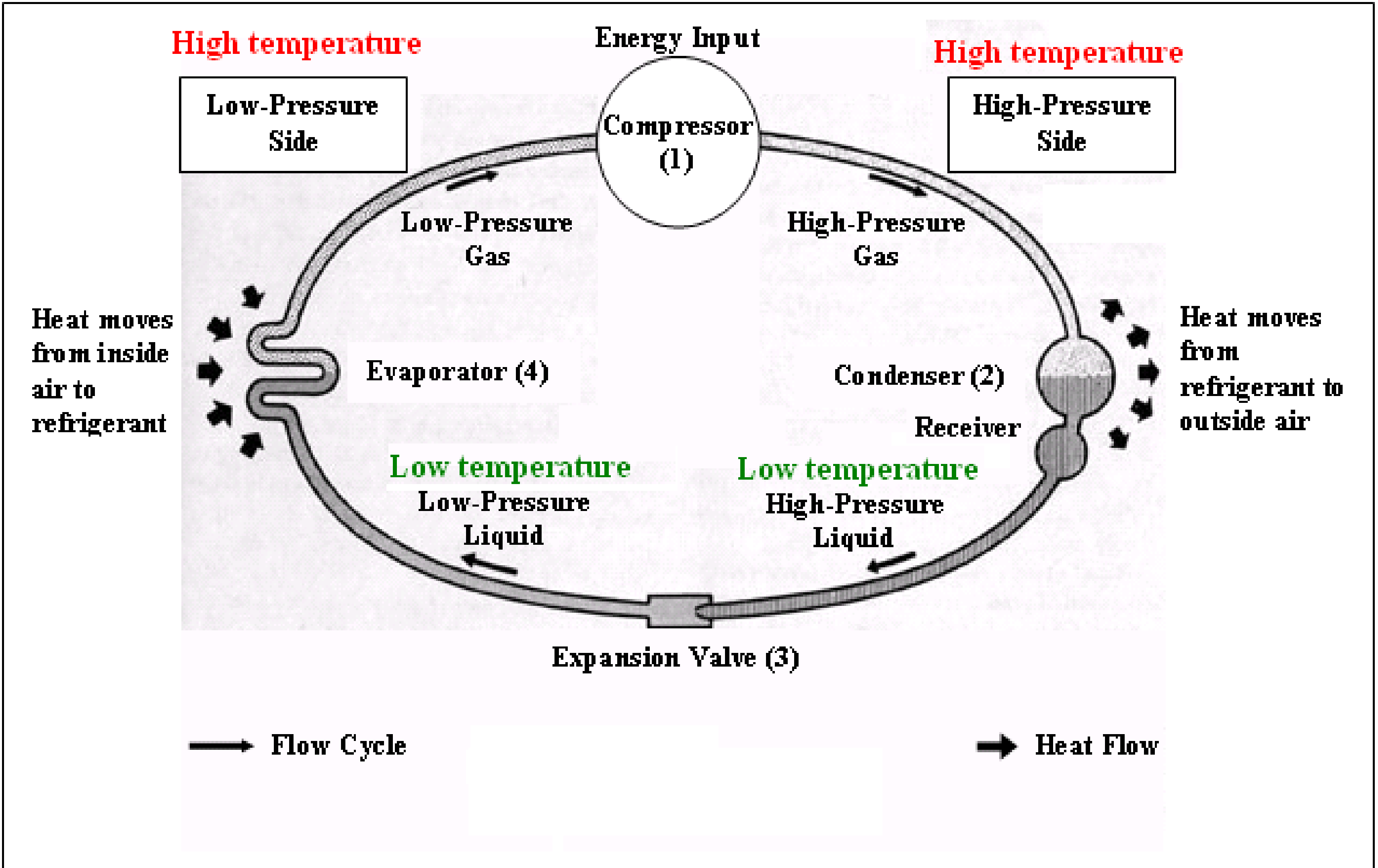
Evaporator:

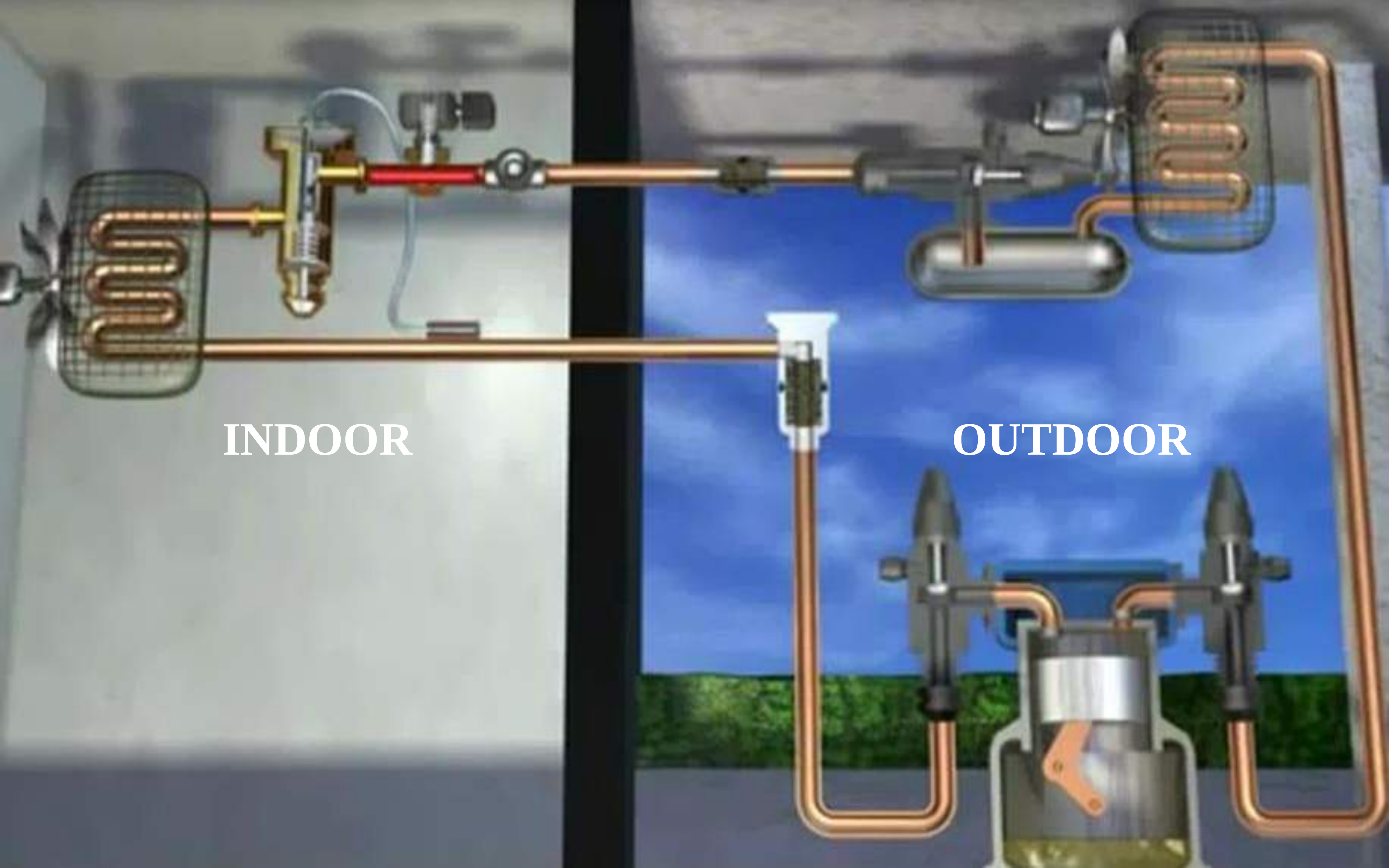
An evaporator consists of coils of pipe in which the liquid-vapour refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium (air,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

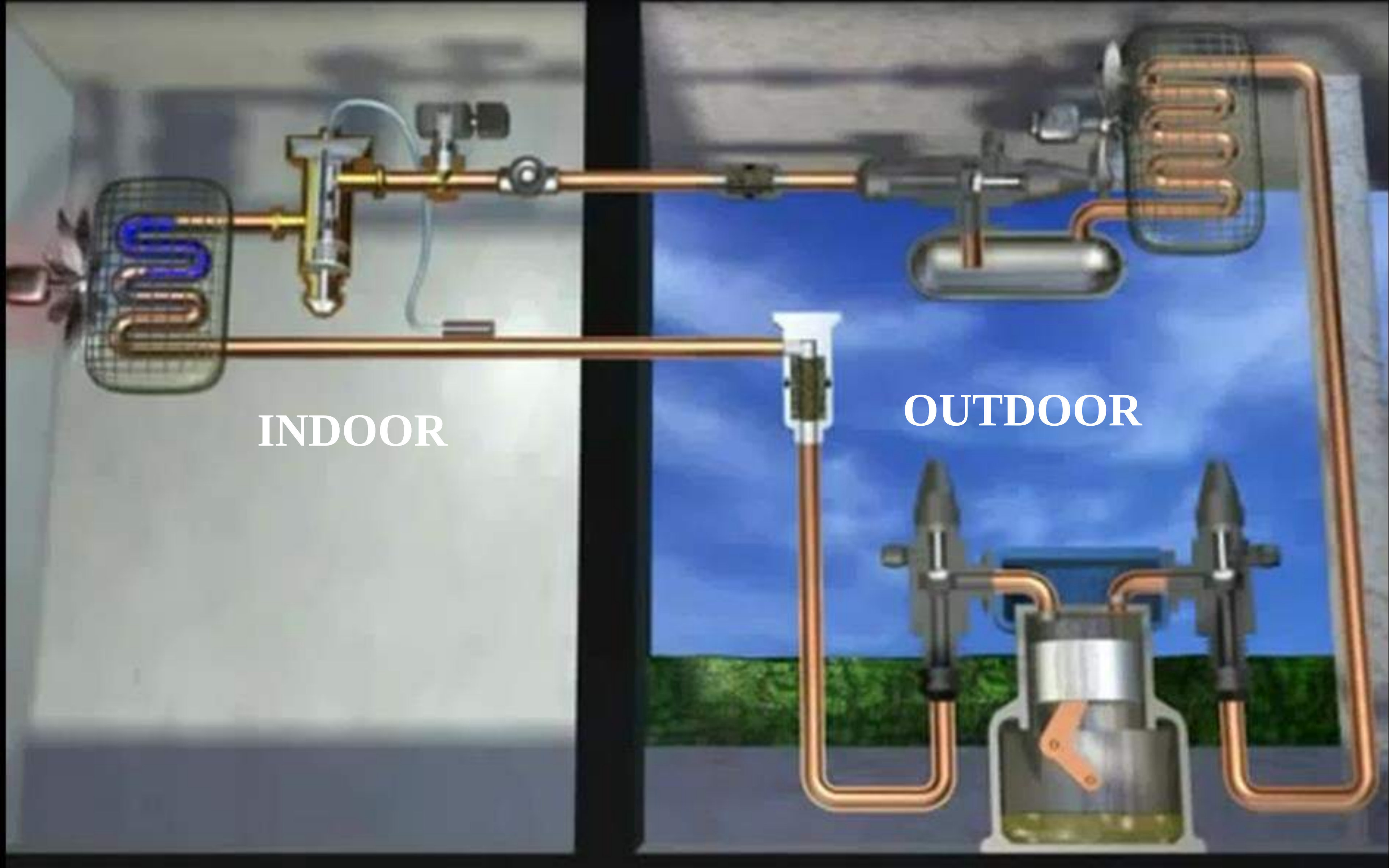

EVAPORATOR OUTLET
C
1
2
3
4
5
6
7
B
A
A. Outdoor Air
B. Recirculated Air
C. Cool and Fresh Air
1. Evaporator Blower
2. Evaporator
3. Expansion Valve
4. Compressor
5. Receiver Drier
6. Condenser
7. Condenser Fan
High pressure (liquid)
High pressure (gas)
Low pressure (liquid)
Low pressure (gas)
wikiHow

THE WORKING PRINCIPLES
OF
EVAPORATOR AND CONDENSER

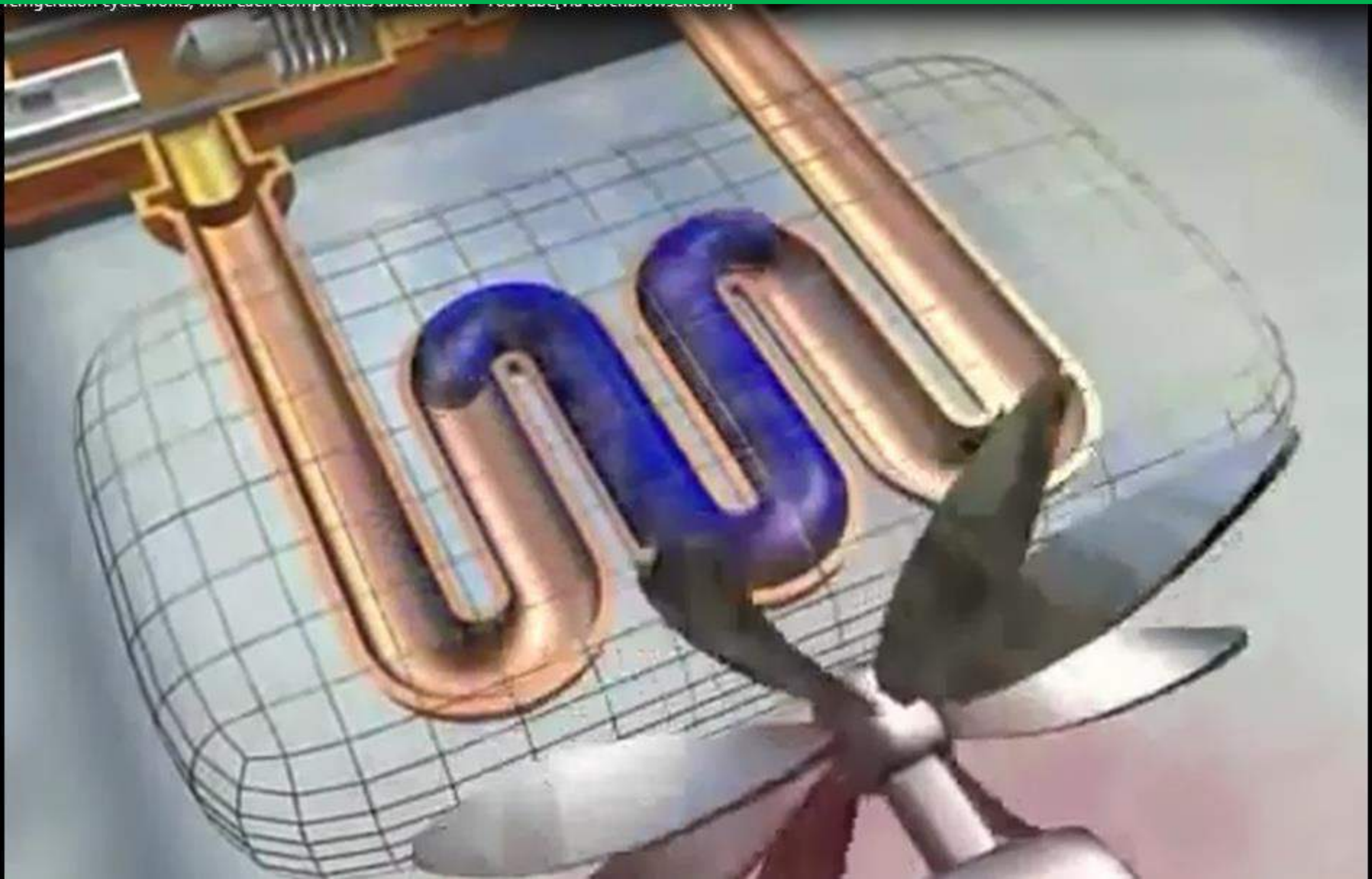
HOW DOES IT WORK ?



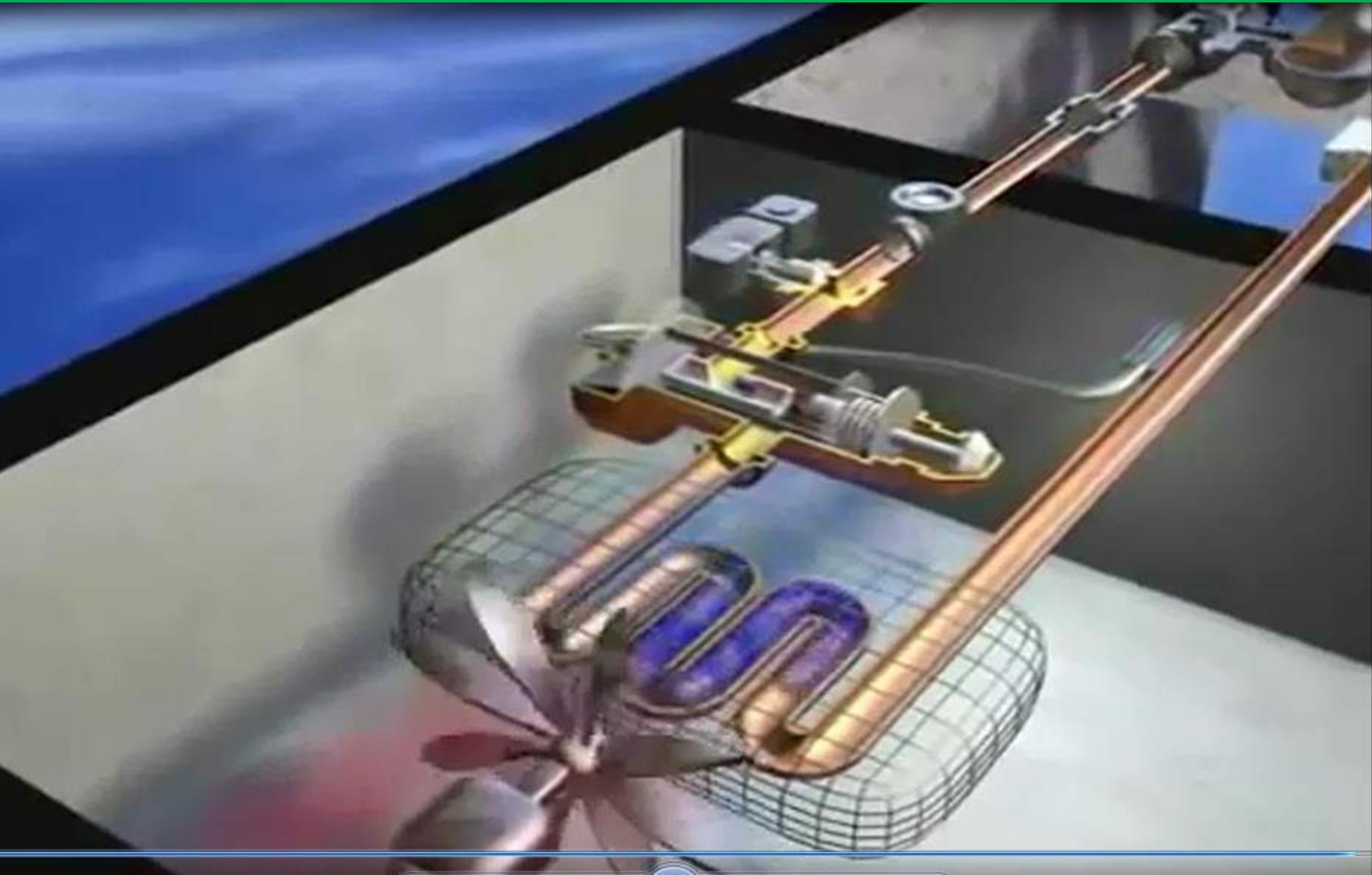

INDOOR
OUTDOOR


INDOOR
OUTDOOR

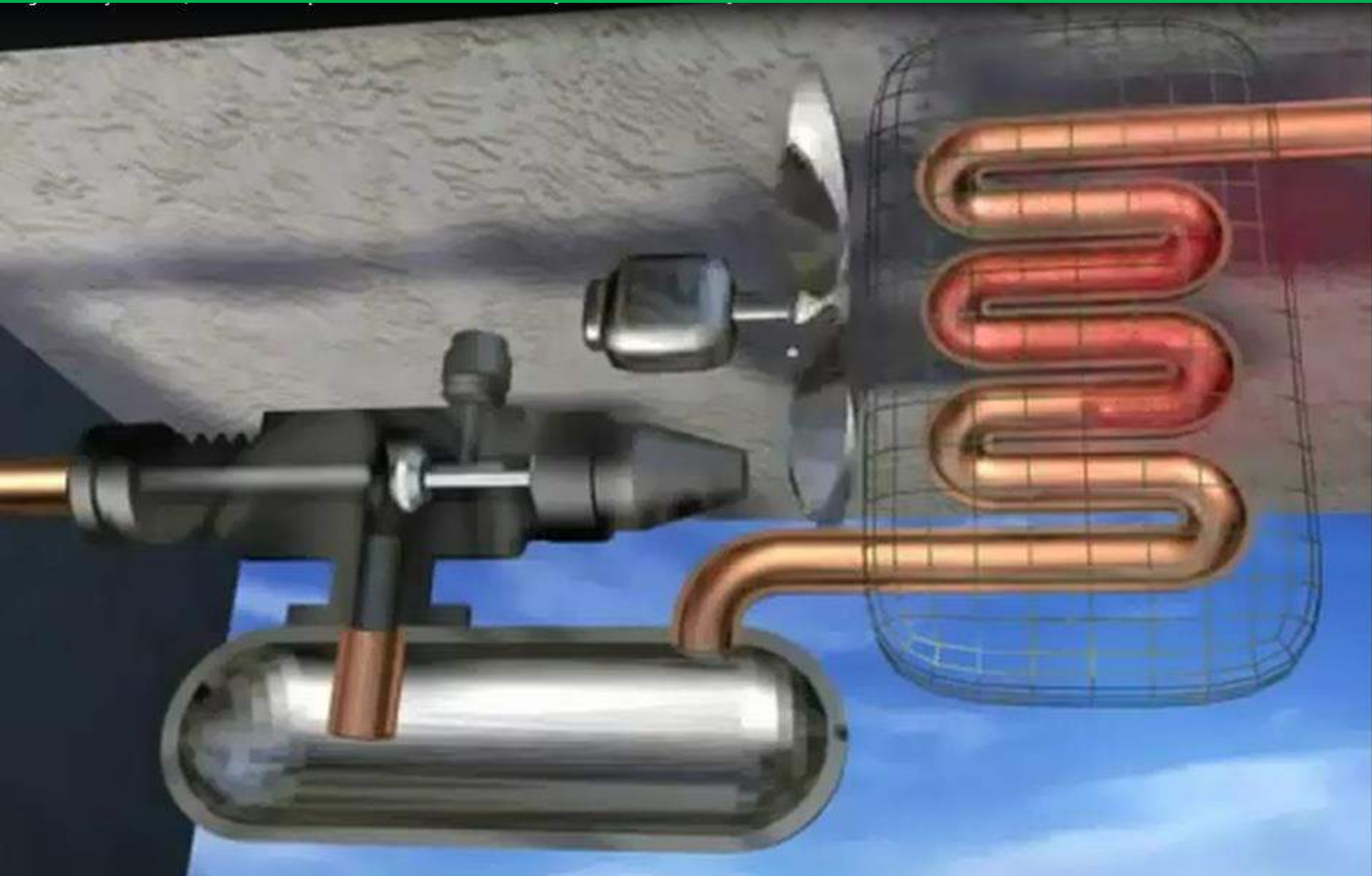
THE WORKING PRINCIPLE OF AN EVAPORATOR



THE WORKING PRINCIPLE OF AN EVAPORATOR



THE WORKING PRINCIPLE OF A CONDENSER



THE WORKING PRINCIPLE OF A CONDENSER

EVAPORATOR?

An evaporator is a heat device or heat exchanger that is used in to cool a space by extracting heat from the space and transfer the heat to a low temperature liquid through its tube

EVAPORATOR : The Purpose, the Parts, the Process

The purpose of the evaporator is to receive the low-pressure and temperature liquid from the expansion valve and convert this liquid into gas, while extracting heat from the space to be cooled.

The evaporator consists of pipes, usually made of cooper and cooling fins usually made of aluminum.

In the evaporator, the refrigerant turns into gas at low pressure and temperature, while absorbing heat from the space to be cooled. The cooling down is done by the evaporator, which the air from the refrigerated area and blows it through the evaporator fines. When the air has passed through the evaporator fins and gave up its heat, it returns to the refrigerated area a lot cooler and drier. As the refrigerant evaporates, the vapor is returned to the suction side of the compressor via the suction line.

Therefore, it could be stated stepwisely that in evaporator:

- the refrigerant turns into a low pressure and temperature gas that could absorb heat.
- the evaporator blower sucks in relatively hot air from the refrigerated area/space to be cooled.
- the relatively hot air passes through the evaporator fins and is cooled by the low pressure and temperature gas by means of heat exchanging process.

CONDENSER?

An condenser is a heat device or heat exchanger that is used to receive the high-pressure and temperature gas from a source and converts the gas into liquid, while emitting heat to the sink/surroundings.

CONDENSER : The Purpose, the Parts, the Process

The condenser function is the opposite of the evaporator function. The purpose of the condenser is to receive the high-pressure and temperature gas from the Compressor and convert this gas into liquid, while emitting heat to the surroundings.

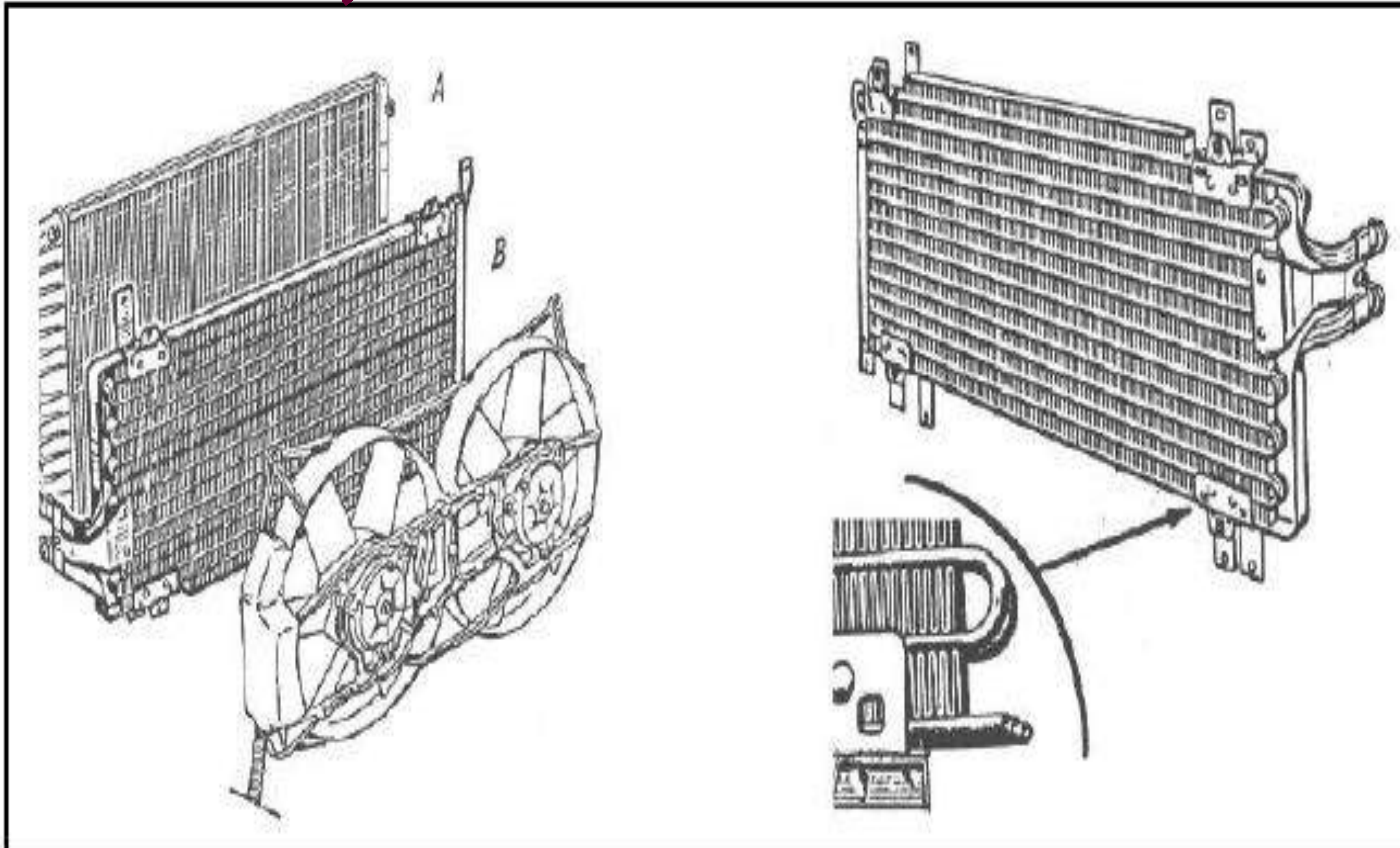
The condenser consists of pipes, usually made of cooper and cooling fins usually made of aluminum.

The refrigerant in its gas state flows through the condenser pipes, while the air from the surrounding is (by cooling) around the fins.

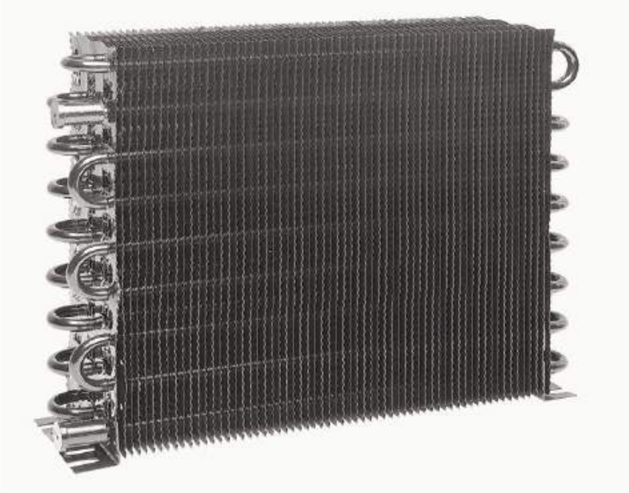
It could stated stepwisely that the condenser:

- Gets high pressure and temperature refrigerant gas from the compressor.
- Converts the gas to a liquid at the outlet of the condenser by heat exchanging process
- Uses fins to enhance the rate of heat transfer from the primary surfaces, the tubes
- Additionally, a fan can be used to increase heat transfer to the outside.
- Therefore, it acts as a radiator that heats the outside environment .

FINS, FANS ! WHY ?



FINS! WHAT FOR?



Fins are employed to enhance the heat transfer rate between the primary surface and its conductive, convective, radiative environment. In refrigeration and air conditioning systems, refrigerant flows through the evaporative tubes absorbing heat from the surrounding air to maintain a temperature below the surrounding or refrigerant flows through the condenser tubes emitting heat to the surrounding air. As the outer surface of the evaporator/condenser is air, the fin surface are commonly employed to reduce the convective resistance at the air side of the heat exchanger device.

FANS! WHY?

The fan's purpose is to move the air through the evaporator or the condenser. The heat exchange depends upon the temperature difference between the air and the refrigerant. The greater the difference will be, the greater will be the heat amount that is exchanged between the air and the refrigerant.

When the fan operates at its higher speed, it delivers its greatest volume of air across the fins and coils for a rapid evaporation. As the area is cooled down, it will soon reach a temperature, in which little extra cooling will result, if the fan is allowed to continue at its high-volume flow. A reduction in the fan speed will decrease the airflow volume but the lower volume rate will allow the air to remain in contact with the fins and coils for a longer period of time and give up its heat to the refrigerant.

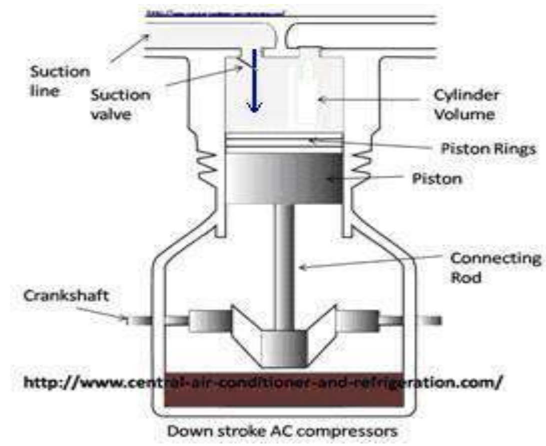
COMPRESSOR

The compressor:

- Circulates the refrigerant in the circuit.
- Compresses the refrigerant that leaves the evaporator.
- Raises its temperature to enable heat transfer to the outside.

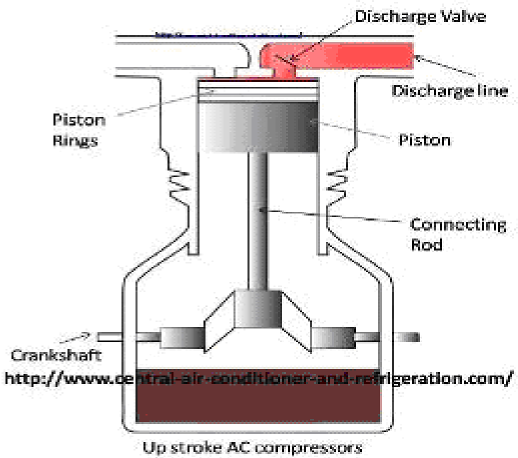
WORKING PRINCIPLE OF COMPRESSOR

Electricity energizes the motor to rotate the compressor crankshaft. Reciprocating compressors have a cylinder, piston, connecting rod, crankshaft, cylinder head and valves. The operating cycle is shown in the diagram.

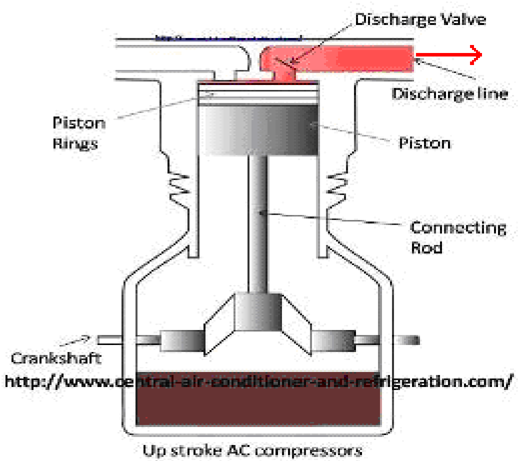


On the down stroke of the piston, a low pressure area is created between the top of the piston, the cylinder head and the suction line of the air conditioning evaporator. Cold refrigerant vapor rushes through the suction valve inlet and into the low pressure area

HOW DOES IT WORK?

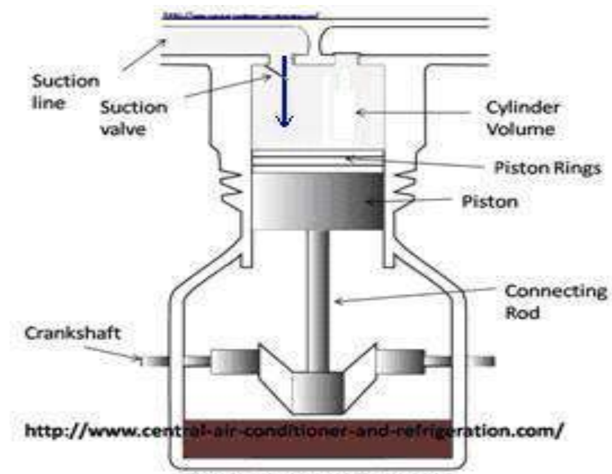


On the up stroke, the suction valve closes and piston decreases the volume of the refrigerant gas, thus increasing its pressure.



The exhaust (discharge) valve is forced open with the increasing pressure. The vapor is compressed and forced into the discharge (high) side of the refrigeration system.

HOW DOES IT WORK?

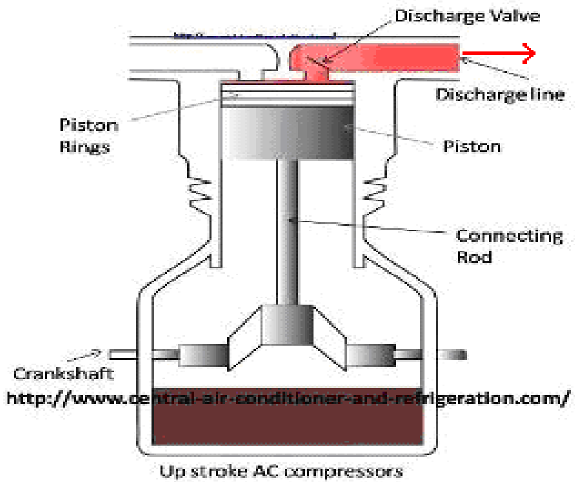


Down stroke AC compressors

When the piston reaches the top of the cylinder, the discharge valve closes, and the suction valve opens as the piston starts down again drawing in cold refrigerant vapor to complete the cycle.

Note that the connecting rod attached between the crankshaft and piston serves to change rotary motion into reciprocating (back and forth) motion.

HOW DOES IT WORK?



The piston rings prevent the vapor from escaping between the piston and cylinder walls and improve the operating efficiency.

The compressor housing or crankcase contains the bearing surfaces for the crankshaft and stores the oil that lubricates the compressor parts.

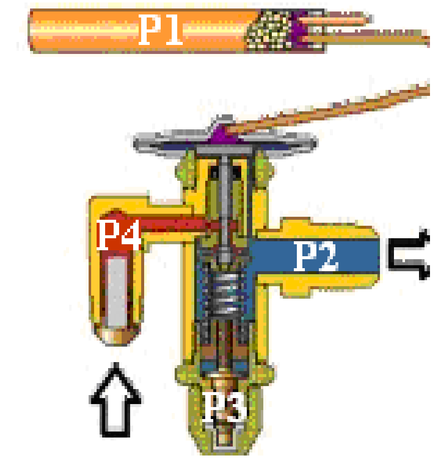
THERMAL EXPANSION VALVE

The thermal expansion valve (TEV or TXV):

- <u>Main objective:</u> To regulate refrigerant flow
- Also achieves:
- Increased outlet pressure from the compressor
- Reduced pressure to the evaporator
- Lowers the temperature of the liquid coolant
- Regulates the cooling output of the evaporator
- Prevents ice formation on the evaporator pipes

THERMAL EXPANSION VALVE

How does the TEV or TXV work:

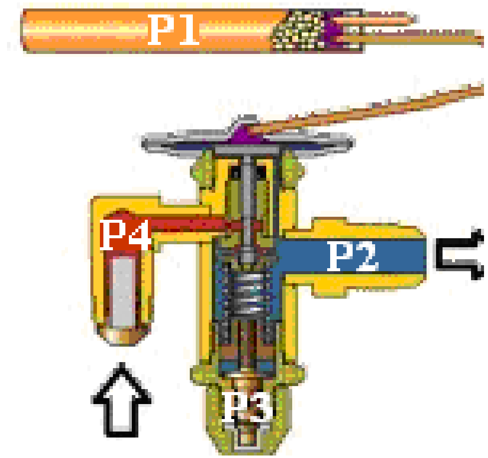


As the thermostatic expansion valve regulates the rate at which liquid refrigerant flows into the evaporator, it maintains a proper supply of refrigerant by matching this flow rate against how quickly the refrigerant evaporates (boils off) in the evaporator coil.

To do this, the TEV responds to temperature of the refrigerant vapor as it leaves the evaporator (P1) and the pressure in the evaporator (P2).

It does this by using a movable valve pin against the spring pressure (P3) to precisely control the flow of liquid refrigerant into the evaporator (P4):

THERMAL EXPANSION VALVE



Pressure Balance Equation

P1+P4 = P2+P3

P1 = Bulb pressure (opening force)

P2 = Evaporator pressure (closing force)

P3 = Superheat spring pressure
(closing force – usually adjustable)

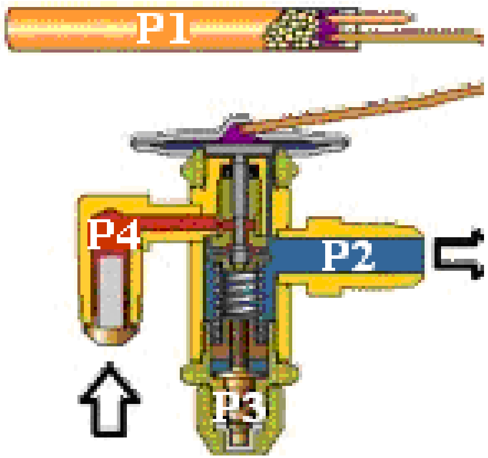
P4 = Liquid pressure (opening force)

To do this, the TEV responds to temperature of the refrigerant vapor as it leaves the evaporator (P1) and the pressure in the evaporator (P2).

It does this by using a movable valve pin against the spring pressure (P3) to precisely control the flow of liquid refrigerant into the evaporator (P4):

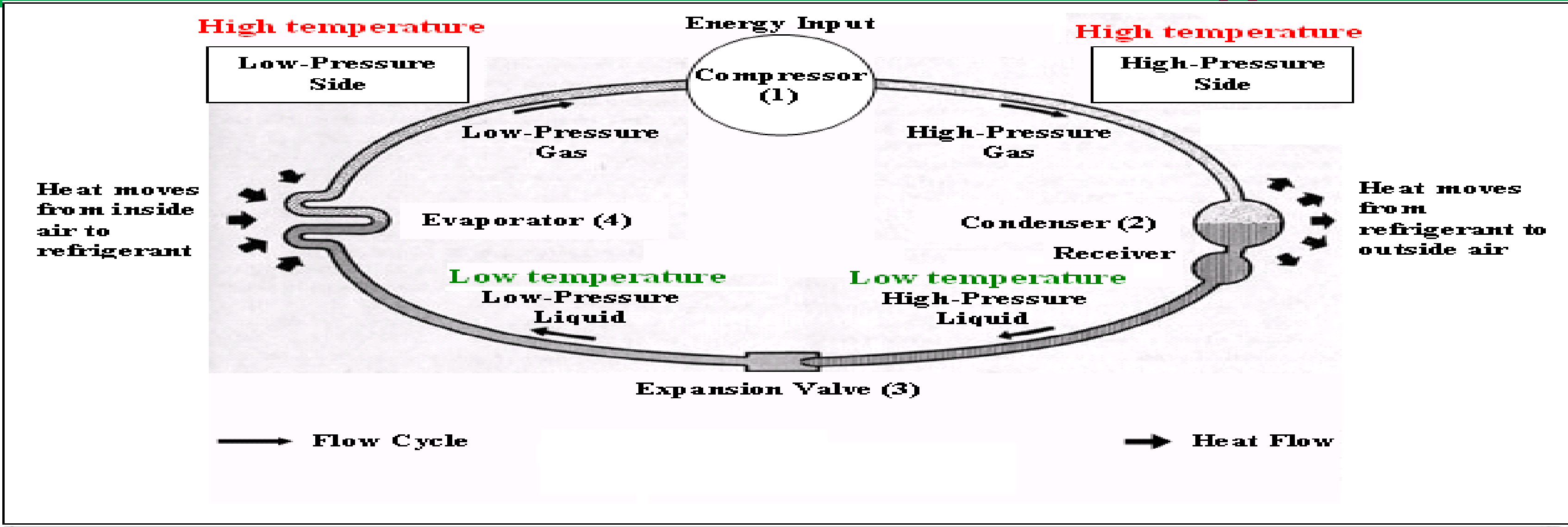
THERMAL EXPANSION VALVE

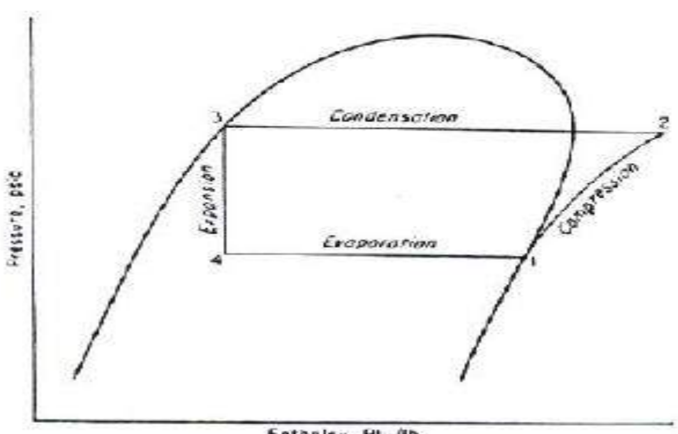
When the flow of the liquid refrigerant is restricted by the valve pin:



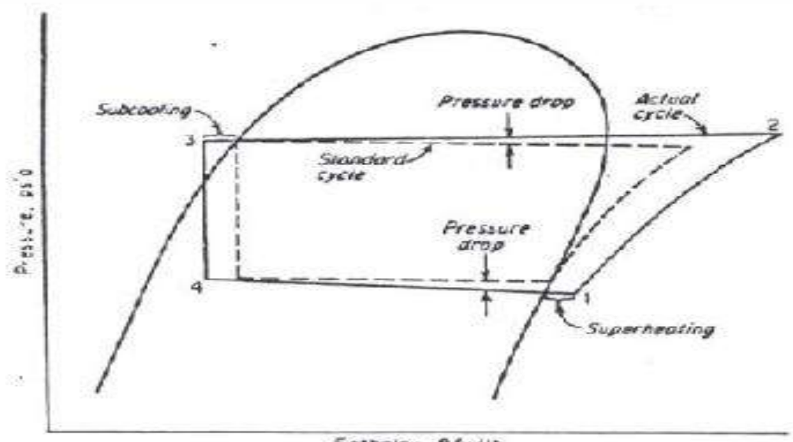
- The pressure on the liquid refrigerant drops.
- A small amount of liquid refrigerant is converted (boils) to gas, due to the drop in pressure.
- This "flash gas" has a high degree of energy transfer, as sensible heat of the refrigerant is converted to latent heat.
- The low pressure liquid and vapor combination moves into the evaporator, where the rest of the liquid refrigerant "boils off" into a gas as it absorbs heat from its surroundings.

From the CYCLE to the P-H diagrams

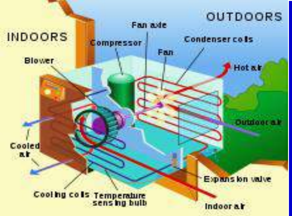




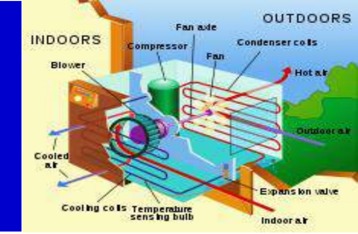
The theoretical cooling process as shown on a p-h diagram

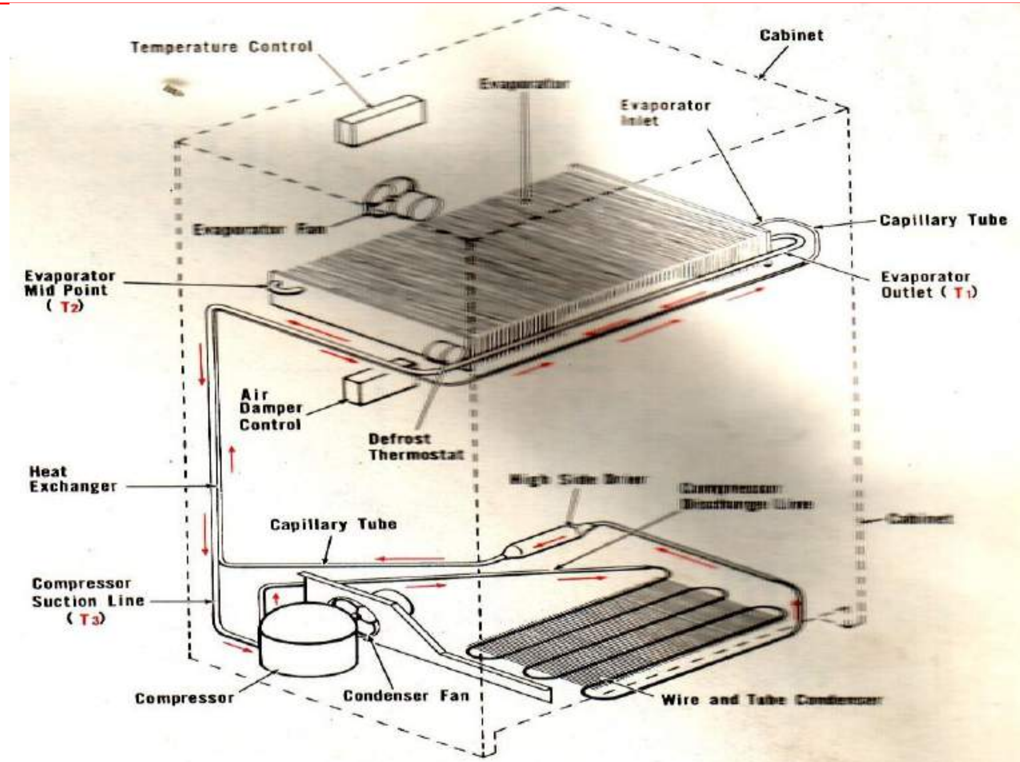


The real cooling process as shown on a p-h diagram



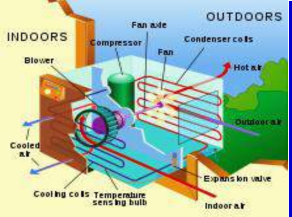
REFRIGERATION SYSTEM SCHEMATIC



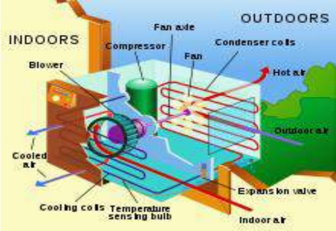


REFRIGERANT SYSTEM SCHEMATIC AND TEMPERATURE TEST POINTS

Fig. 10-12. Cycle diagram for a refrigerator with frozen food compartment and automatic electrical defrost. Proper operation may be checked by determining temperatures at test points, T_1, T_2 and T_3. Recommended operating temperatures are: T_1 = —17 to —16 F. (—27 C.). T_2 = —17 to —16 F. (—27 C.). T_3 = 75 to 95 F. (24 to 35 C.). (Amana Refrigeration, Inc.)



THE HIDDEN PARTS OF A REFRIGERATION SYSTEM



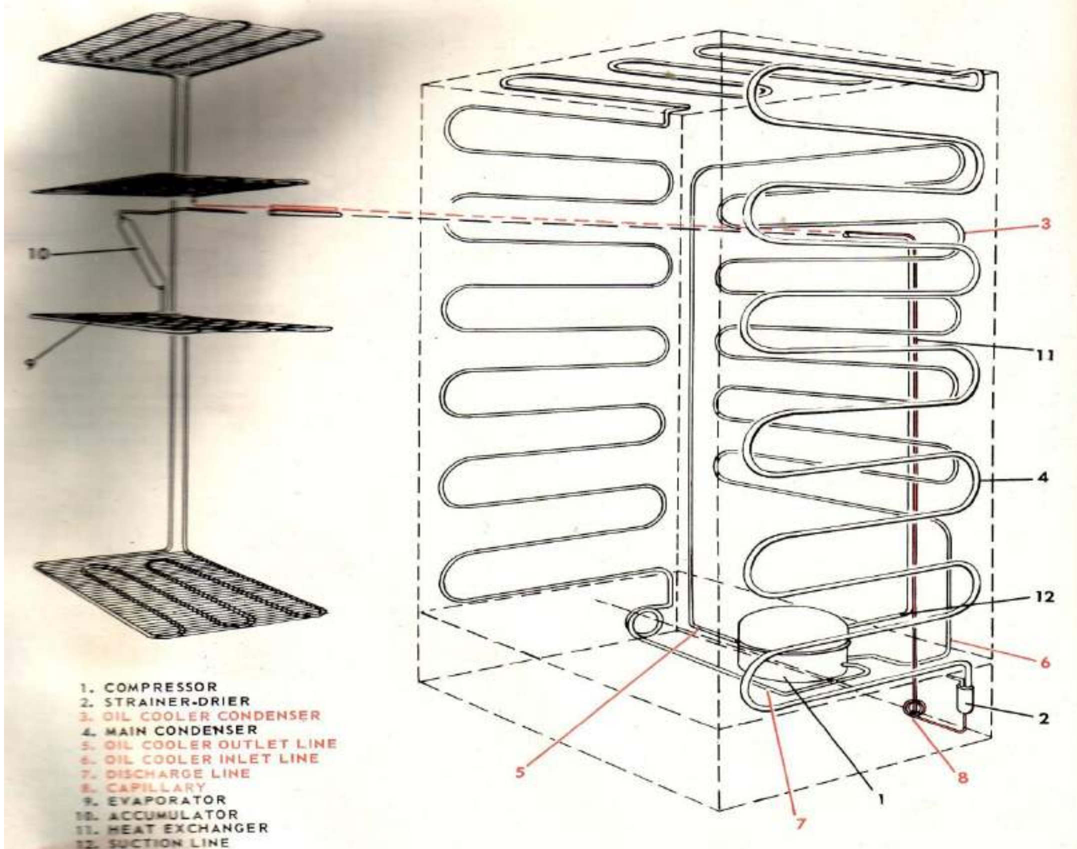
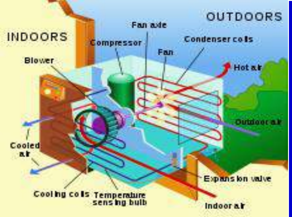
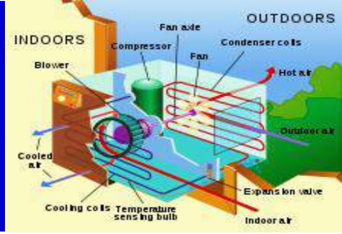


Fig. 4-6. Shelf type evaporator 9. This shows evaporator as it forms the shelf in upright freezer. Accumulator 10 is located at outlet of evaporator. This is a small reservoir to catch refrigerant not needed in evaporator.



VAPOUR COMRESSION REFRIGERATION SYSTEM



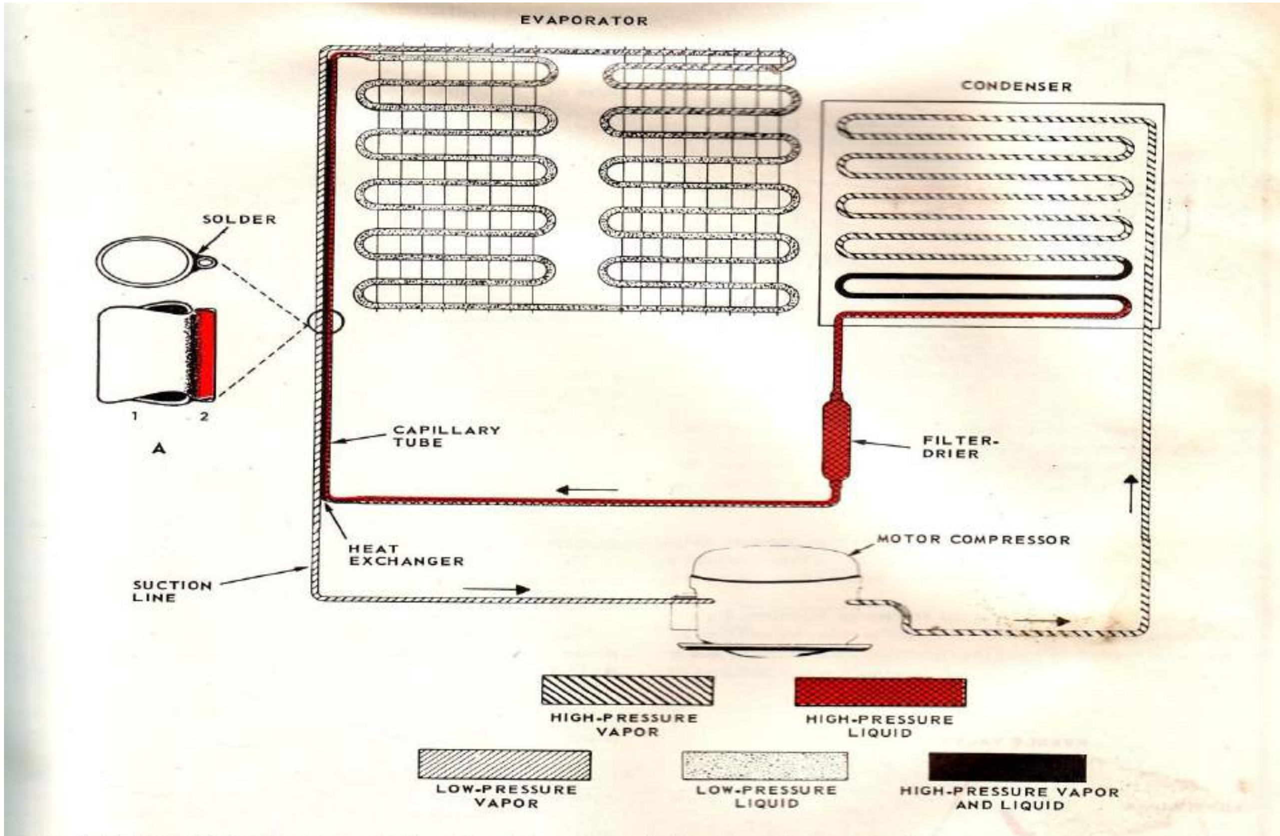
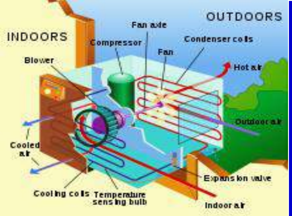
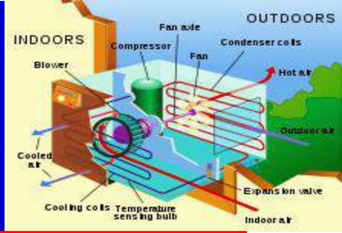


Fig. 4-17. Refrigerating system using capillary tube refrigerant control. Filter-drier is located in liquid line ahead of connection to capillary tube. Most of the capillary tube is fastened to suction line which provides heat exchange. A—Enlarged cross-section of suction line (1) and capillary tube (2) showing how they are soldered or brazed together. (Kelvinator, Inc.)



VAPOUR COMRESSION REFRIGERATION SYSTEM



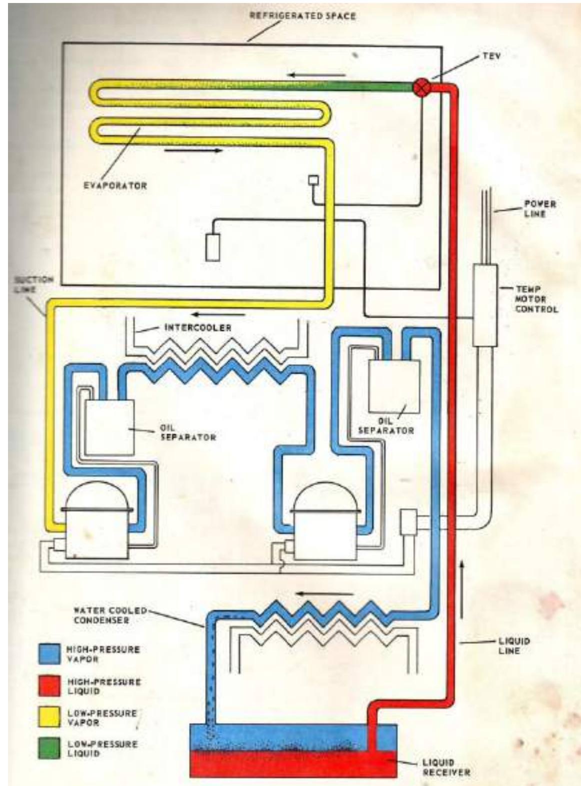
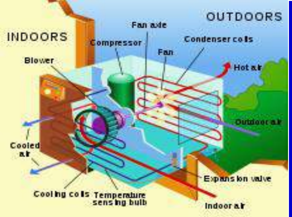
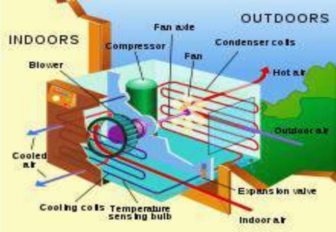


Fig. 3-11. Compound refrigerating system.



VAPOUR COMRESSION REFRIGERATION SYSTEM



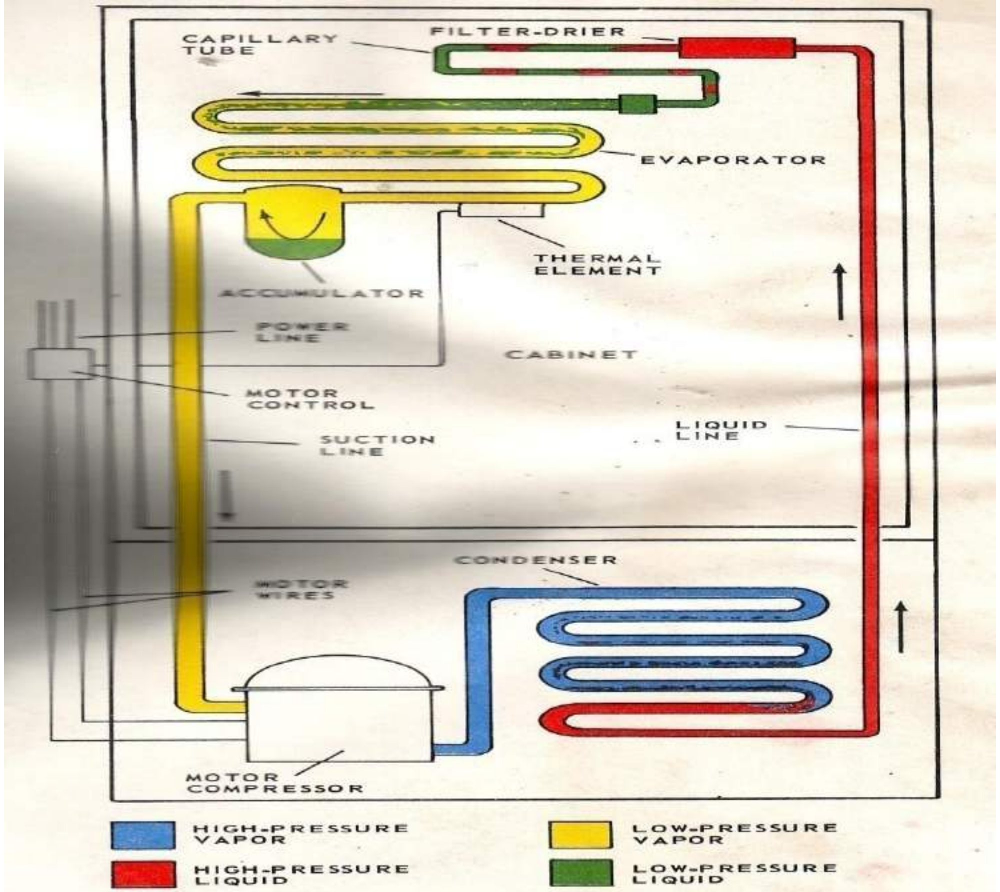
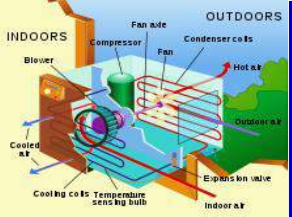
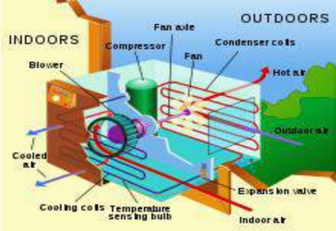


Fig. 3-9. Compression system using capillary tube type refrigerant control.



VAPOUR COMRESSION REFRIGERATION SYSTEM



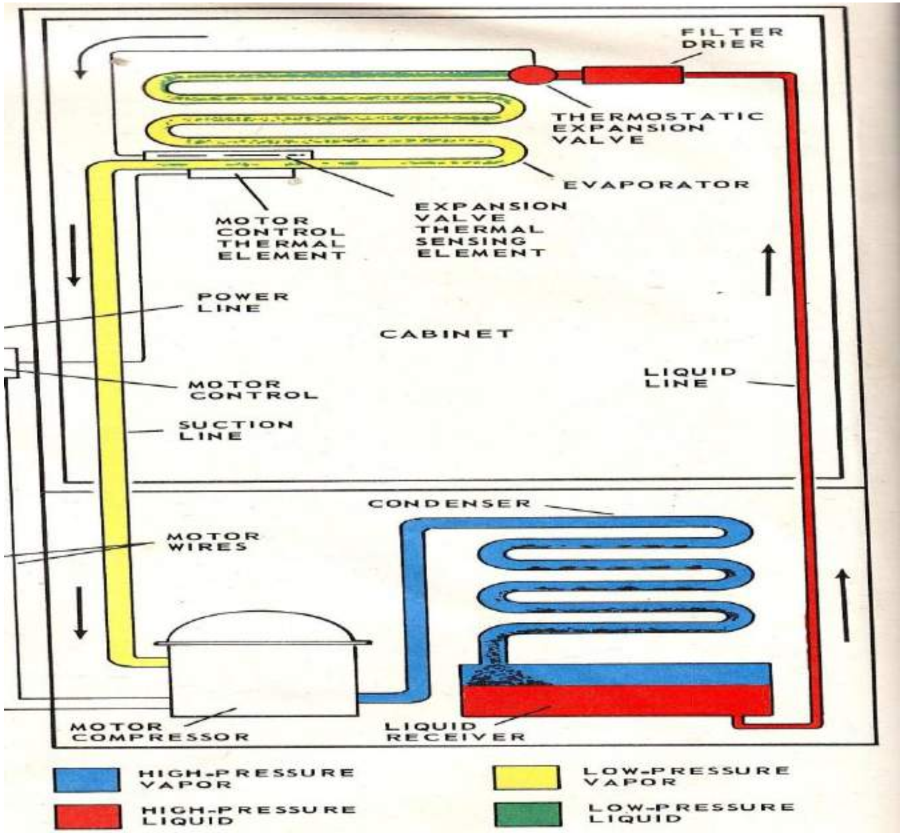
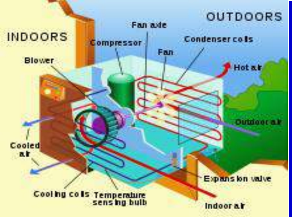


Fig. 3-8. Compression system using thermostatically controlled expansion valve (TEV).



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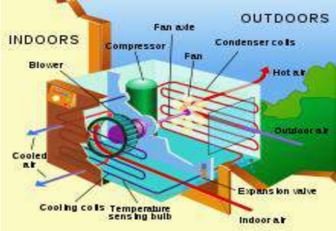


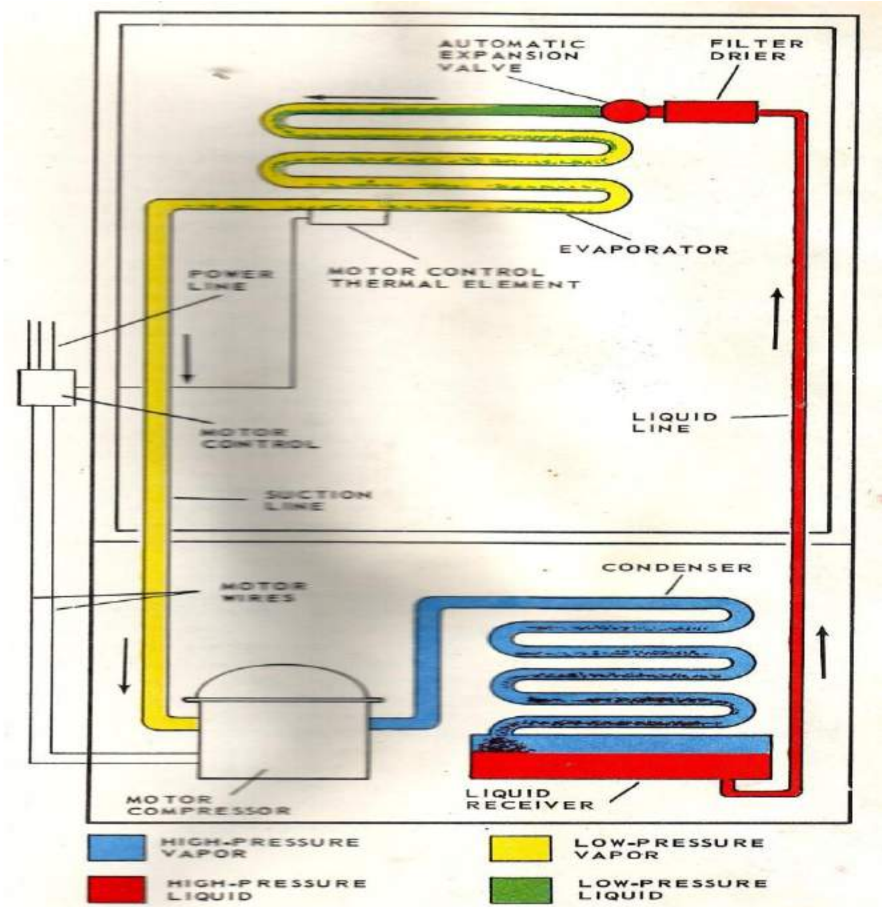
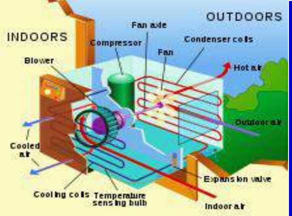
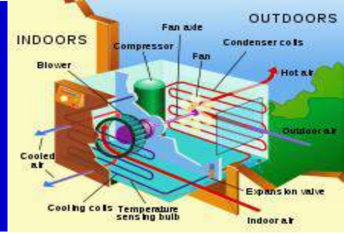
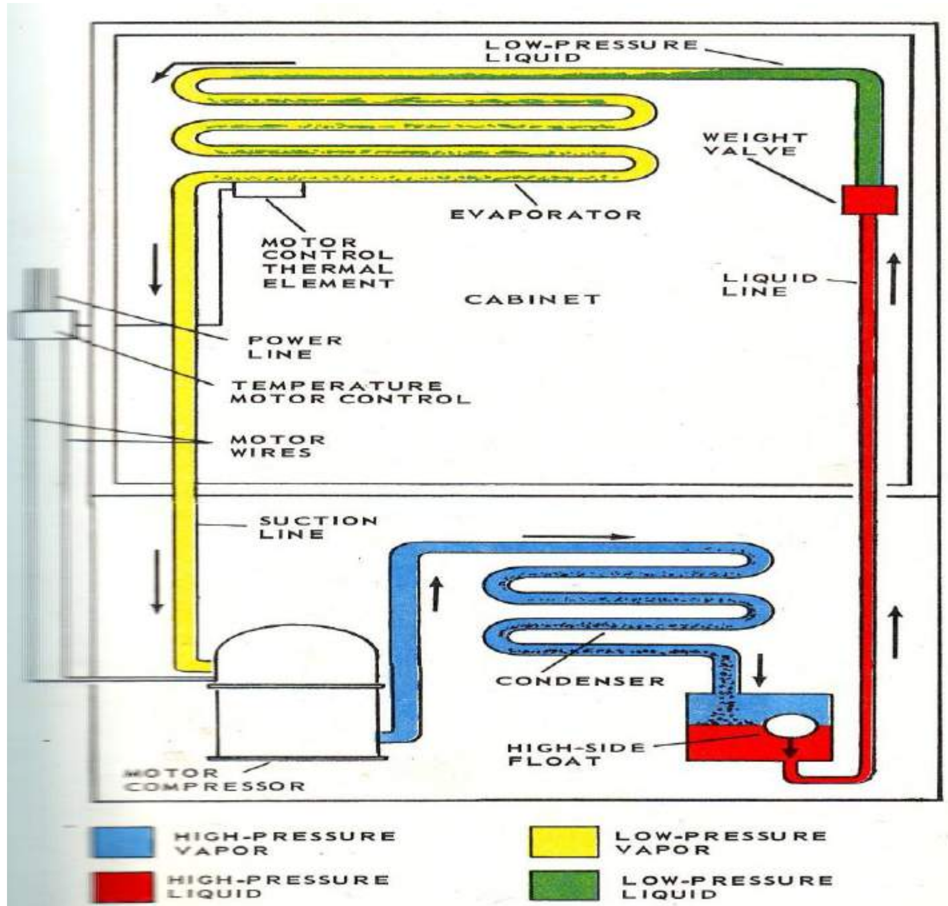


Fig. 3-7. Compression system using automatic expansion valve refrigerant control (AEV).



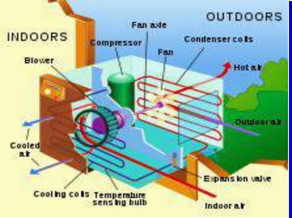
VAPOUR COMRESSION REFRIGERATION SYSTEM

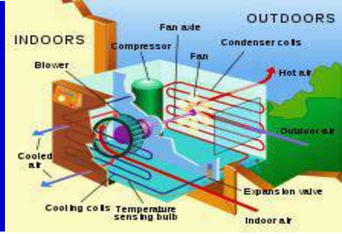




Compression system using high-side float refrigerant control.

VAPOUR COMRESSION REFRIGERATION SYSTEM





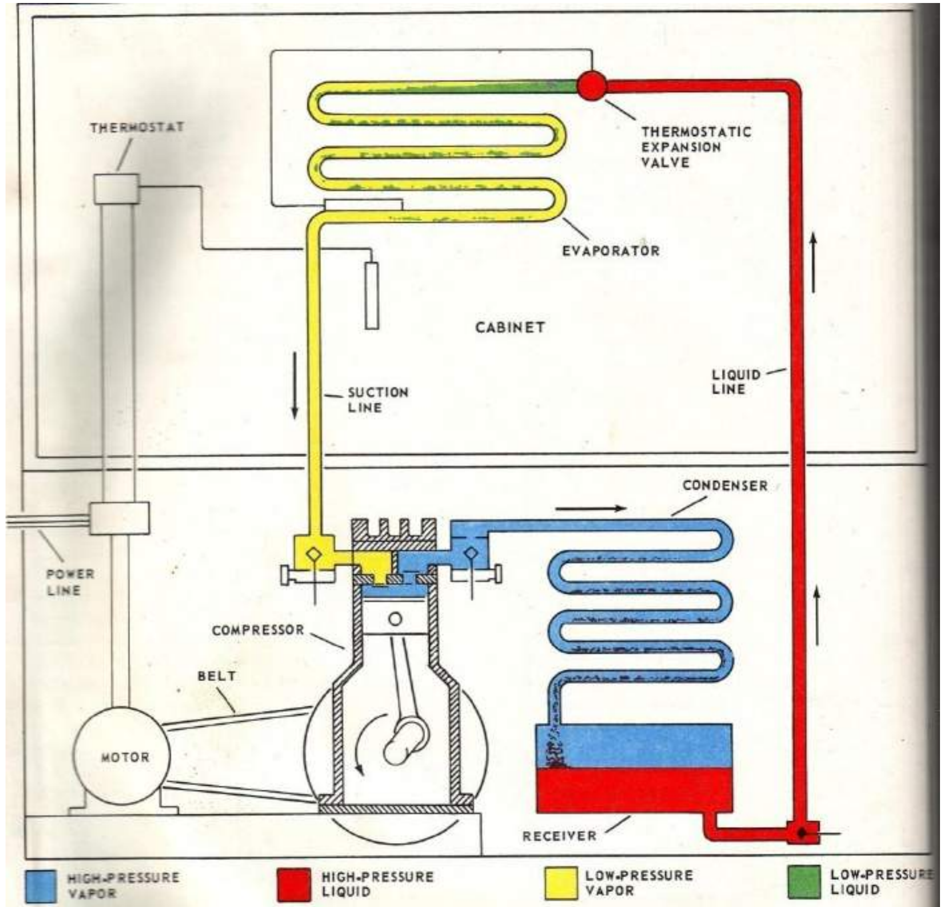
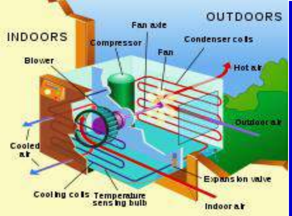
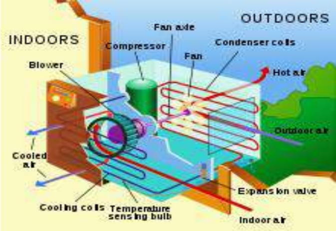


Fig. 3-5. Compression system using external drive (open) type compressor. Crankshaft seal is required at the place where the crankshaft extends through the crankcase of compressor.

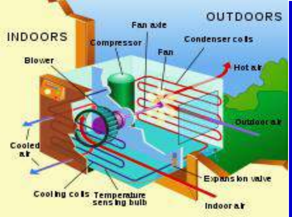


MULTISTAGE VAPOUR COMPRESION SYSTEM

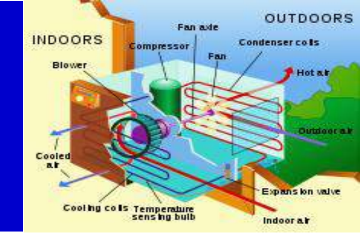


MULTISTAGE VAPOUR COMPRESION SYSTEM

For a given condensation temperature, the lower the evaporator temperature, the higher becomes the compressor pressure ratio. For a reciprocating compressor, a high pressure ratio across a single stage means low volumetric efficiency (ratio of the act volume of gas drawn at evaporator pressure and temperature to the Piston displacement). Also, with dry compression the high pressure ratio results in high compressor discharge temperature which may damage the refrigerant. To reduce the work of compression and improve the COP, multistage compression with intercooling may be adopted.

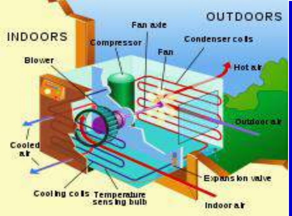


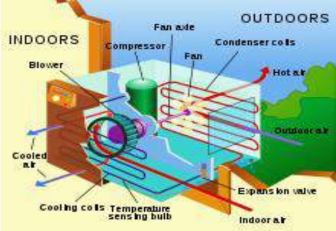
MULTISTAGE VAPOUR COMPRESION SYSTEM



In refrigeration plant where different temperatures are required to be maintained at vapour points in the plant such as in hotels, large restaurants, institution, industrial plants and food markets where the food products are received in large quantities and stored at different temperatures e.g. fresh fruits, fresh vegetables, fresh cut meats, frozen products, diary products, canned goods, bottle goods all have different conditions of temperature and humidity for storage. In such case, multiple evaporators and compressors are needed since each location is cooled by its own evaporator in order to obtain more satisfactory control of the location.

MULTISTAGE VAPOUR COMPRESION SYSTEM





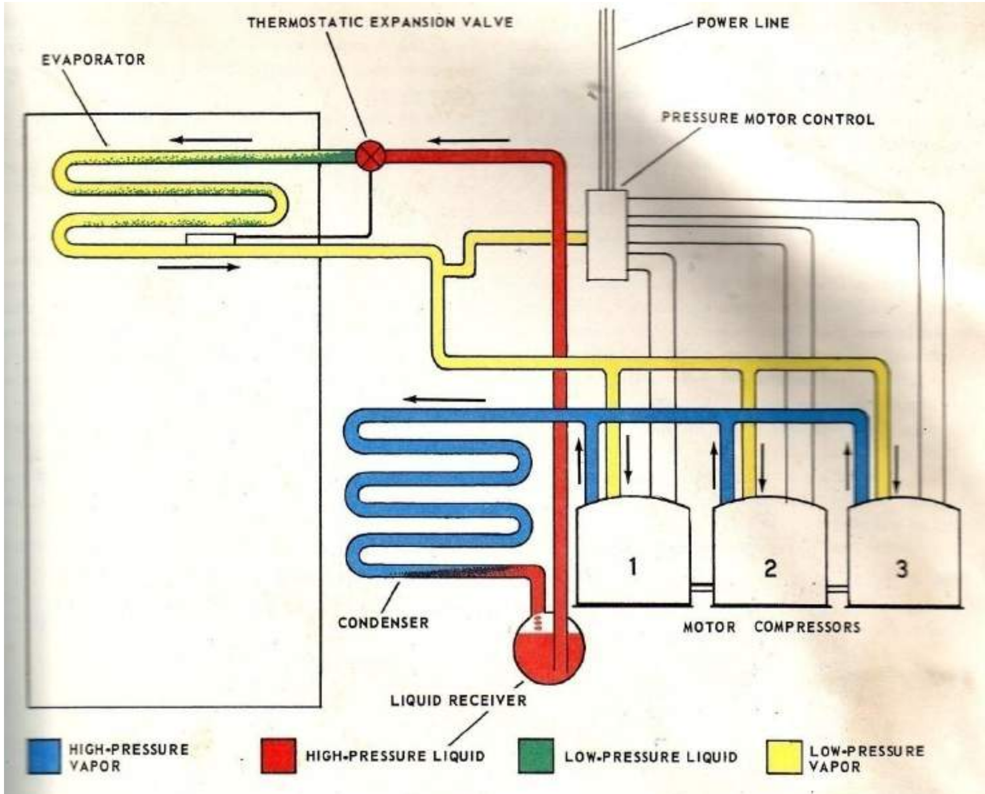
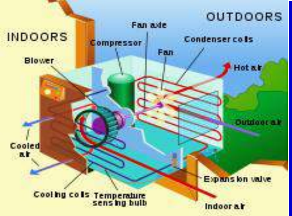
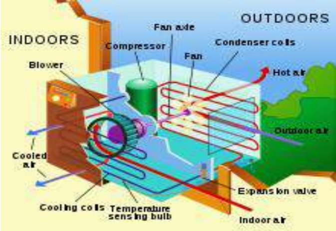


Fig 3-13. Modulating refrigeration cycle mechanism, which uses three motor compressors. Pressure motor control is arranged to operate one or more compressors as needed.



MULTISTAGE VAPOUR COMPRESION SYSTEM



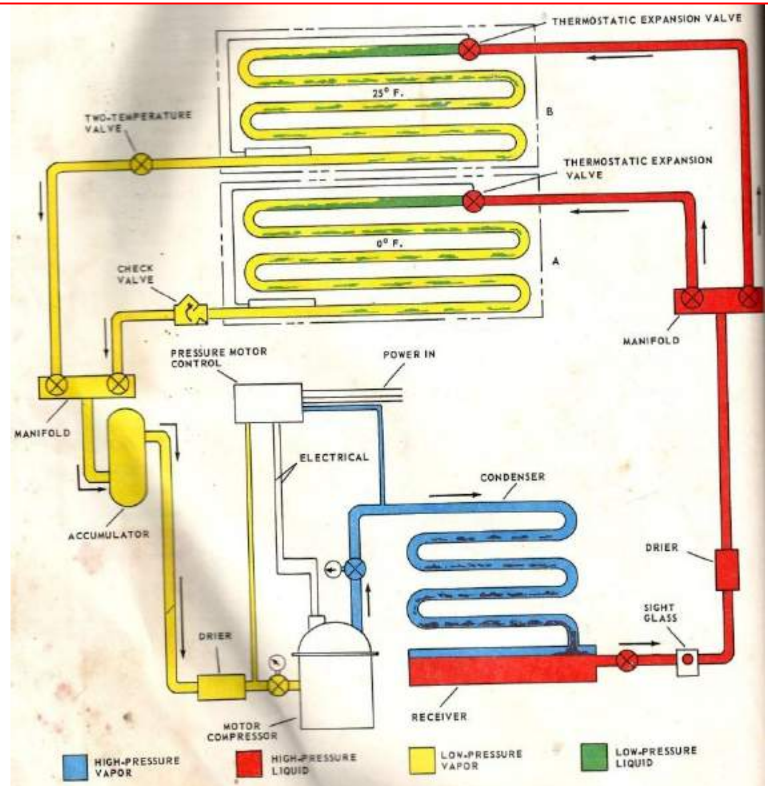
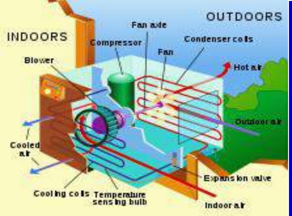
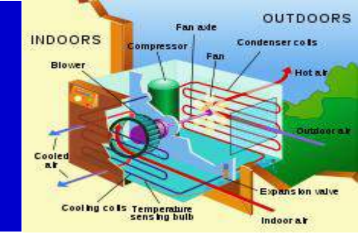


Fig. 3-10. A multiple evaporator system. Evaporator A operates at 0 F. (−18 C.). Evaporator B operates at 25 F. (−4 C.).



CASCADE REFRIGERATION SYSTEM



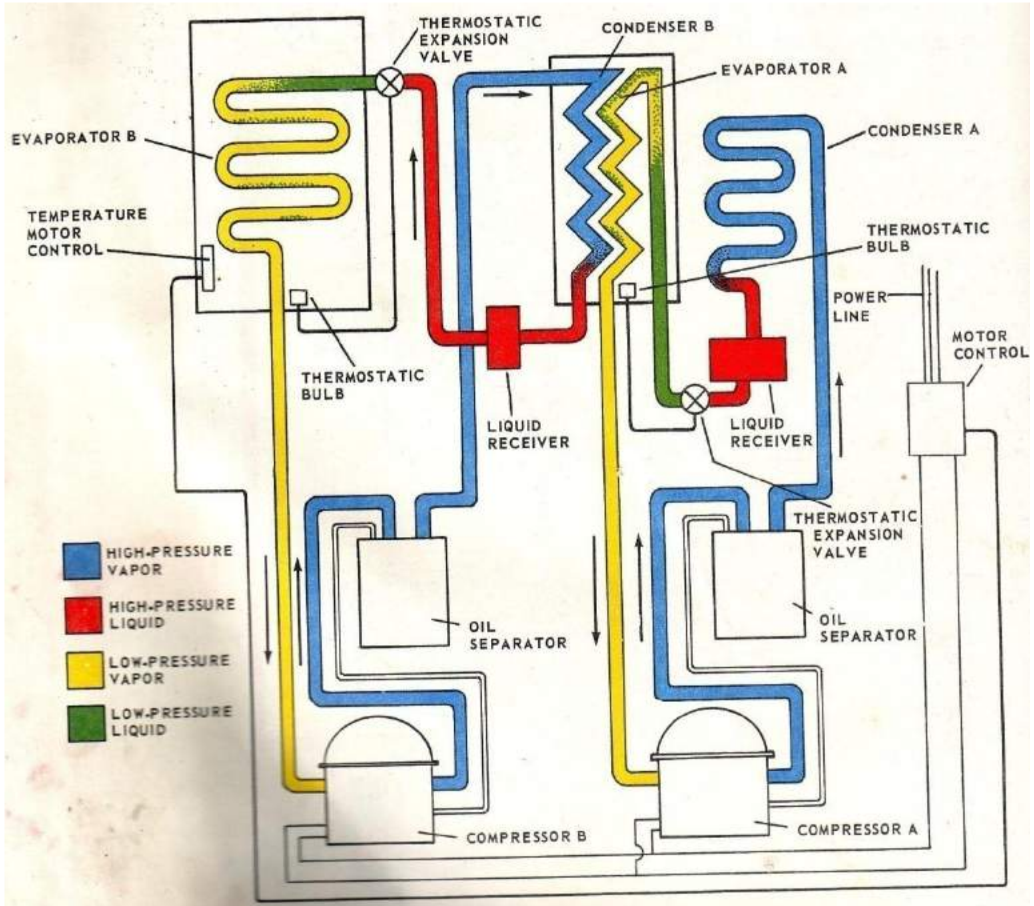


Fig. 3-12. Cascade refrigerating system.

Vapour Absoption Refrigeration System

The absorption cycle is a process by which refrigeration effect is produced through the use of two fluids and some quantity of heat input, rather than electrical input as in the more familiar vapor compression cycle.

The refrigeration system working on vapour absorption cycle was developed by a Frenchman, Ferdinand Carré, and brought to the US during the Civil War when the North cut off the supply of natural ice from the South.

Heat-driven system: work input is very low, but a larger heat input is required

More expensive and complex, larger, less efficient than vapor-compression systems

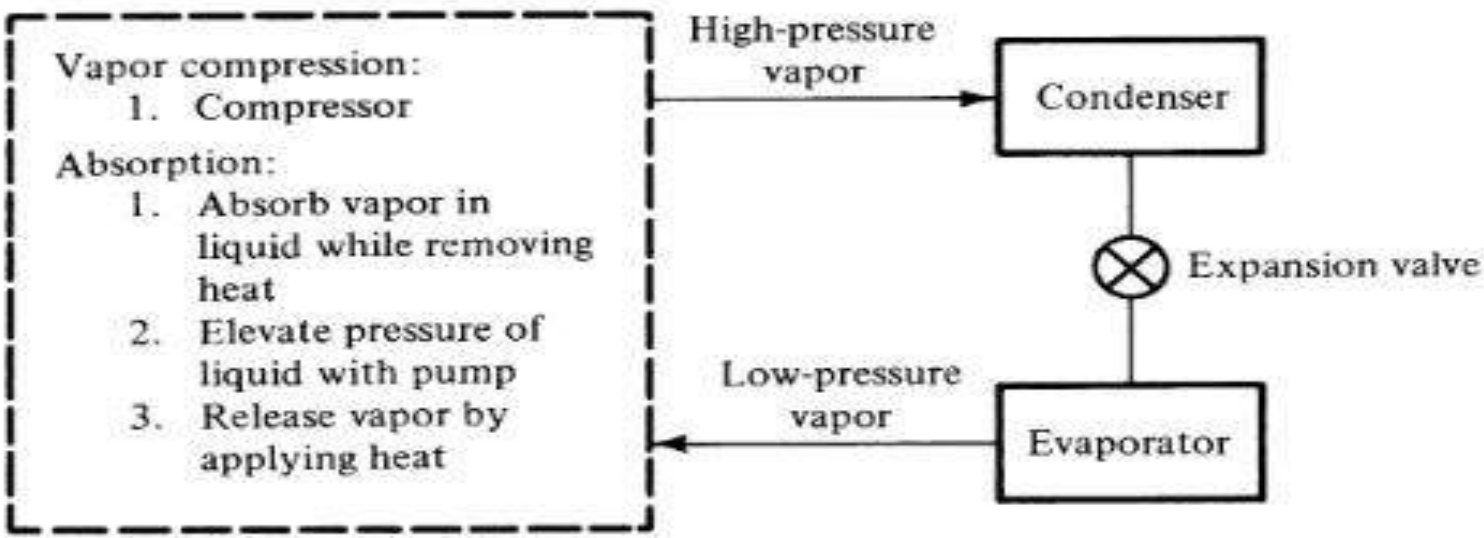
Used when unit cost of heat (thermal energy) is low or thermal energy is available that would otherwise be wasted

Used primarily in large commercial and industrial applications

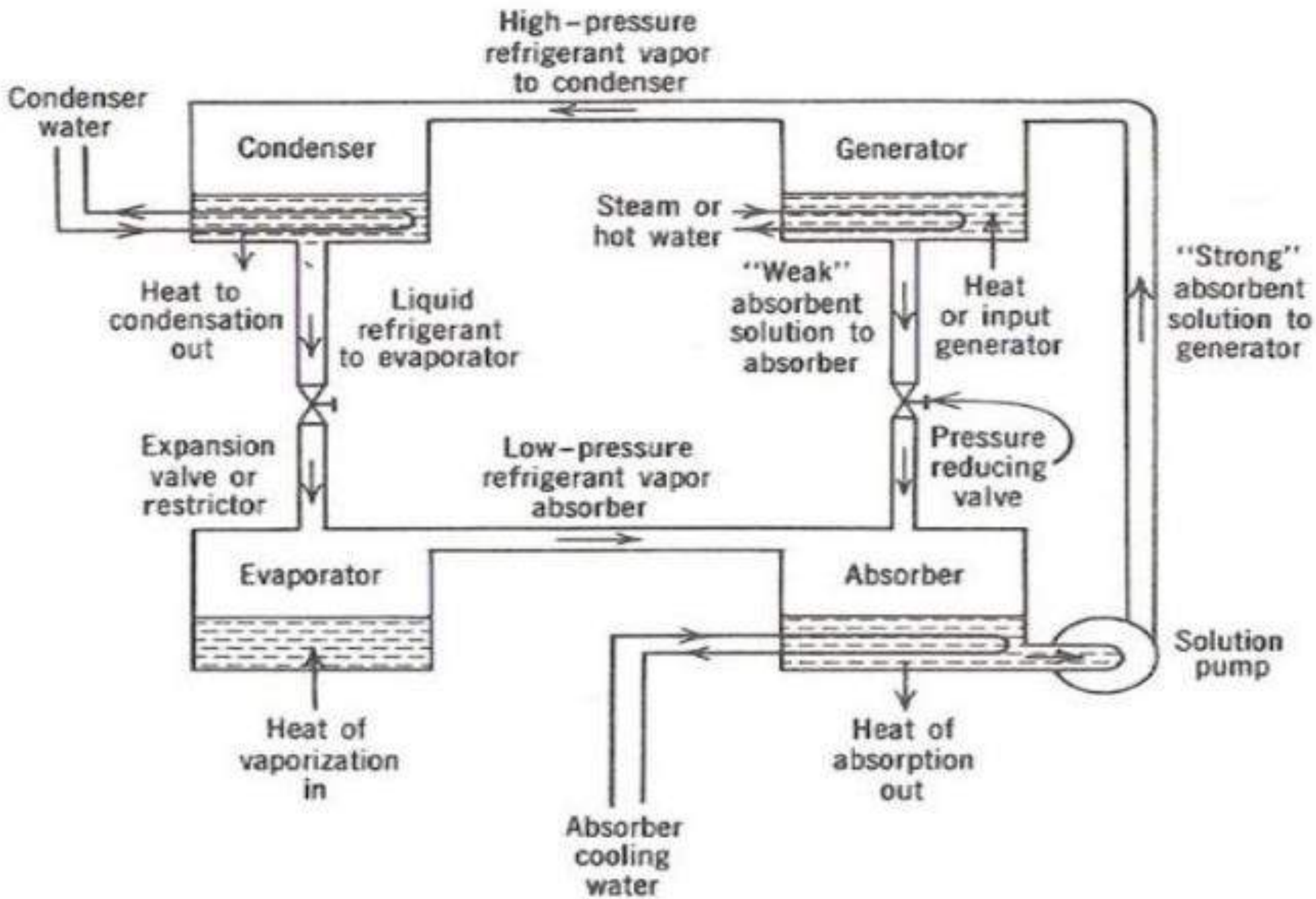
May include a secondary loop for safety reasons and for ease and cost of set-up

Absorption Cycle

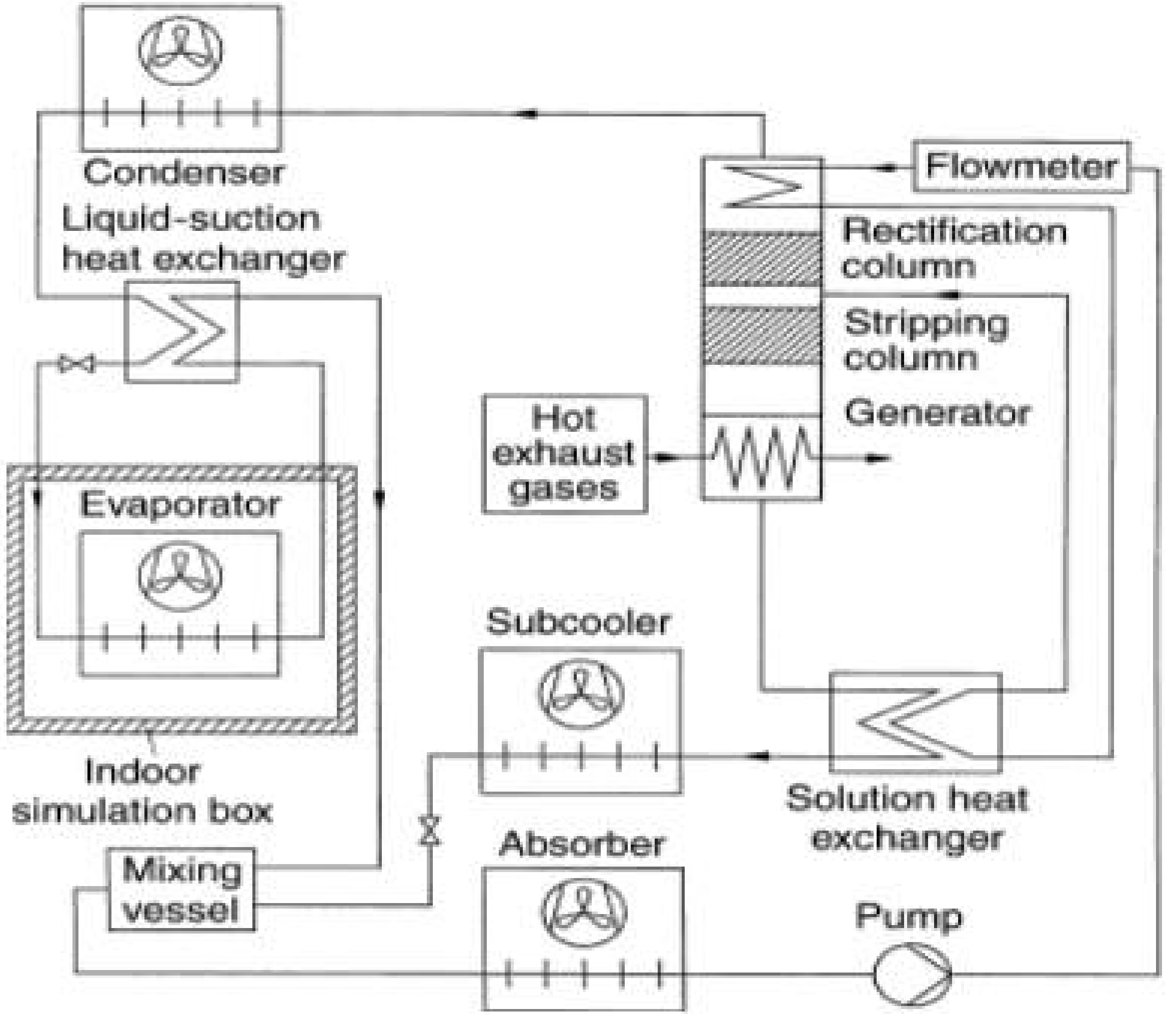
- Compressor is replaced with a more complex system



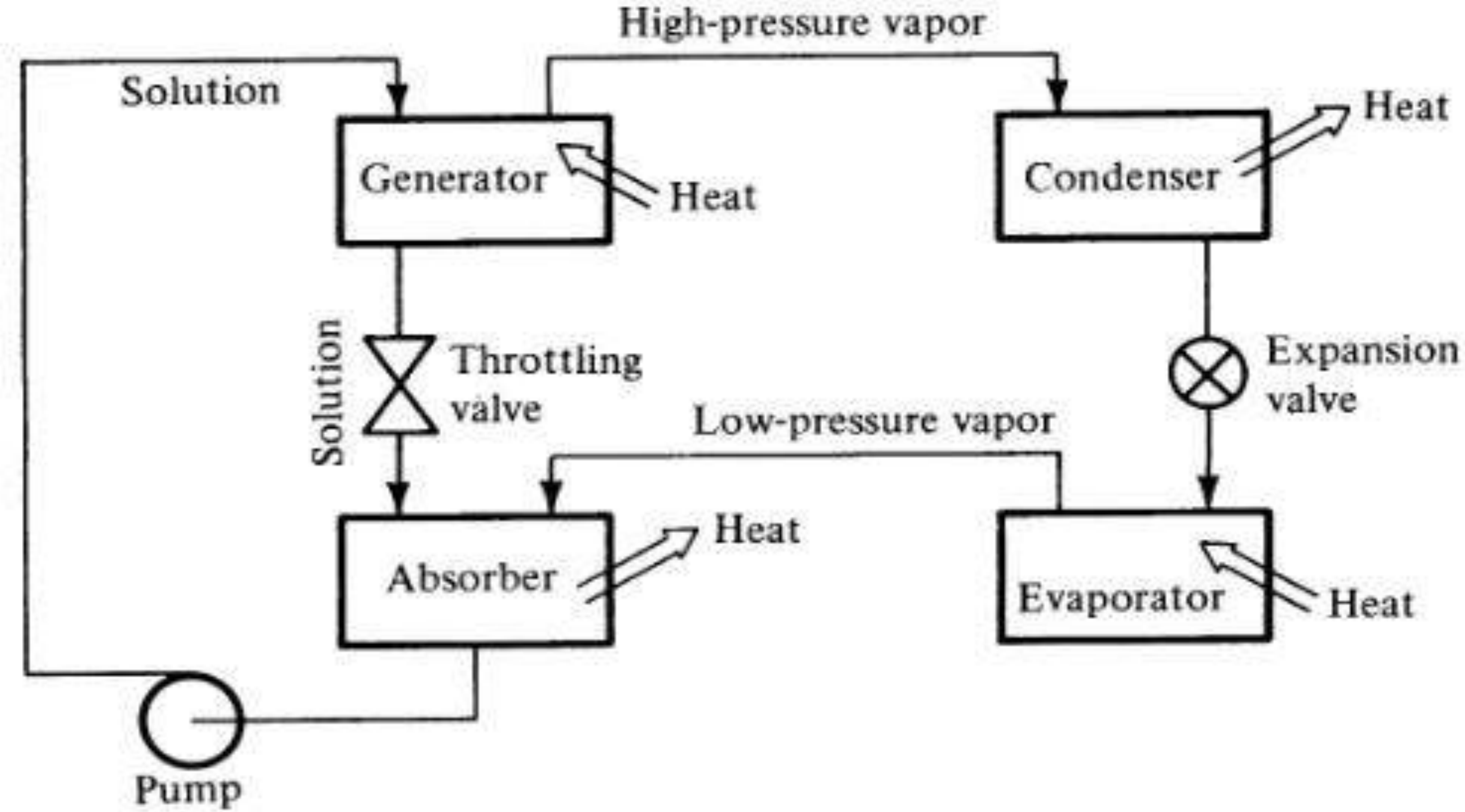
VAPOUR ABSOPTION REFRIGERATION SYSTEM



VAPOUR ABSOPTION REFRIGERATION SYSTEM



SIMPLE SCHEMATIC DIAGRAM OF VAPOUR ABSOPTION REFRIGERATION CYCLE



STEP OR OPERATION PRINCIPLE OF VAPOUR ABSOPTION SYSTEM

Low pressure vapor from evaporator is absorbed by liquid solution in absorber. This process is exothermic. If heat weren't removed, the temp would rise and absorption would cease.

Absorber is cooled by water or air.

Low pressure liquid is pumped to a higher pressure and enters the generator.

Heat from a high temp source drives the vapor out of the liquid

The liquid returns to the absorber through a throttling valve, returning to a low pressure.

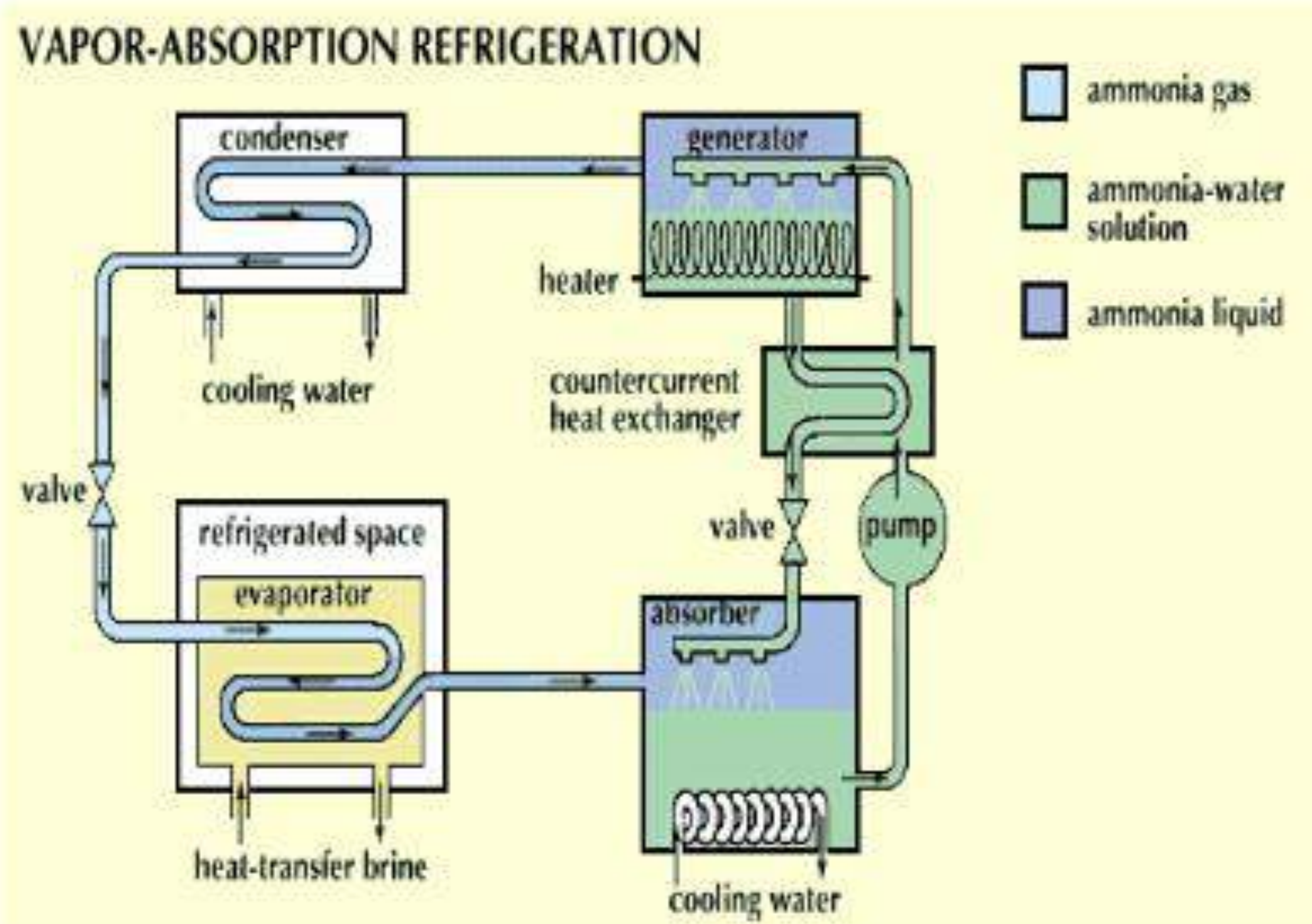
The high-pressure vapor is sent to a condenser, expansion valve, and then the evaporator.

Common Refrigerants Used in VAS

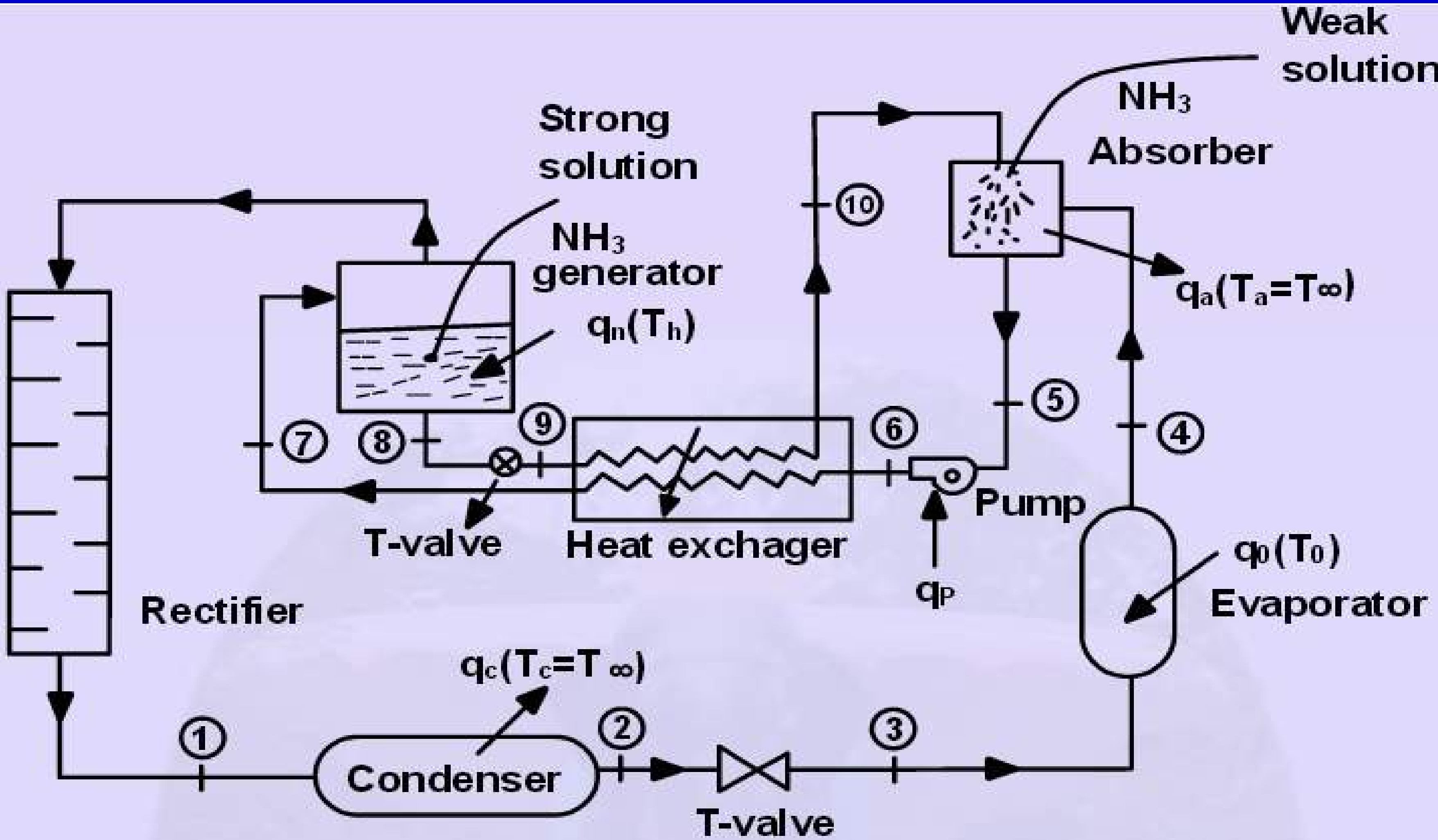
- Ammonia-water systems, ammonia is the refrigerant

- Water-lithium bromide ,   water is the refrigerant

- Water-lithium chloride ,   water is the refrigerant
- R134a-DMac


VAPOR-ABSORPTION REFRIGERATION
ammonia gas
ammonia-water solution
ammonia liquid
condenser
generator
heater
cooling water
countercurrent heat exchanger
valve
pump
refrigerated space
evaporator
absorber
heat-transfer brine
cooling water

VAPOUR ABSOPTION REFRIGERATION CYCLE



WORKING PRINCIPLE OF NH3-H2O VAPOUR ABSORPTION REFRIGERATION SYSTEM

Some liquids like water have great affinity for absorbing large quantities of certain vapors (NH_3) and reduce the total volume greatly. The absorption refrigeration system differs fundamentally from vapor compression system only in the method of compressing the refrigerant. An absorber, generator and pump in the absorption refrigerating system replace the compressor of a vapor compression system. Figure 6.7 shows the schematic diagram of a vapor absorption system. Ammonia vapor is produced in the generator at high pressure from the strong solution of NH_3 by an external heating source. The water vapor carried with ammonia is removed in the rectifier and only the dehydrated ammonia gas enters into the condenser. High pressure NH_3 vapor is condensed in the condenser. The cooled NH_3 solution is passed through a throttle valve and the pressure and temperature of the refrigerant are reduced below the Refrigeration Cycles temperature to be maintained in the evaporator. The low temperature refrigerant enters the evaporator and absorbs the required heat from the evaporator and leaves the evaporator as saturated vapor. Slightly superheated, low pressure NH_3 vapor is absorbed by the weak solution of NH_3 which is sprayed in the absorber as shown in the Fig. Weak NH_3 solution (aqua–ammonia) entering the absorber becomes strong solution after absorbing NH_3 vapor and then it is pumped to the generator through the heat exchanger. The pump increases the pressure of the strong solution to generator pressure. The strong NH_3 solution coming from the absorber absorbs heat form high temperature weak NH_3 solution in the heat exchanger. The solution in the generator becomes weak as NH3 vapor comes out of it. The weak high temperature ammonia solution from the generator is passed to the heat exchanger through the throttle valve. The pressure of the liquid is reduced to the absorber pressure by the throttle valve.

Summary of the Working Principle of NH3-H2O VAS

Ammonia vapor passes through the condenser, expansion valve, and evaporator.

In the absorber it reacts with and is absorbed by the water in an exothermic reaction. Heat is removed with cooling water.

Solution is pumped to the regenerator, increasing the pressure.

Heat is added in the regenerator, and ammonia and a little water vaporizes.

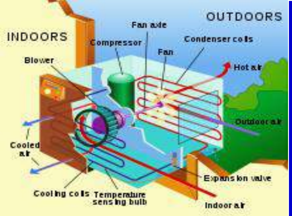
Ammonia and water vapor are separated in the rectifier. Ammonia goes to the condenser & water is returned to the regenerator.

Hot liquid solution goes through a regenerator, where some heat is transferred to the liquid leaving the pump.

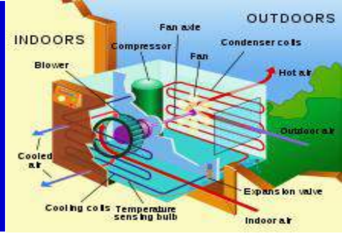
The now somewhat cooler liquid goes through an expansion valve, taking it to a lower pressure and temperature

Comparison between Vapor Compression and Absorption system:

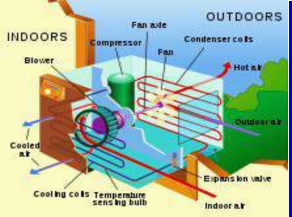
Absorption system	Compression System
a) Uses low grade energy like heat. Therefore, may be worked on exhaust systems from I.C engines, etc.	a) Using high-grade energy like mechanical work.
b) Moving parts are only in the pump, which is a small element of the system. Hence operation is smooth.	b) Moving parts are in the compressor. Therefore, more wear, tear and noise.
c) The system can work on lower evaporator pressures also without affecting the COP.	c) The COP decreases considerably with decrease in evaporator pressure.
d) No effect of reducing the load on performance.	d) Performance is adversely affected at partial loads.
e) Liquid traces of refrigerant present in piping at the exit of evaporator constitute no danger.	e) Liquid traces in suction line may damage the compressor.
f) Automatic operation for controlling the capacity is easy.	f) It is difficult.



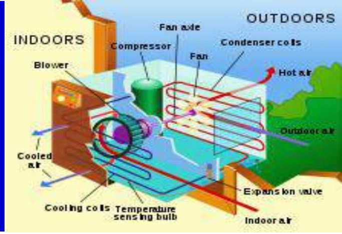
TIME FOR QUESTIONS



QUESTION?



LECTURE 2



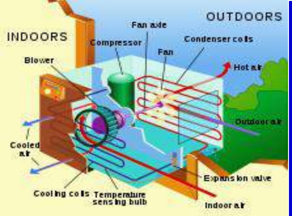
REFRIGERANTS AND MONTREAL PROTOCOL

THE DEFINITION AND HISTORY OF REFRIGERANTS

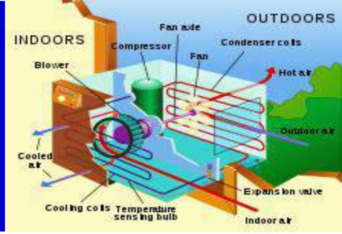
According to ASHRAE standard 34-1978, Refrigerant is defined as the medium of heat transfer in a refrigerating system which picks up heat by evaporating at low temperature and pressure and gives up heat on condensing at higher temperature and pressure.

Many of the refrigerants used during the early periods did not survive, mainly due to their toxicity. Ammonia, however, continues to be a refrigerant of choice for food freezing applications even today in spite of its toxicity, mainly due to its excellent thermodynamic and thermal properties. Carbon dioxide used in the early days of refrigeration is again being considered as a refrigerant in spite of its high operating pressures. Hydrocarbons used in the early part of the last century were quickly discontinued because of their flammability. However, hydrocarbons have made a successful comeback and are being used extensively in small domestic refrigerators and freezers in recent years. The discovery of CFCs in the late twenties revolutionized the refrigeration industry. Both CFCs and hydrochlorofluorocarbons (HCFCs) are non-toxic, possess excellent thermodynamic properties, and are non-flammable. Both CFCs and HCFCs dominated the refrigeration industry for nearly 70 years till the Montreal Protocol imposed a ban due to their contribution to ozone depletion. In the last two decades, hydrofluorocarbons (HFCs), which possess zero Ozone Depletion Potential (ODP), have gradually replaced CFCs. Very recently, global warming due to emission of various gases into the atmosphere has been the issue being dealt with by the Kyoto Protocol HFCs which have high Global Warming Potential (GWP) are also being banned in spite of the fact that they are ozone friendly. Hydrofluorooelifins (HFOs), which have very low GWP and invented very recently are expected to replace HFCs in many applications. A detailed discussion on the different refrigerants is given below.

1800–1900	Ethyl alcohol, methyl amine, ethyl amine, methyl chloride, ethyl chloride, sulphur dioxide, carbon dioxide, ammonia
1900–1930	Ethyl bromide, carbon tetrachloride, water, propane, isobutene, gasoline, methylene chloride
1931–1990	Chlorofluorocarbons, hydrochlorofluorocarbons, ammonia, water
1990–2010	Hydrofluorocarbons, ammonia, isobutene, propane, carbon dioxide, water
Immediate future	Hydrofluorooelifins, hydrofluorocarbons, hydrocarbons, carbon dioxide, water



INTRODUCTION

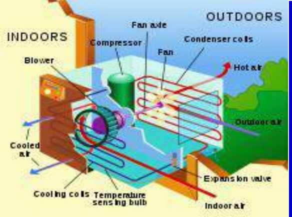


Over the years, there have radical changes in the selection and use of refrigerants, mainly in response to the environmental issues of ‘holes in the ozone layer’ and ‘global warming or greenhouse effect’. These refrigerants include R11, R12, R22, R502 and ammonia (R717) of which only ammonia is considered environmentally friendly, but it is not readily suited to commercial or air-conditioning refrigeration applications because of its toxicity, flammability and attack by copper.

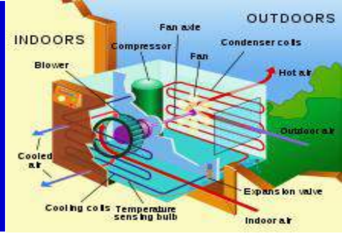
REFRIGERANTS FROM DIFFERENT CHEMICAL GROUP

No.	Refrigerant	Boiling Point @1 atm(K)	Freezing Point (K)	Critical Temp (K)	Critical Pr (bar)	ODP	GWP
CFCs (Chlorofluorocarbons)							
R113	Trichlorotrifluroethane	320.73	238.16	487.3	34.4	0.9	5200
R11	Trichloroflurомethane	296.98	162.05	471.2	44.1	1	4000
R114	Dichlorotetrafluroethane	276.94	179.27	418.9	32.6	0.7	16600
R12	Dichlorodifluromethane	243.37	115.38	385.2	41.2	1	12200
R115	Chloropentafluroethane	233.83	167.05	353.1	31.5	0.6	39200
HCFCs(Hydrochlorofluorocarbons)							
R141b	Dichlorofluroethane	305.16	–	483.35	46.4	0.15	600
R123	Dichlrotrifluroethane	301.03	166.01	457.15	36.76	0.02	80
R22	Chlorodifluromethane	232.40	113.16	363.15	49.78	0.05	1480
HFCs (Hydrofluorocarbons)							
R245fa	Pentafluropropane	288.44	166.49	383.4	31.5	0	790
R134a	Tetrafluroethane	247.00	176.55	374.25	40.67	0	1160
R507	Azeotrope - Blend	226.05	255.38	344.05	37.92	0	1400
R125	Pentafluroethane	224.59	170.01	339.25	36.2	0	3360
R32	Difluromethane	221.44	137.05	351.4	58.08	0	440
R23	Trifluromethane	191.10	118.16	298.75	48.37	0	24000
HFOs (Hydrofluorooellifins)							
R1234yf	2,3,3,3-Tetrafluoropropene	244.15	220.00	367.85	33.82	0	4
FCs /PFCs (Fluorocarbons/Perfluorocarbons)							
R218	Octofluropropane	241.66	113.16	344.95	26.8	0	9300
R14	Tetraflurомethane	145.22	89.27	227.65	37.43	0	6500

Hydrocarbons							
R600	Butane	272.66	134.66	425.12	37.7	0	0
R290	Propane	231.07	85.49	369.83	42.1	0	0
R170	Ethane	184.35	90.38	305.32	48.5	0	0
R1150	Ethylene	169.44	104.27	282.34	50.3	0	0
R50	Methane	111.66	90.94	190.56	45.9	0	0
Inorganic Compounds							
R718	Water	373.16	273.16	647.13	219.4	0	0
R717	Ammonia	239.83	195.44	405.65	113.0	0	0
R744	Carbon dioxide	194.72	216.55	304.21	73.9	0	1
R728	Nitrogen	77.38	63.16	126.2	33.9	0	0
R702n	Hydrogen	20.38	13.99	33.19	13.2	0	0
R704	Helium	4.22	_	5.2	2.3	0	0
HFEs (Hydrofluoroethers)							
HFE-7100	Methoxynonafluorobutane	334.16	138.16	468.45	22.3	0	320
HFE-7200	Ethoxynonafluorobutane	349.16	135.16	482.0	19.8	0	55
HFE-7000	Methooxyheptafluropropane	307.16	150.38	438.15	24.8	0	400



IDEAL REFRIGERANT PROPERTIES

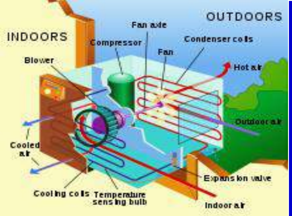


Ideal properties for a refrigerant for vapour compression cycles

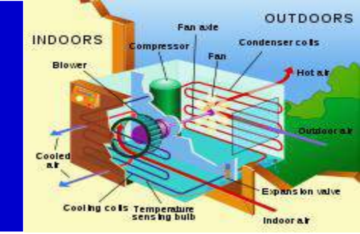
The requirements for the working fluid are as follows:

1. A high latent heat of vaporization
2. High density of suction gas
3. Non-corrosive, non-toxic and non-flammable
4. Critical temperature and triple point outside the working range
5. Compatibility with materials of construction, with lubricating oils, and with other materials present in the system
6. Convenient working pressures, i.e. not too high and preferably not below atmospheric pressure
7. High dielectric strength (for compressors having integral electric motors)
8. Low cost
9. Ease of leak detection
10. Environmentally friendly

No single working fluid has all these properties and a great many different chemicals have been used over the years. The present situation has been dominated by the need for fluids which are environmentally friendly.

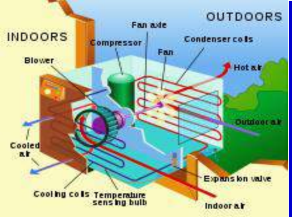


REFRIGERANTS APPLICATIONS

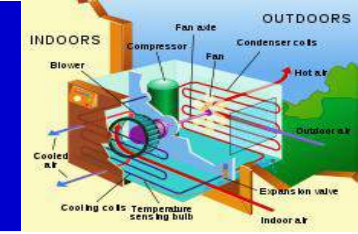


TYPICAL USES OF REFRIGERANTS BEFORE 1987

TYPICAL APPLICATION	REFRIGERANTS RECOMMENDED
Domestic refrigerators and freezers	R12
Small retail and supermarkets	R12, R22, R502
Air-conditioning	R11, R114, R12, R22
Industrial	R717, R22, R502, R13B1
Transport	R12, R502



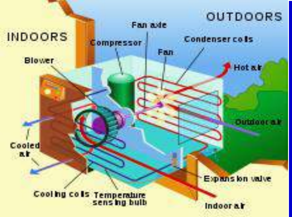
GLOBAL WARMING POTENTIAL



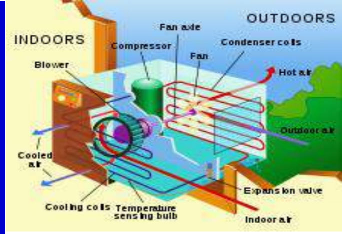
Global warming potential (GWP)

Global warming is the increasing of the world's temperatures, which results in melting of the polar ice caps and rising sea levels. It is caused by the release into the atmosphere of so-called 'greenhouse' gases, which form a blanket and reflect heat back to the earth's surface, or hold heat in the atmosphere. The most infamous greenhouse gas is carbon dioxide (CO2), which once released remains in the atmosphere for 500 years, so there is a constant build-up as time progresses.

The main cause of Carbon dioxide emission is in the generation of electricity at power stations. Each kWh of electricity used in the UK (as example) produces about 0.53 kg of the gas and it is estimated that refrigeration compressors in the UK consume 12.5 billion kWh per year.



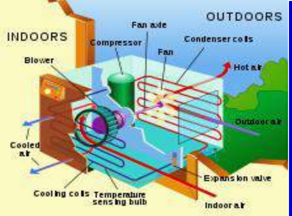
OZONE DEPLETION POTENTIAL AND MONTREAL PROTOCOL



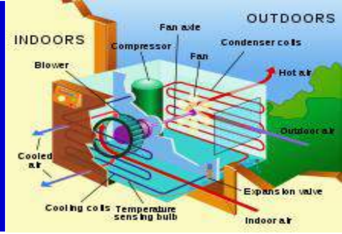
Ozone depletion potential (ODP)

The ozone layer in our upper atmosphere provides a filter for ultraviolet radiation, which can be harmful to our health. Research has found that the ozone layer is thinning, due to emissions into the atmosphere of chlorofluorocarbons (CFCs), halons and bromides.

THE MONTREAL PROTOCOL in 1987 agreed that the production of these chemicals would be phased out by 1995 and alternative fluids developed. From Table 3.1, R11, R12, R114 and R502 are all CFCs used as refrigerants, while R13B1 is a halon. They have all ceased production within those countries which are signatories to the Montreal Protocol. The situation is not so clear-cut, because there are countries like Russia, India, China etc. who are not signatories and who could still be producing these harmful chemicals.



SET DATES OF BAN



It should be noted that prior to 1987, total CFC emissions were made up from aerosol sprays, solvents and foam insulation, and that refrigerant emissions were about 10% of the total. However, all the different users have replaced CFCs with alternatives. R22 is an HCFC and now regarded as a transitional refrigerant, in that it will be completely phased out of production by 2030, as agreed under the Montreal Protocol. A separate European Community decision has set the following dates.

OZONE DEPLETION EFFECTS

The atmosphere is divided into layers defined by the distance above the surface of the earth as follows:

0–15 kilometers (Troposphere)

15–50 kilometers (Stratosphere)

50–85 kilometers (Mesosphere)

•

>85 kilometers (Thermosphere)

A proportion of the sun’s energy is emitted as ultraviolet (UV) radiation which can be divided into three types according to the wave length:

UVA : 3200 – 4000 Å

UVB : 2900 – 3200 Å

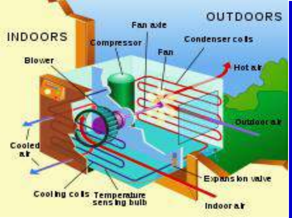
UVC : < 2900 Å (1 Å = 10–10m)

OZONE DEPLETION EFFECTS

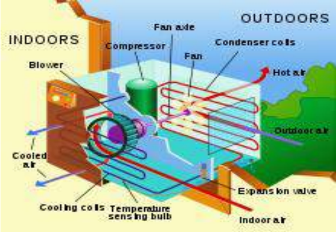
The short wavelength bands of the UV radiation are harmful to the life on earth in many ways. A layer of the stratosphere, 20–40 km thick and rich in ozone, filters out a major portion of this harmful UV radiation from reaching the earth's surface. Chemically stable chlorofluorocarbon (CFC) refrigerant molecules remain for a very long time in the atmosphere and can therefore reach the ozone layer. In the stratospheric area an energetic UV photon strikes the CFC molecule. The energy of the impact releases a chlorine atom, which is chemically very active and reacts with an ozone molecule. Through this interaction, the ozone molecule is destroyed. This is a complicated chain reaction leading to the 'ozone hole'.

Health and environmental effects of ozone depletion can be multifarious. Because biological life on this planet evolved only after the ozone shield developed, enormous potential for harm exists if the shield is damaged. DNA, the genetic code present in all living cells is damaged by UV radiation, UVC being the most damaging. A significant reduction in ozone in the upper atmosphere could result in long-time increase in skin cancer and cataracts, and probably damage the human immune system. Environmental damage and the resulting economic losses could be because of decreased yields of major agricultural crops, and reduced productivity of phytoplankton with possible implications for the aquatic food chain, resulting in substantial losses at the larval stage of many fish (e.g. anchovies, shrimps and crabs)

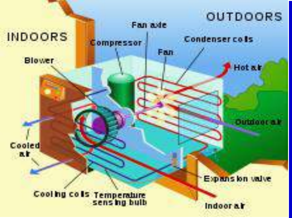
The extent of damage that a refrigerant can cause to the ozone layer is quantified by the Ozone Depletion Potential (ODP), which is the ratio of impact caused by the substance on ozone to that caused by CFC 11.



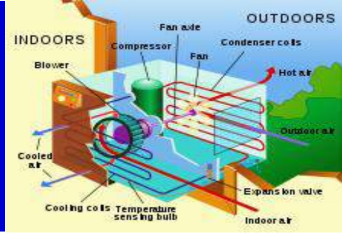
SET DATES FOR REFRIGERANT BAN



- 1/1/2000 CFCs banned for servicing existing plants
- 1/1/2000 HCFCs banned for new systems with a shaft input power greater than 150kW
- 1/1/2001 HCFCs banned in all new systems except heat pumps and reversible systems
- 1/1/2004 HCFCs banned for *all* systems
- 1/1/2008 Virgin HCFCs banned for plant servicing



NEWLY DEVELOPED REFRIGERANTS



HFCFC/HFC service-blends (transitional alternatives)

R401A R401B R409A

HFC–Chlorine free (long-term alternative)

R134A

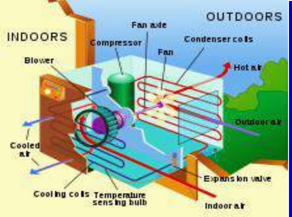
HFC–Chlorine free–blends–(long-term alternatives)

R404A ISCEON 59 R407A R407B

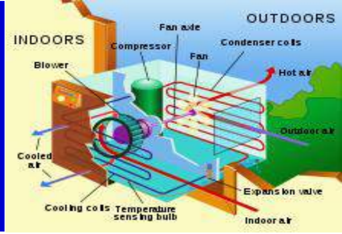
R407C R410A R411B

Halogen free (long-term alternatives)

R717 ammonia R600a R114 R290 R1270



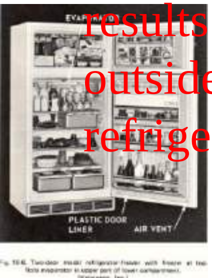
AMMONIA AND THE HYDROCARBONS

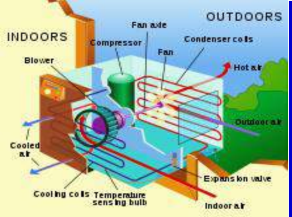


Ammonia and the hydrocarbons

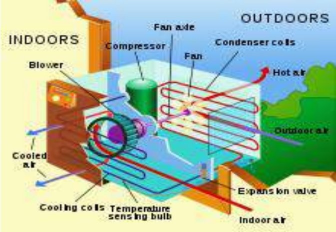
These fluids have virtually zero ODP and zero GWP when released into the atmosphere and therefore present a very friendly environmental picture. Ammonia has long been used as a refrigerant for industrial applications. The engineering and servicing requirements are well established to deal with its high toxicity and flammability.

There have been developments to produce packaged liquid chillers with ammonia as the refrigerant for use in air-conditioning in supermarkets, for example. Ammonia cannot be used with copper or copper alloys, so refrigerant piping and components have to be steel or aluminum. This may present difficulties for the air conditioning market where copper has been the base material for piping and plant. One property that is unique to ammonia compared to all other refrigerants is that it is less dense than air, so a leakage of ammonia results in it rising above the plant room and into the atmosphere. If the plant room is outside or on the roof of a building, the escaping ammonia will drift away from the refrigeration plant.



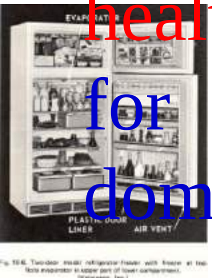


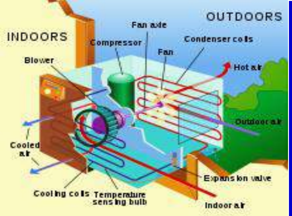
AMMONIA AND THE HYDROCARBONS



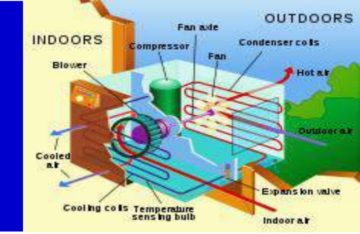
The safety aspects of ammonia plants are well documented and there is reason to expect an increase in the use of ammonia as a refrigerant.

Hydrocarbons such as propane and butane are being successfully used as replacement and new refrigerants for R12 systems. They obviously have flammable characteristics which have to be taken into account by health and safety requirements. However, there is a market for their use in sealed refrigerant systems such as domestic refrigeration and unitary air-conditioners.

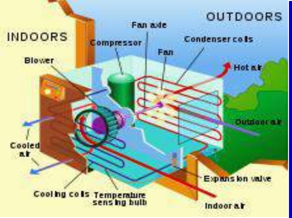




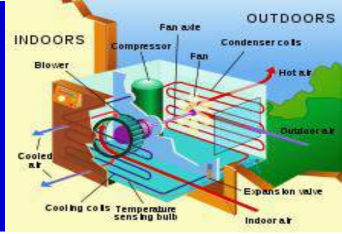
TOTAL EQUIVALENT WARMING IMPACT



The newly developed refrigerant gases also have a global warming potential if released into the atmosphere. For example, R134a has a GWP of 1300, which means that the emission of 1 kg of R134a is equivalent to 1300 kg of CO2. The choice of refrigerant affects the GWP of the plant, but other factors also contribute to the overall GWP and this has been represented by the term *total equivalent warming impact* (TEWI). This term shows the overall impact on the global warming effect, and includes refrigerant leakage, refrigerant recovery losses and energy consumption. It is a term which should be calculated for each refrigeration plant. Other newly developed refrigerants include R404a HFC R407c HFC R410a HFC R411b HCFC R717 ammonia R290 propane R600a isobutene R1270 propylene



REFRIGERANT BLENDS



REFRIGERANT BLENDS

Many of the new, alternative refrigerants are ‘blends’, which have two or three components, developed for existing and new plants as comparable alternatives to the refrigerants being replaced. They are ‘zeotropes’ with varying evaporating or condensing temperatures in the latent heat of vaporization phase, referred to as the ‘temperature glide’ improving plant performance, by correct design of the heat exchangers.

Blends or mixtures are used either to obtain different desired properties such as bubble point temperature, oil solubility, flammability, as drop-in-substitutes for older refrigerants that are no longer produced, etc. by combining different fluids or to obtain variable temperature refrigeration. The mixtures used in refrigeration systems can be divided into four categories, namely, azeotropes, near-azeotropes, zeotropes and very wide boiling zeotropes.

No.	Blend/ Constituents	Compo-sition	Boiling Pt @1atm(K)	Dew Pt @1atm(K)	Critical Temp.(K)	Critical Pr.(bar)
R404a	Zeotrope (R125/143a/134a)	44/52/4	226.59	227.36	–	–
R407c	Zeotrope (R32/125/134a)	23/25/52	229.39	236.46	–	–
R410a	Zeotrope (R32/125)	50/50	221.6	221.65	–	-–
R507	Azeotrope (R125/143a)	50/50	226.4	226.4	344.1	37.9

Chloroflurocarbons (CFC)

These are fully halogenated fluids that have high ODP and were found to be the most responsible for the creation of ozone hole. Use of formerly popular CFCs such as R12 and R11 in ne equipment was banned by the Montreal Protocol. While R12 recovered from old systems may still be available, new lots of CFCs are no longer being produced.

Hydrochlorofluorocarbons (HCFC)

Unlike fully-halogenated CFCs, which contain only carbon and halogen atoms, in the case of partially-halogenated HCFCs, not all hydrogen atoms are replaced by halogen atoms. The remaining hydrogen atoms facilitate partial breakdown of the compounds in the troposphere. For this reason these compounds are less harmful to the stratospheric ozone layer, though they still have the some potential to damage the ozone layer. However, since they are known to cause global warming, HCFCs are no longer used in the industrialized countries of the West. Phase-out of HCFCs (mainly HCFC22, which is still widely used in India) is being accelerated.

Hydrofluorocarbons (HFC)

Hydrofluorocarbons contain fluorine but no chlorine or bromine in the molecule, so that their ODP is zero. Some examples of HFCs are R23, R32, R125, 134a, 143a and 152a. A problem with HFCs is that they are chemically stable and can accumulate in the atmosphere contributing to the global warming. Hence, HFCs need to be eventually replaced.

Hydrofluorooelifins (HFO)

These also belong to a class of HFCs, but are derived from unsaturated hydrocarbon molecules such as propylene. HFOs are relatively unstable, have a small atmospheric lifetime and therefore a small GWP. R1234yf and R1234ze are two HFO refrigerants invented recently. R1234yf has been widely accepted for use in cars by the automobile industry because of its very low GWP of 4. As soon as it becomes commercially available, R1234yf is expected to replace R134a, which is currently being widely used in air-conditioning plants, automobile air conditioners, domestic refrigerators, etc. There are also attempts to find mixtures of R1234yf and other HFCs such as R32 for use in other applications such as domestic air conditioners since mixtures containing R1234yf will have low GWP, typically less than 1000.

Fluoroiodocarbons (FIC)

These are a group of chemicals containing fluorine, iodine and carbon such as, trifluoromethyl iodide (CF_3I) perfluoroethyliodide (C_2F_5I) and perfluoropropyl iodide (C_3F_7I). The FICs are reported to have zero ODP and negligible GWP due to their very short life periods. These can also be used in blends. A blend of C3F7 and HFC 152a (51/49 mole percent) was run in a refrigerator without oil change for over 1,500 hours without apparent ill effects. Measurements showed that the energy efficiency and capacity were equal to or slightly better than CFC 12.

Hydrocarbons

Several hydrocarbons have excellent thermodynamic properties and can be used as refrigerants. Though alkanes, ketones, alcohols and ethers can be used, alkanes are the most preferred group. As already mentioned, the main concern is that most of the hydrocarbons are flammable. Here, one should note that in certain industrial applications hydrocarbons have been used as refrigerants since the beginning of the 20th century. Hydrocarbons, for instance, are used in pure or mixture forms as refrigerants in petrochemical plants and in gas liquefaction plants. In LNG plants, mixtures of methane and n-pentane are in common use. With adequate safety precautions flammability will not pose a major problem in the usage of hydrocarbons. Home refrigerators have been sold in tens of millions worldwide, including India, during the last twenty years. The ODP of hydrocarbons is zero, while their GWP is very small.

Natural Inorganic Fluids

Ammonia is an environmentally safe but toxic working fluid which is attracting renewed attention. It possesses the most advantageous thermodynamic and thermo-physical properties needed for refrigeration. Ammonia-based compression systems, mainly for low temperature applications, are well developed.

These are generally suited for industrial surroundings where sufficient knowledge and facilities exist to handle chemical leaks. There are proposals to extend its use into areas occupied by common public (e.g., comfort air conditioning, cooling of display cases in food shops, heat pumps, etc.). But this requires careful planning and design to avoid panic and accidents in case of leaks.

Water has many desirable characteristics for cooling applications such as: thermal and chemical stability, neither toxic nor flammable, high COP and high heat transfer coefficients. Disadvantages of water include sub-atmospheric pressure operation, large specific compressor displacement, limitations of evaporation temperatures above 0°C and problems of lubrication.

Air has been used commercially for aircraft cooling since a long time. In spite of the low COP, this is being used because of the operating conditions (e.g., availability of compressed air and ram effect) and stringent specifications (e.g., low weight, small size, absolute safety, zero toxicity, etc.) which are exclusive to aircrafts. In the light of the new situation created due to the ban on synthetic refrigerants, possible use of air for on-ground applications is being considered actively. It should be noted here that the technology with air as refrigerant will be totally different from that with other working fluids due to the fact that air does not undergo phase change (condensation/evaporation) at the temperature levels encountered in conventional refrigeration applications.

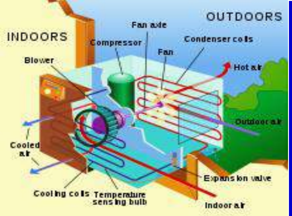
Use of carbon dioxide as refrigerant dates back to the early years of refrigeration. It is environmentally benign. Being the by- product of many energy conversion processes, it is cheap and easily available. Its use as a refrigerant can reduce its release to the atmosphere, thereby making a positive contribution to the environment. Very high operating pressure is a drawback. Because of its low critical point, most of the thermodynamic cycle operates in the single phase region. Since CO2 enters the expansion valve as a superheated vapour, it results in a large energy loss during the throttling process. Carbon dioxide is an excellent refrigerant when both heating and cooling are desired. Also, it is not preferable for use in tropical countries such as India due to the high ambient temperatures which result in high condensing pressures.

COMPARISON OF DIFFERENT REFRIGERANTS

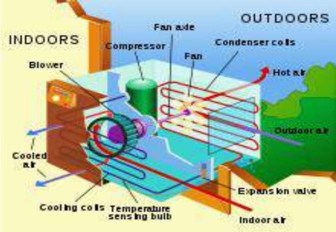
Refrigerant	Toxicity	COP	Cost of refri-gerant	Working pressures	Flammability	Materials of construction	Compatible lubricating oils
CFC/HCFC	Non toxic	High	Low	Low	Non-flammable commonly used	All oils/Synthetic oils materials	Mineral
HFC	Non toxic	High	Low	Low	Non-flammable	All commonly used materials	Synthetic oils only
HFO	Non toxic	High	?	Low	Flammable	All commonly used materials	Synthetic oils only
HC	Non toxic	High	Low	Low	Flammable	All commonly used materials	Mineral oils/ Synthetic oils
NH_3	Toxic	High	Low	Low	Mildly flammable	Only steels. Copper not compatible.	Mineral oils
CO_2	Mildly toxic	Low	Low	Very high	Non flammable	All commonly used materials	Mineral oils/ Synthetic oils

CONCLUSION

Thus, there are no refrigerants in the horizon that completely meet the safety, stability, energy efficiency and environmental friendliness. It seems that the refrigeration industry will have very little choice but to use flammable refrigerants (HFOs, low GWP HFCs, HCs, NH3, etc). Since the energy efficiency of HFOs is somewhat low, mixtures of medium GWP fluids such as R32 and low GWP refrigerants such as R1234yf may be the working fluids of choice in the immediate future. Meanwhile, the quest for better molecules continues. Barring new inventions, natural refrigerants appear to be the best choice in the long term.

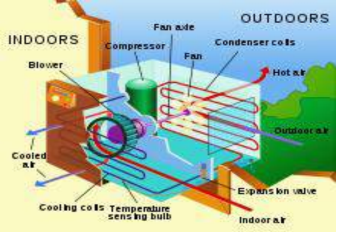


TIME FOR QUESTIONS

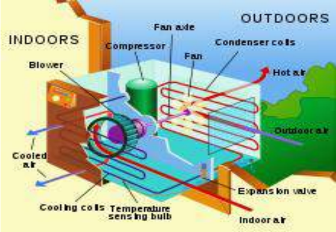


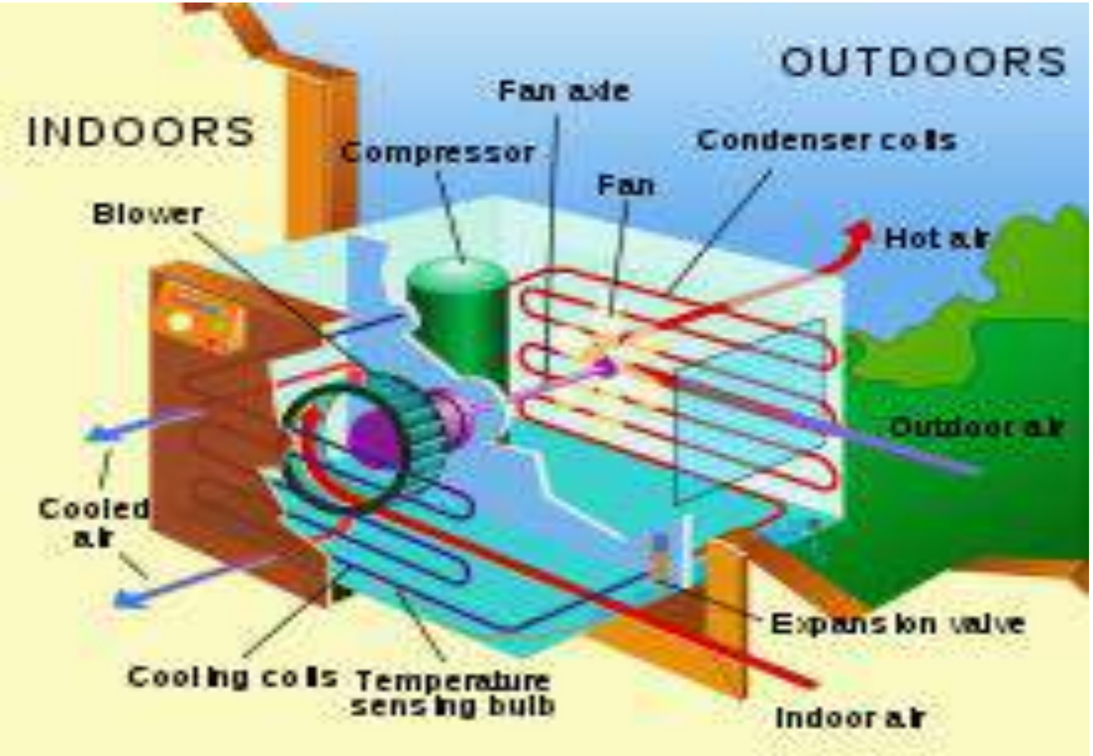
QUESTION?

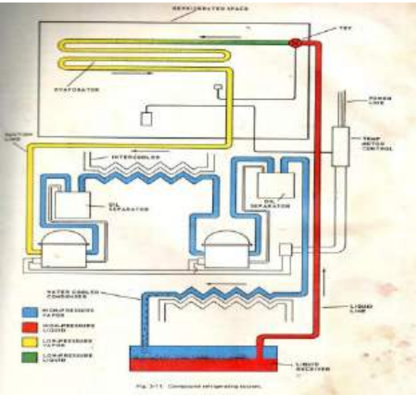
COOLING THE WHOLE STADIUM ?

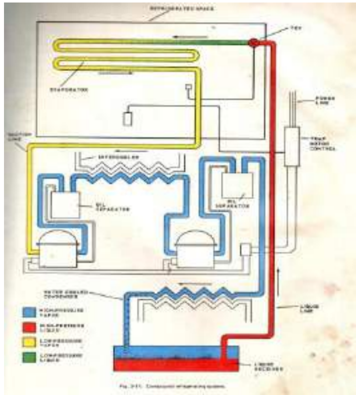


Lecture 4
Air-Conditioning System

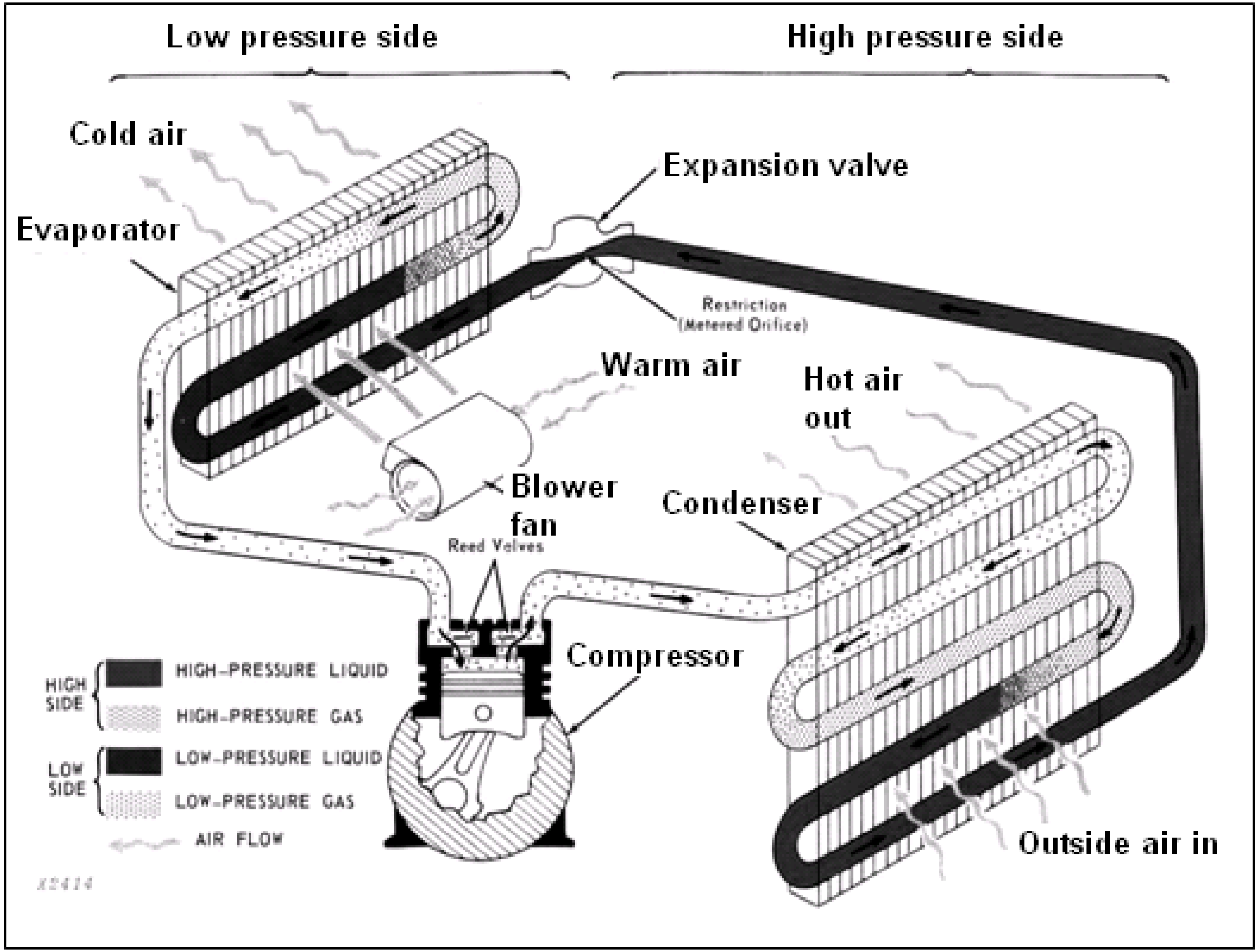


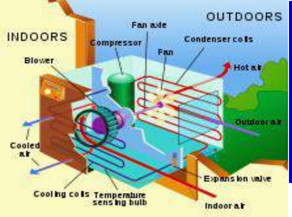




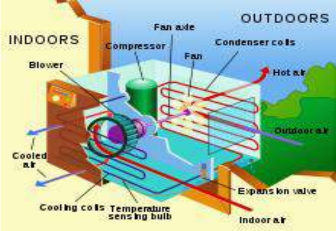


A Window Unit Air-Conditioning System





RADIANT AND CONVECTIVE LOADS



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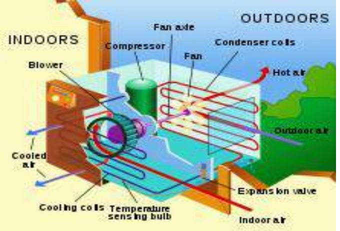
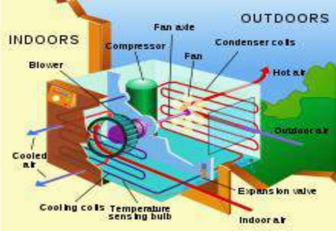
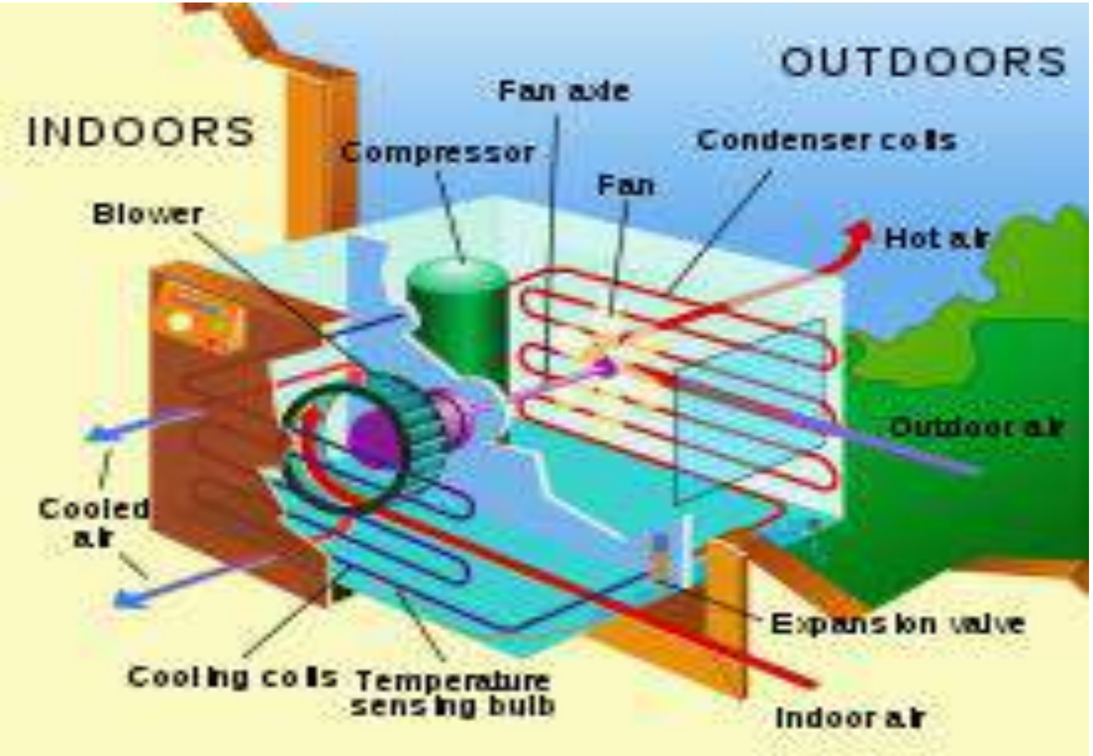
Radiant & Convective Loads

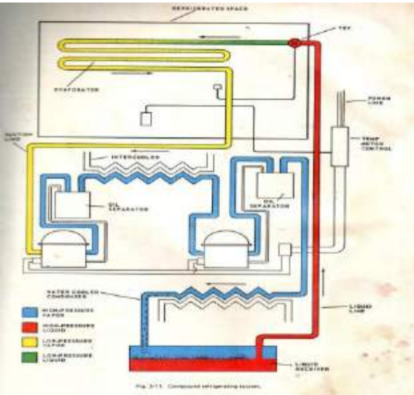
Heat Source	Radiant Portion	Convective Portion
	%	%
Window solar, no inside shade	100	--
Window solar, with inside shade	58	42
Fluorescent lights	50	50
Incandescent lights	80	20
People	33	67
Transmission, external roof and walls	60	40
Infiltration and ventilation	--	100
Machinery and appliances	20 to 80	80 to 20

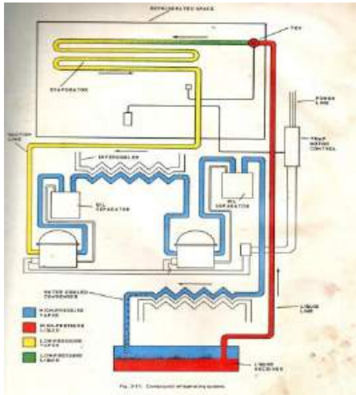


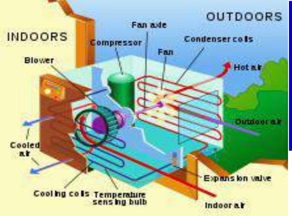
AIR-CONDITIONING SYSTEM



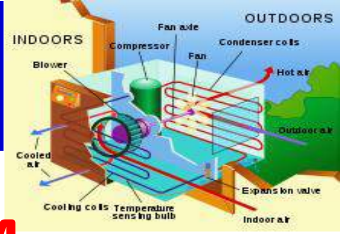








AIR CONDITIONING CLASSIFICATION



CLASSIFICATIONS OF AIR CONDITIONING SYSTEM

- **BASED ON MAJOR FUNCTION**

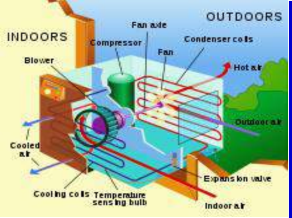
Comfort and industrial air conditioning systems.

- **BASED ON THE SEASON OF THE YEAR**

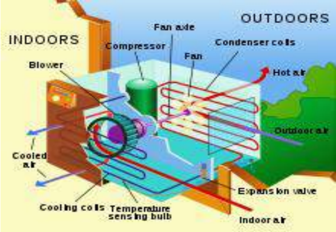
Summer, Winter and Year Round air conditioning system

- **BASED ON THE EQUIPMENT ARRANGEMENT**

Central, Unitary and Combined central and unitary



PRINCIPLE OF AIR-CONDITIONING SYSTEM



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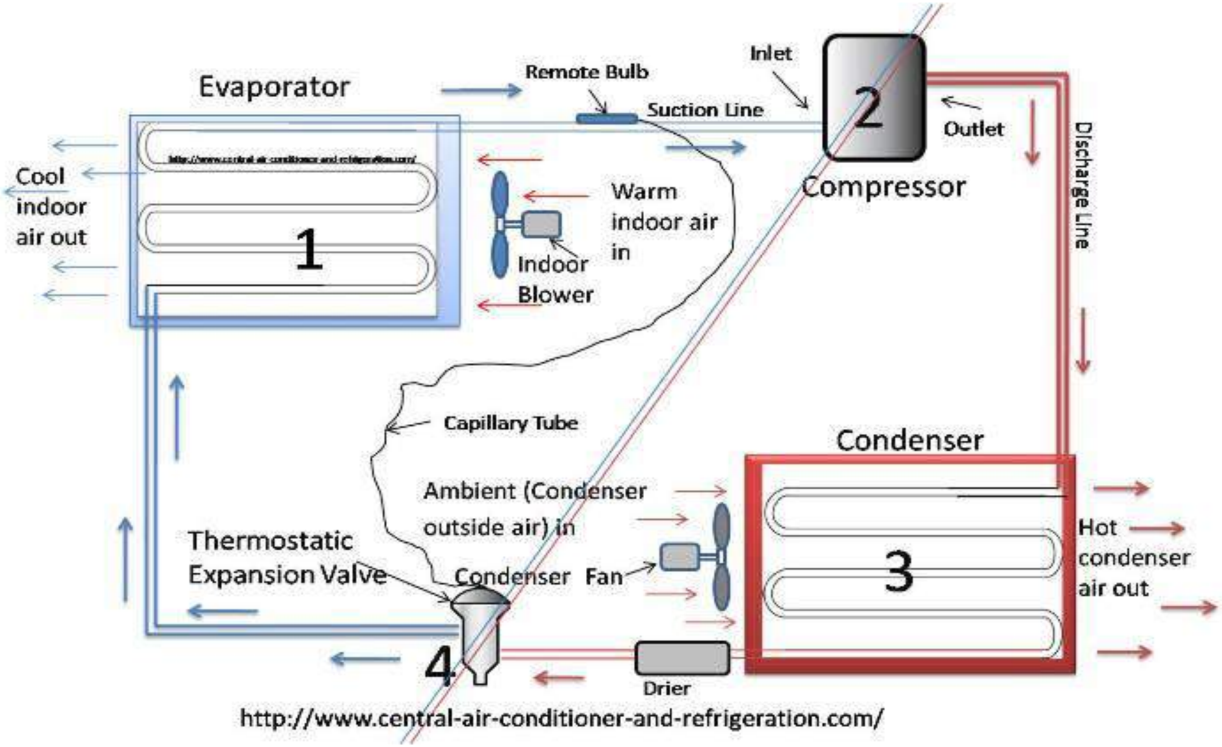
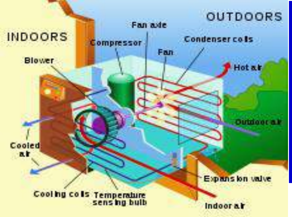
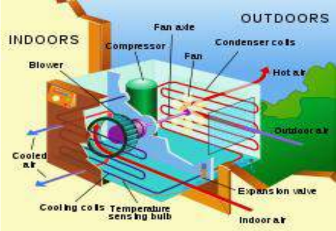




PRINCIPLE OF AIR-CONDSYSTEM



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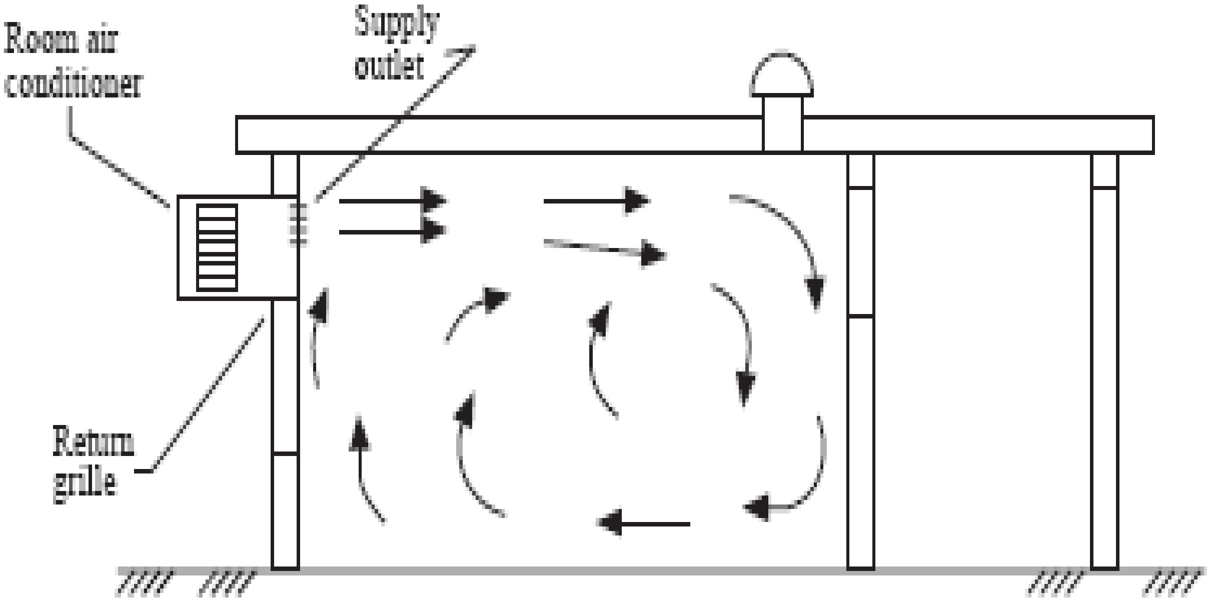
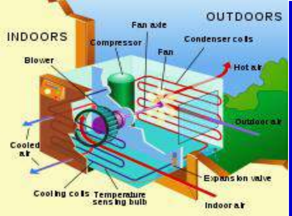
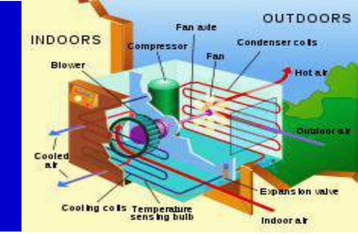
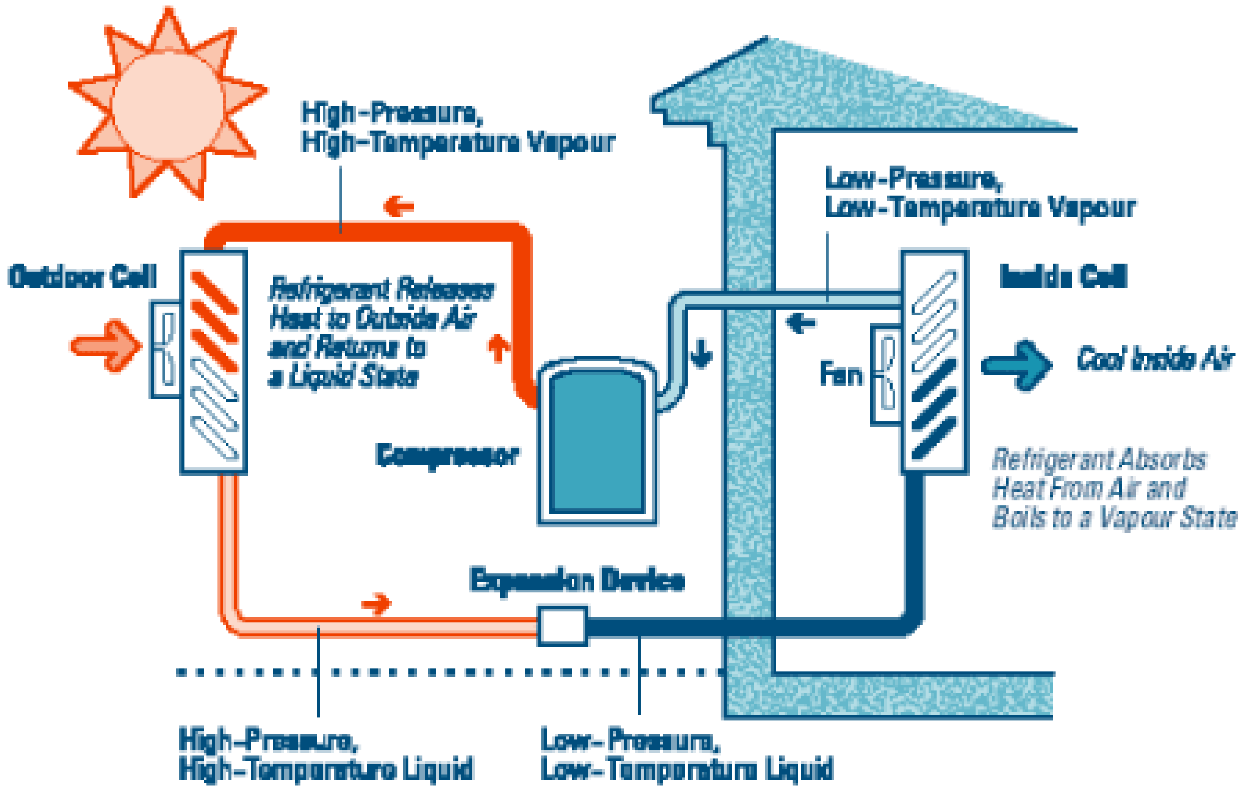
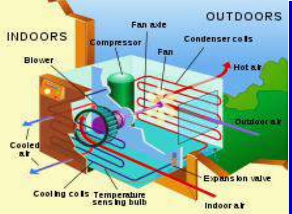




AIR CONDITIONING SYSTEM







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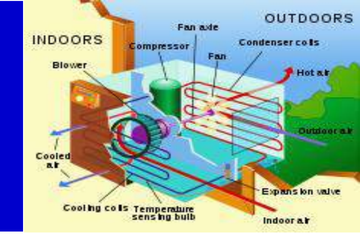
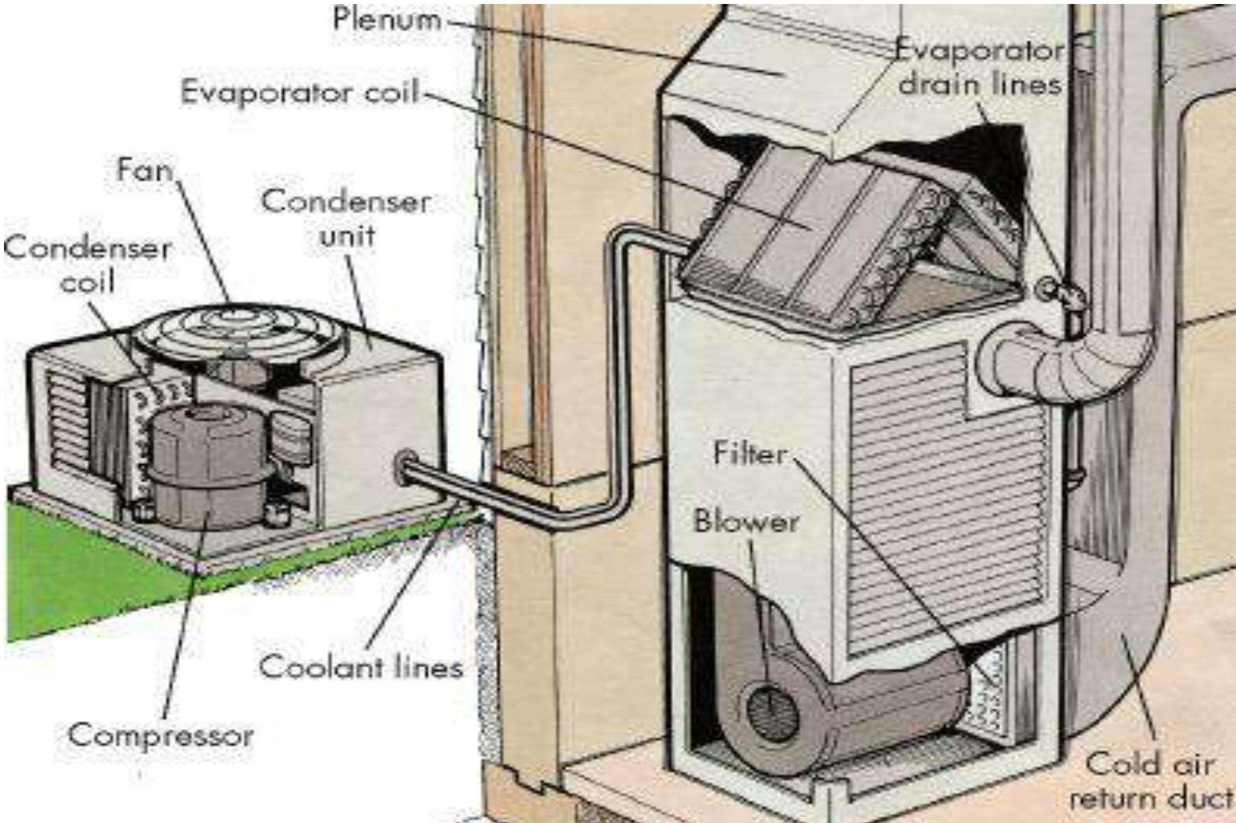
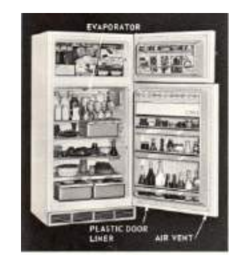
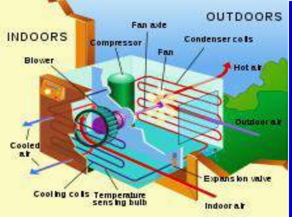
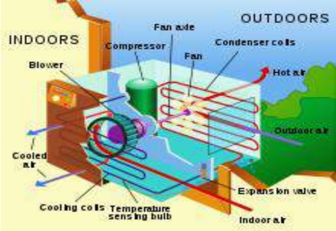


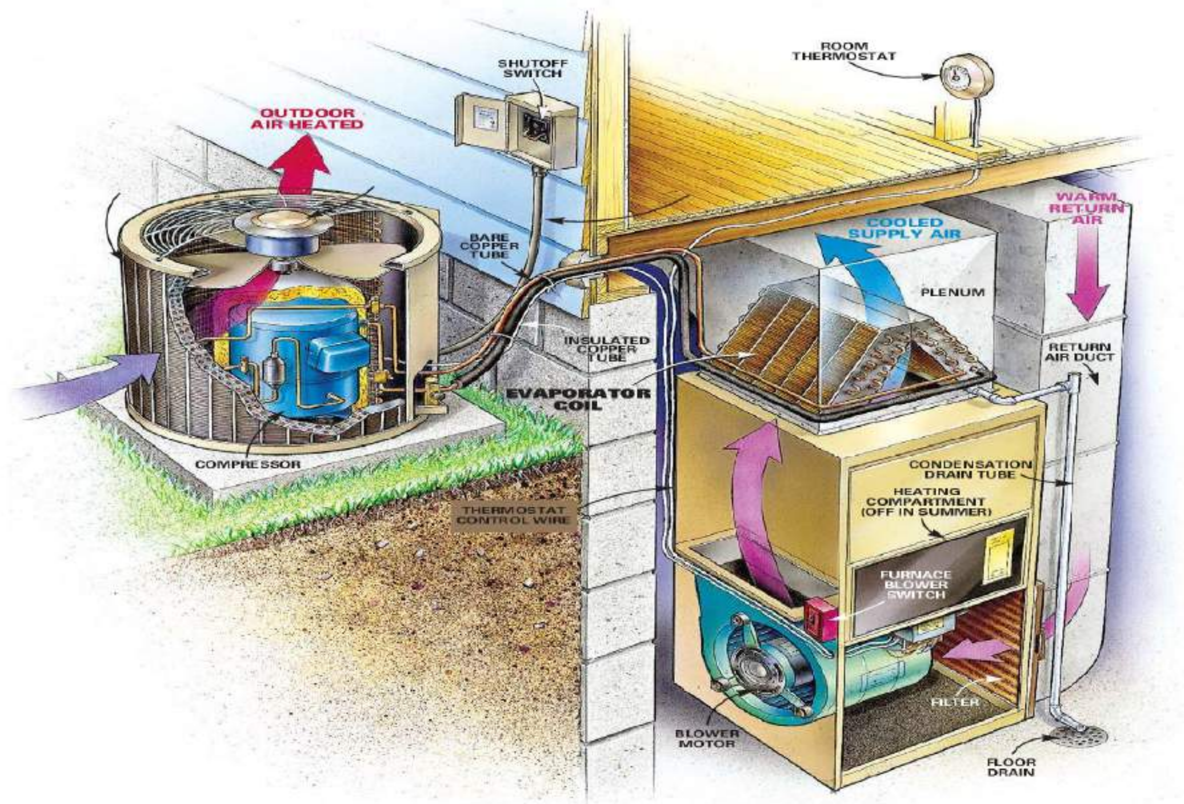


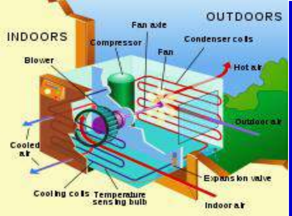




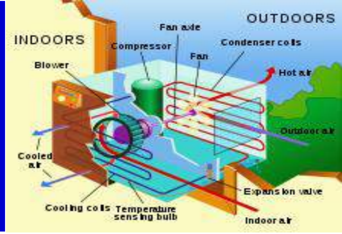
SOME INDOOR AND OUTDOOR PARTS OF A CENTRAL AIR-CONDITIONER

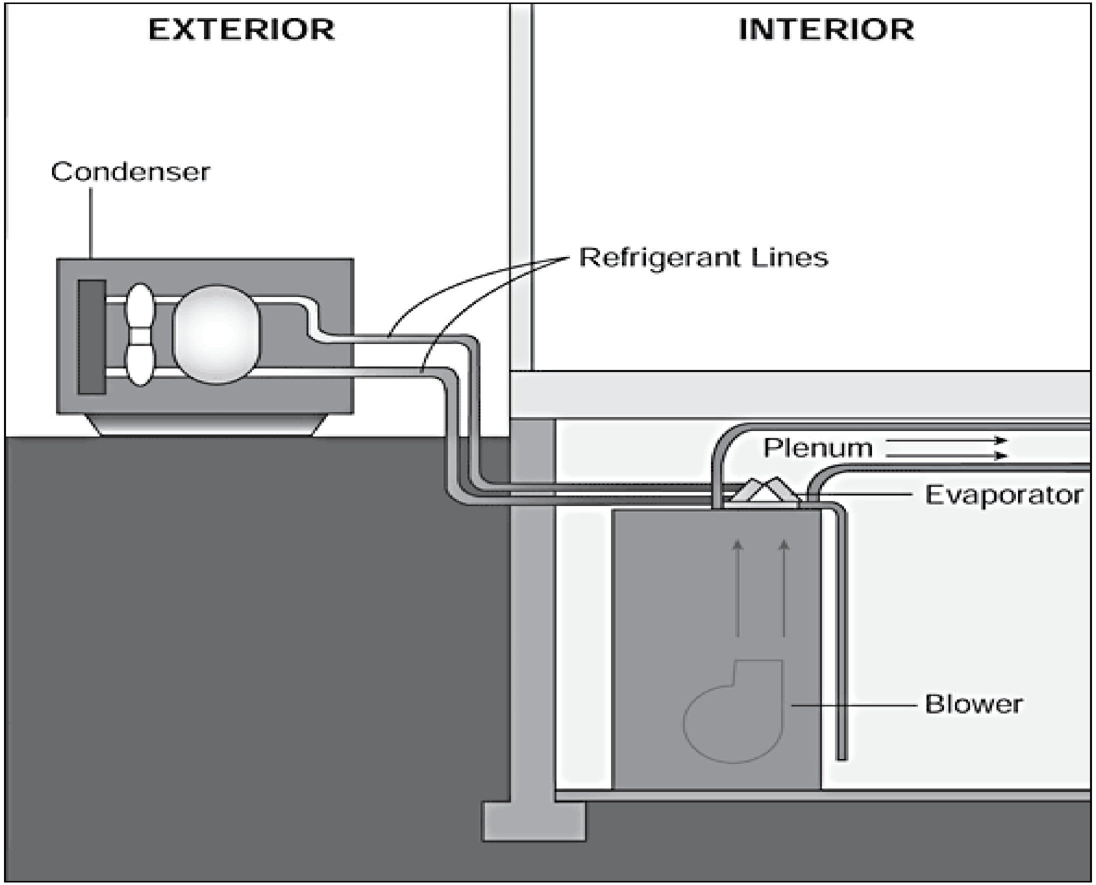


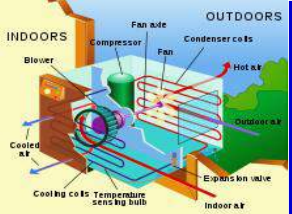




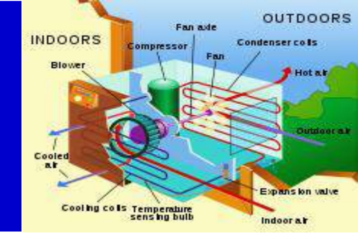
SOME INDOOR AND OUTDOOR PARTS OF A CENTRAL AIR-CONDITIONER







SOME INDOOR AND OUTDOOR PARTS OF A CENTRAL AIR-CONDITIONER WITH THE DUCT SYSTEM



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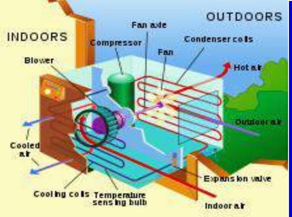
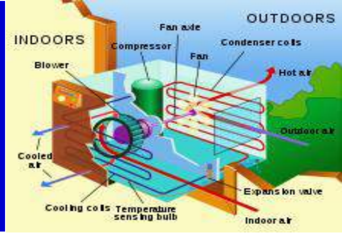


SOURCES OF HEAT LOADS



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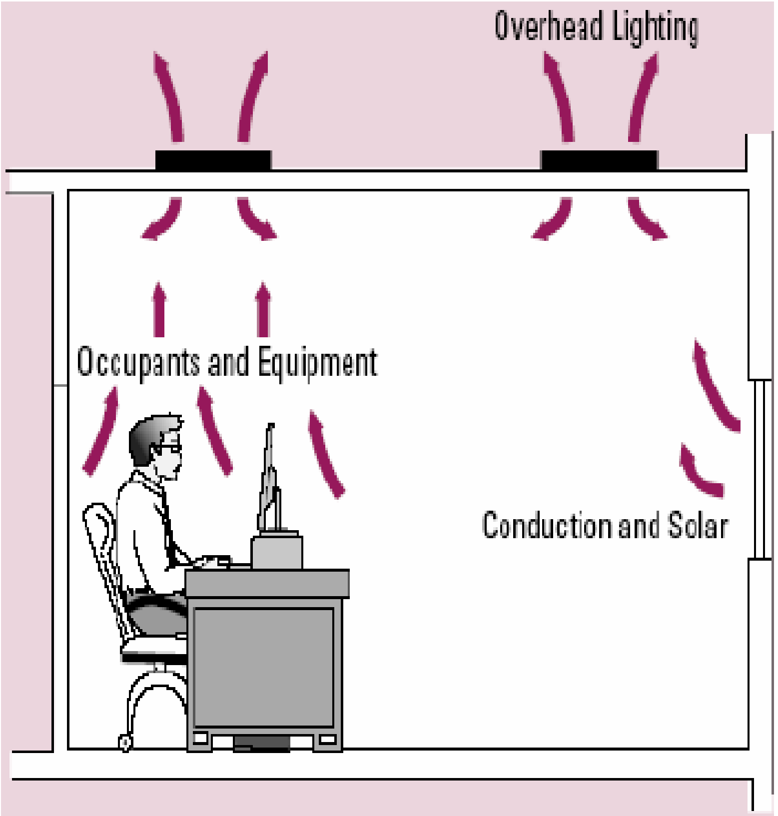
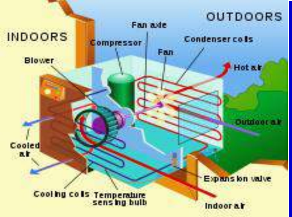
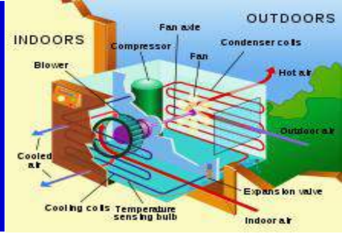
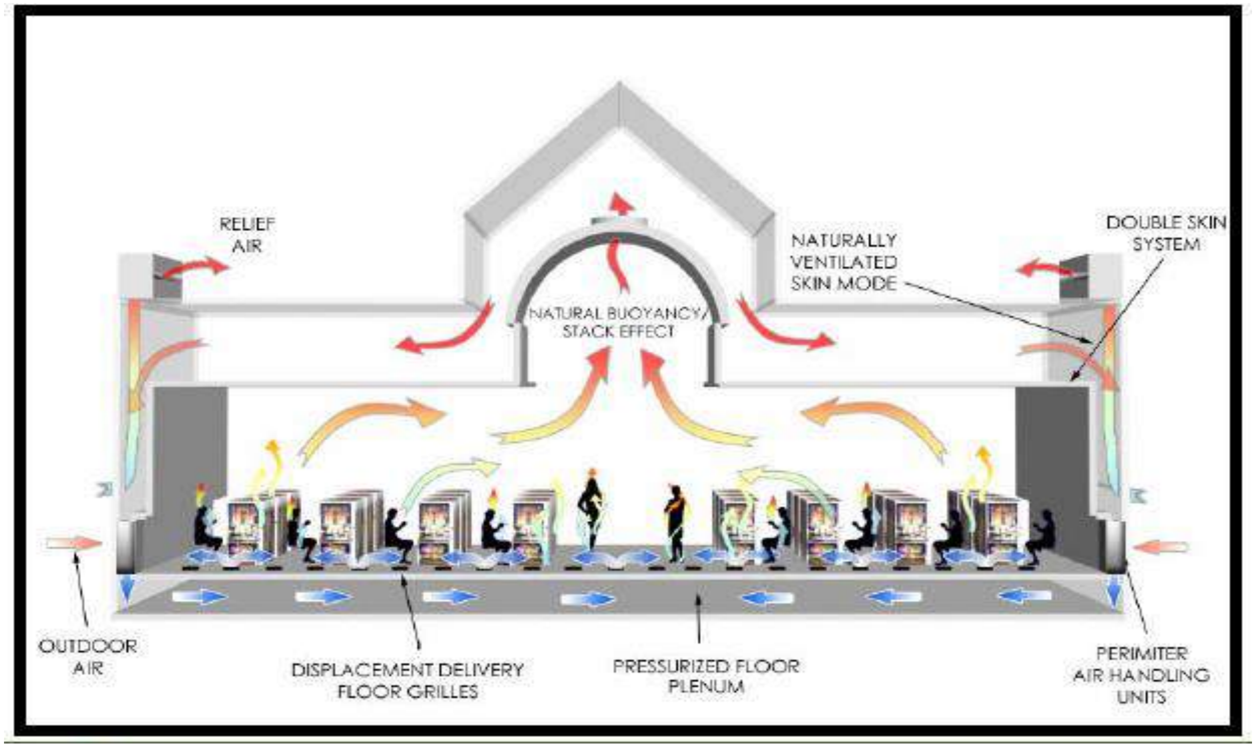
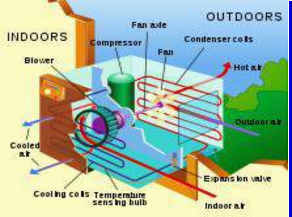




DISPLACEMENT GRILL







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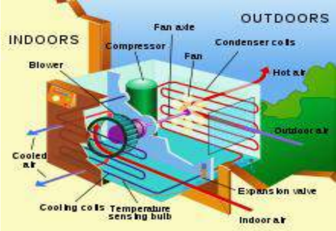
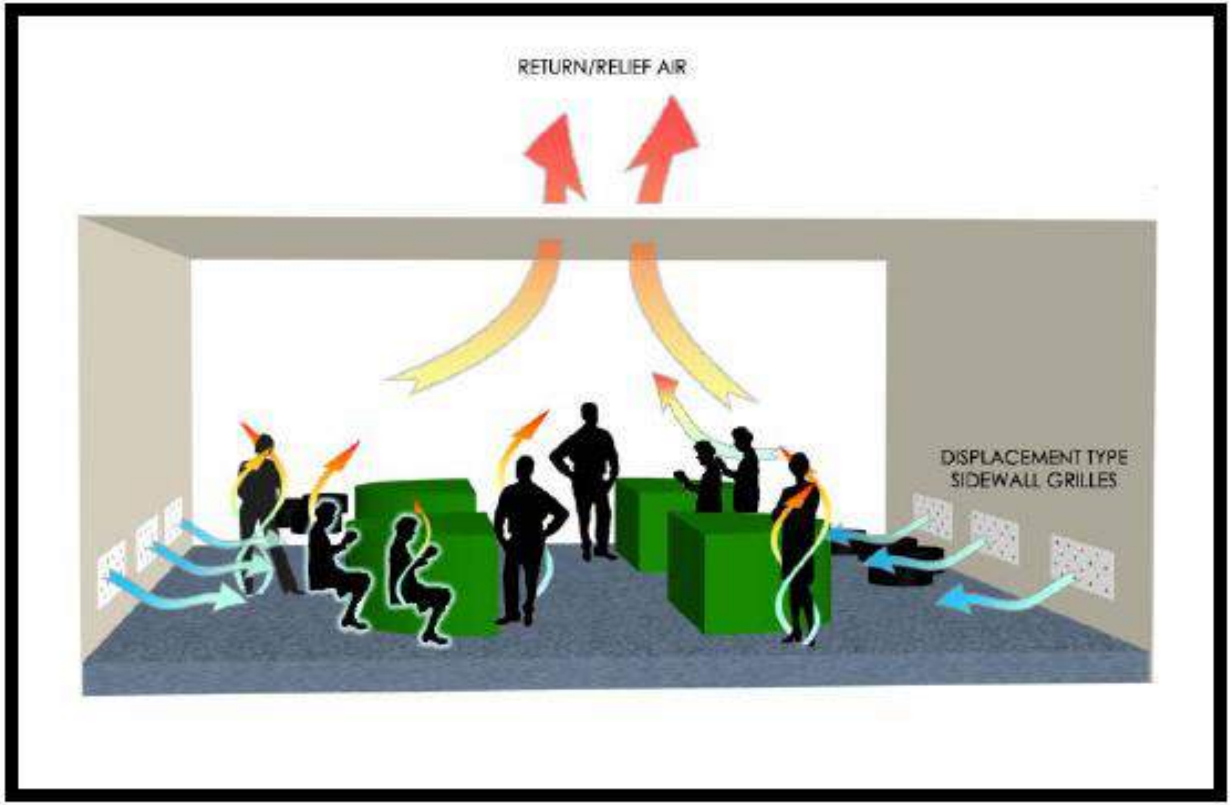
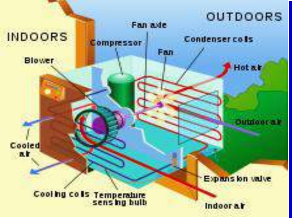
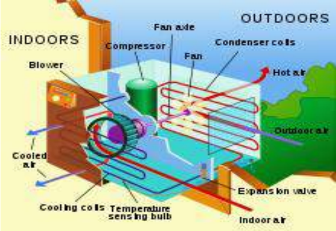
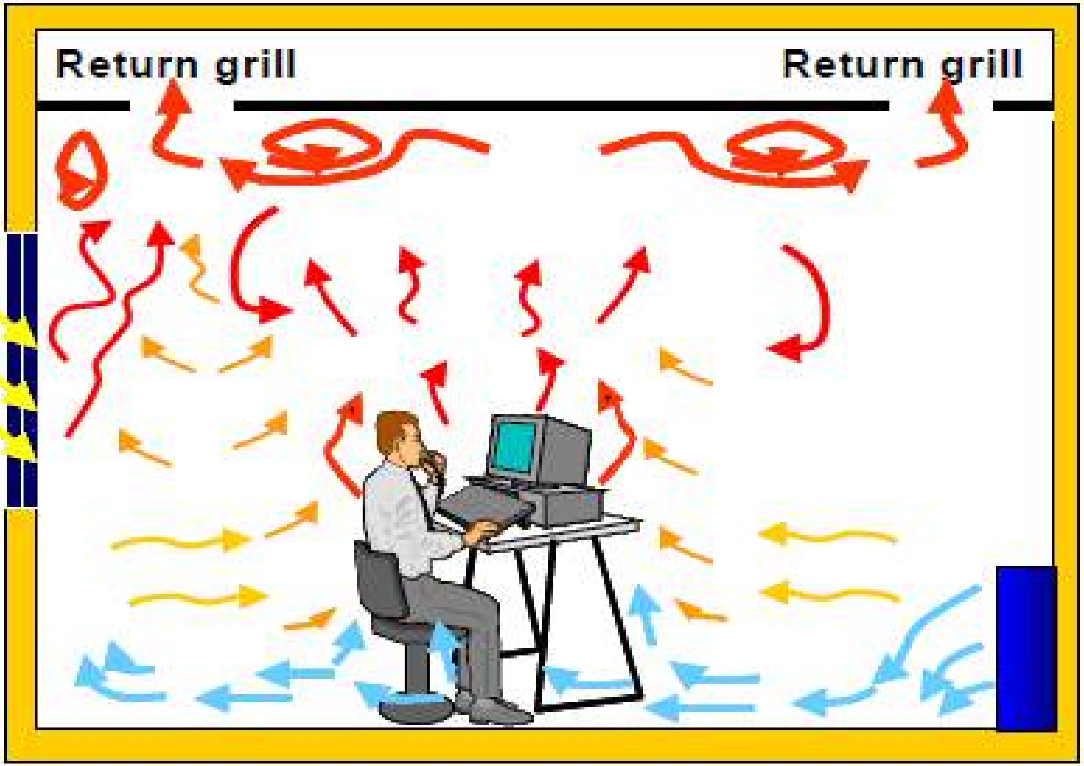


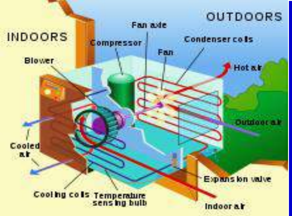




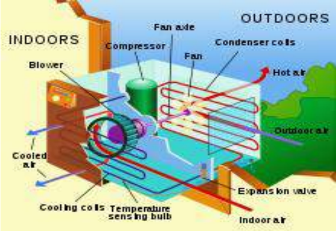
COOLING BY THERMAL STRATIFICATION





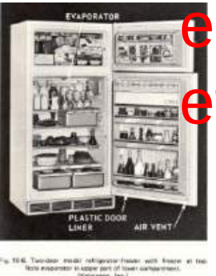


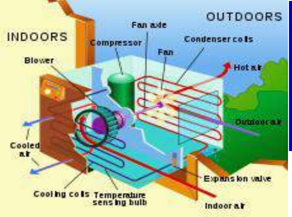
MIXED MODE VENTILATION



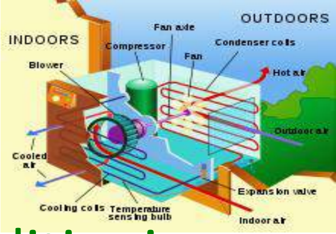
- APPLICATION OF MIXED MODE VENTILATION

  By combining natural ventilation and comfort cooling, the Mixed Mode system really does offer the best of both worlds. Natural ventilation is the preferred low energy strategy option for commercial buildings. Air conditioning can provide the close climate control desired in periods of occasional hot or cold weather. The Mixed Mode cooling system combines these two elements, providing the benefits of both-energy efficiency and improved comfort.

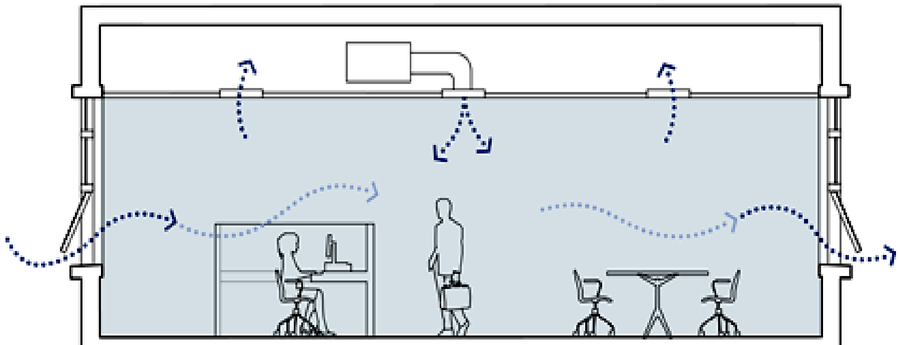




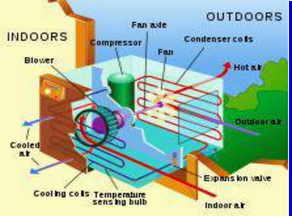
CONCURRENT MIXED MODE OPERATION



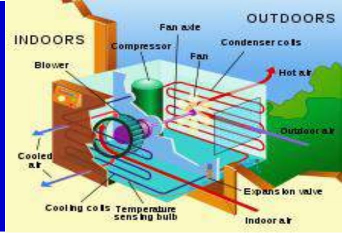
- In concurrent mixed-mode operation, the air conditioning systems and the operable windows operates in the same space and at the same time.



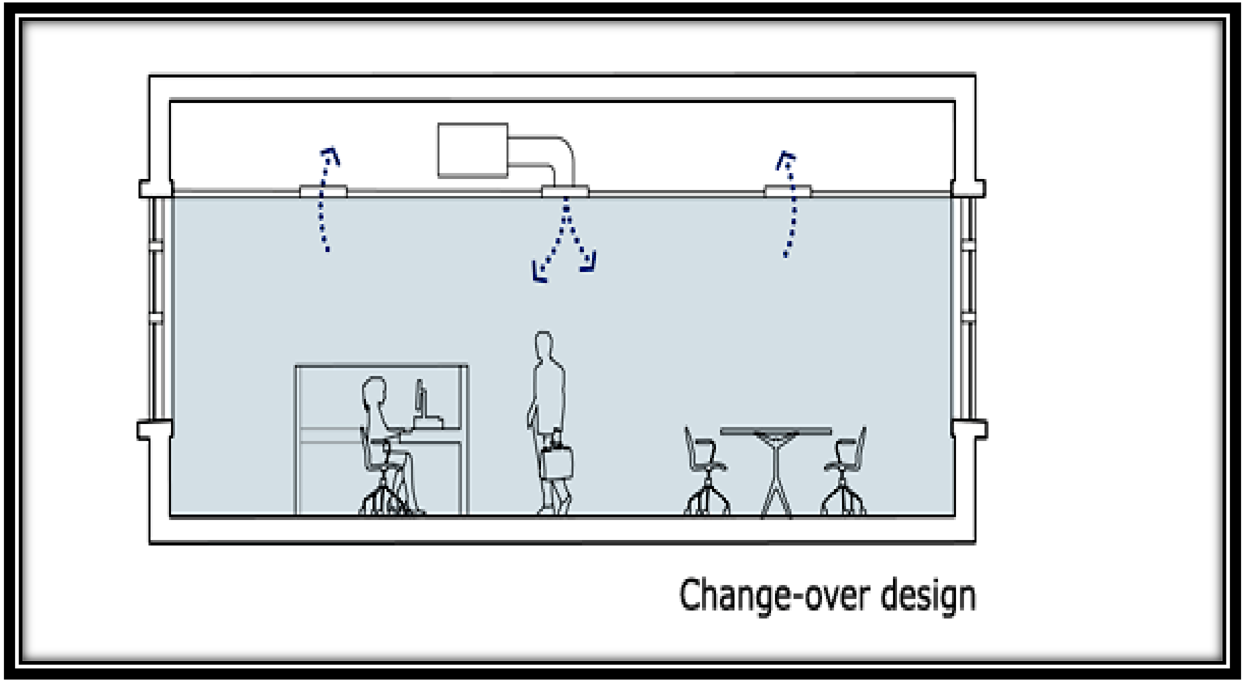
Concurrent mixed-mode operation

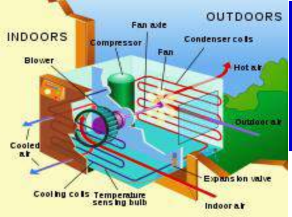


MIXED-MODE OPERATION SYSTEM

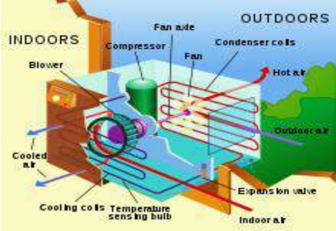


- In this mixed-mode operation, the building "change-over" between natural ventilation and air-conditioning on a seasonal or daily basis.

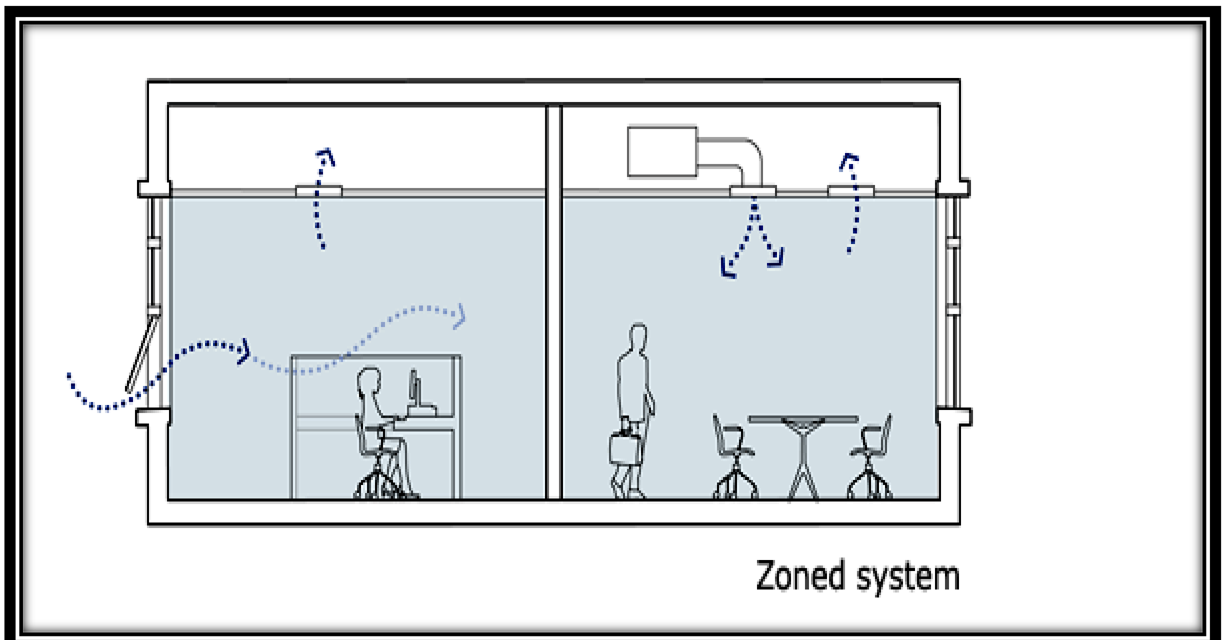




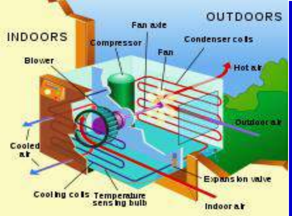
ZONED MIXED-MODE OPERATION SYSTEM



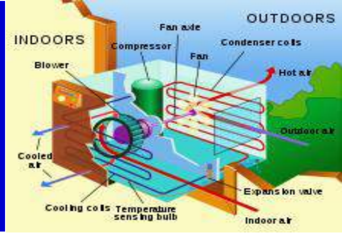
- In zoned operation system, different zones within the building have different conditioning strategies.

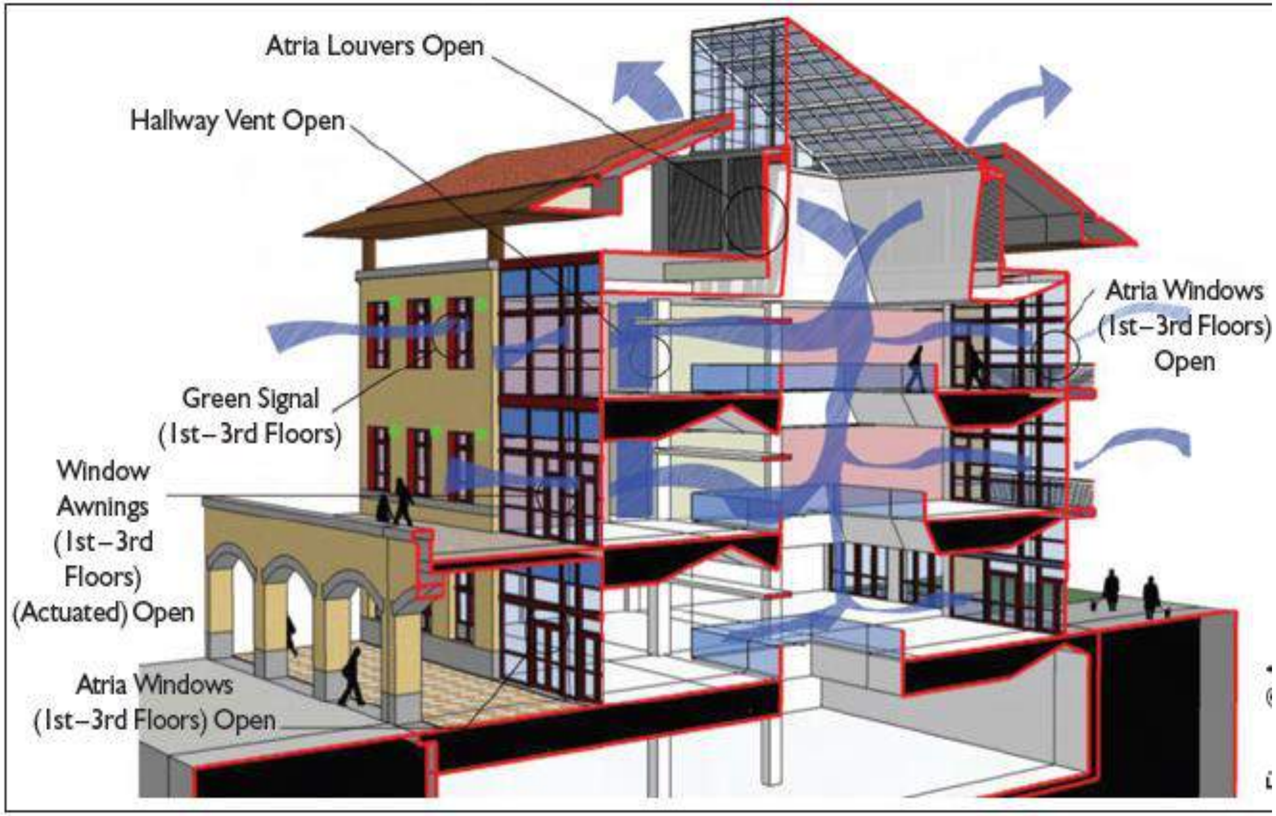


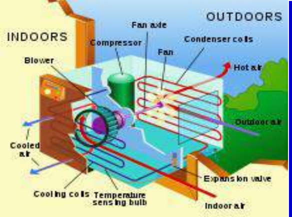
Zoned system



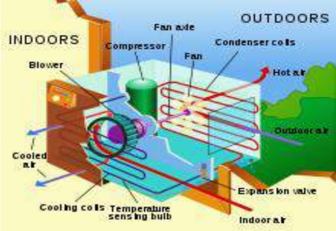
MIXED MODE VENTILATION SYSTEM



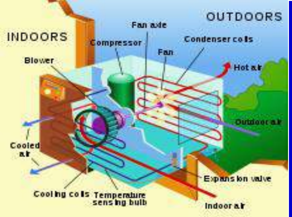




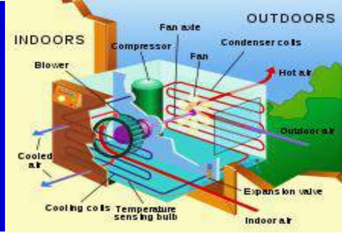
ADVANTAGES OF MIXED-MODE IN BUILDINGS



- ADVANTAGES OF MIXED-MODE BUILDINGS
  - Reduced HVAC energy consumption
  - Higher occupant satisfaction
  - Highly “tunable” buildings
  - Mixed mode can be useful in places where natural ventilation is not suitable (e.g very cold weather) where fully mechanically ventilated rooms are not available.



BENEFITS OF MIXED-MODE VENTILATION

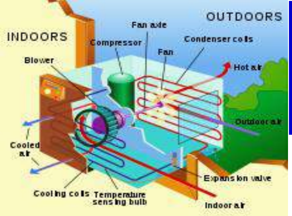


BENEFITS OF MIXED-MODE VENTILATION

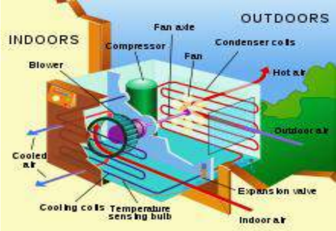
- Energy savings
- Thermal comfort
- Health and productivity

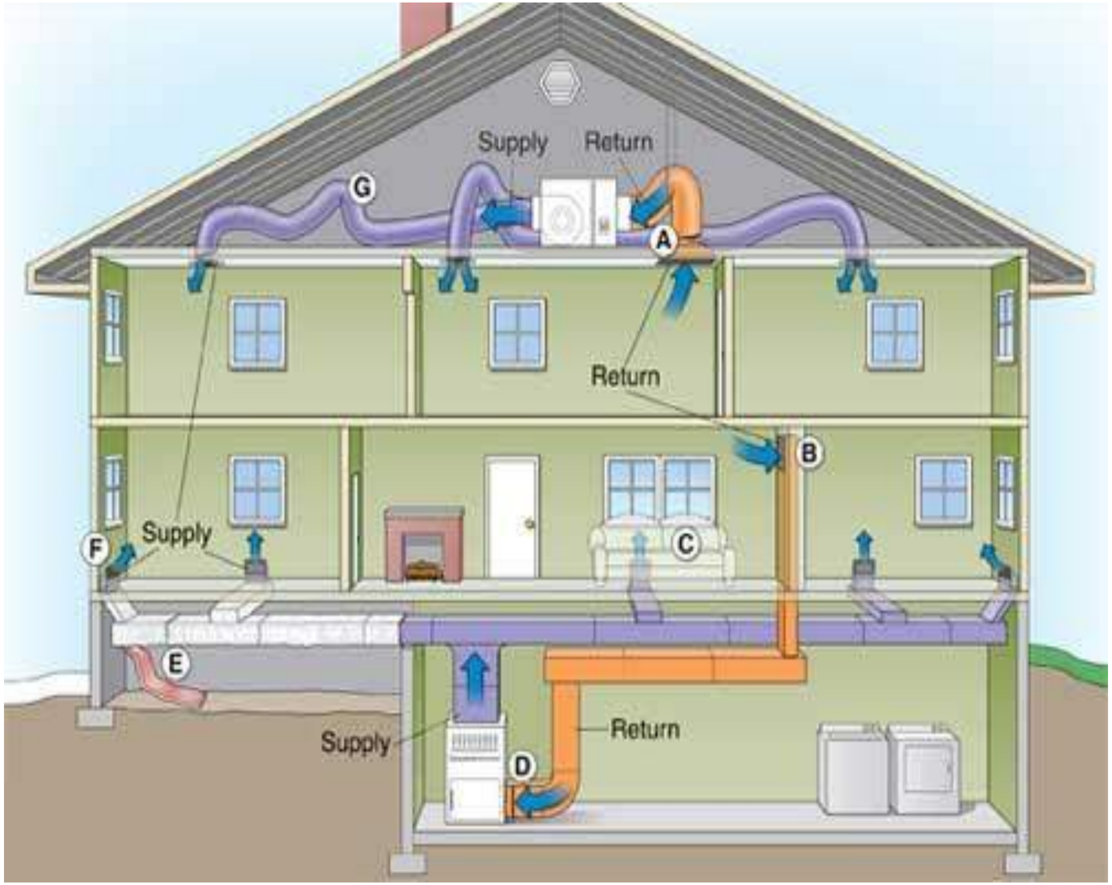
WHY AREN'T WE SEEING MORE MIXED-MODE BUILDINGS?

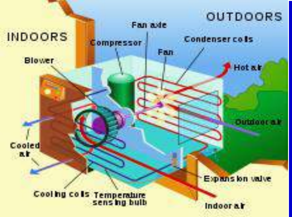
- Building design issues
- Building operations and controls issues
- Fire and safety concerns
- Energy code concerns



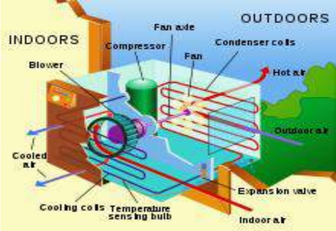
CENTRAL AIR-CONDITIONING SYSTEM







CENTRAL AIR CONDITIONING SYSTEM



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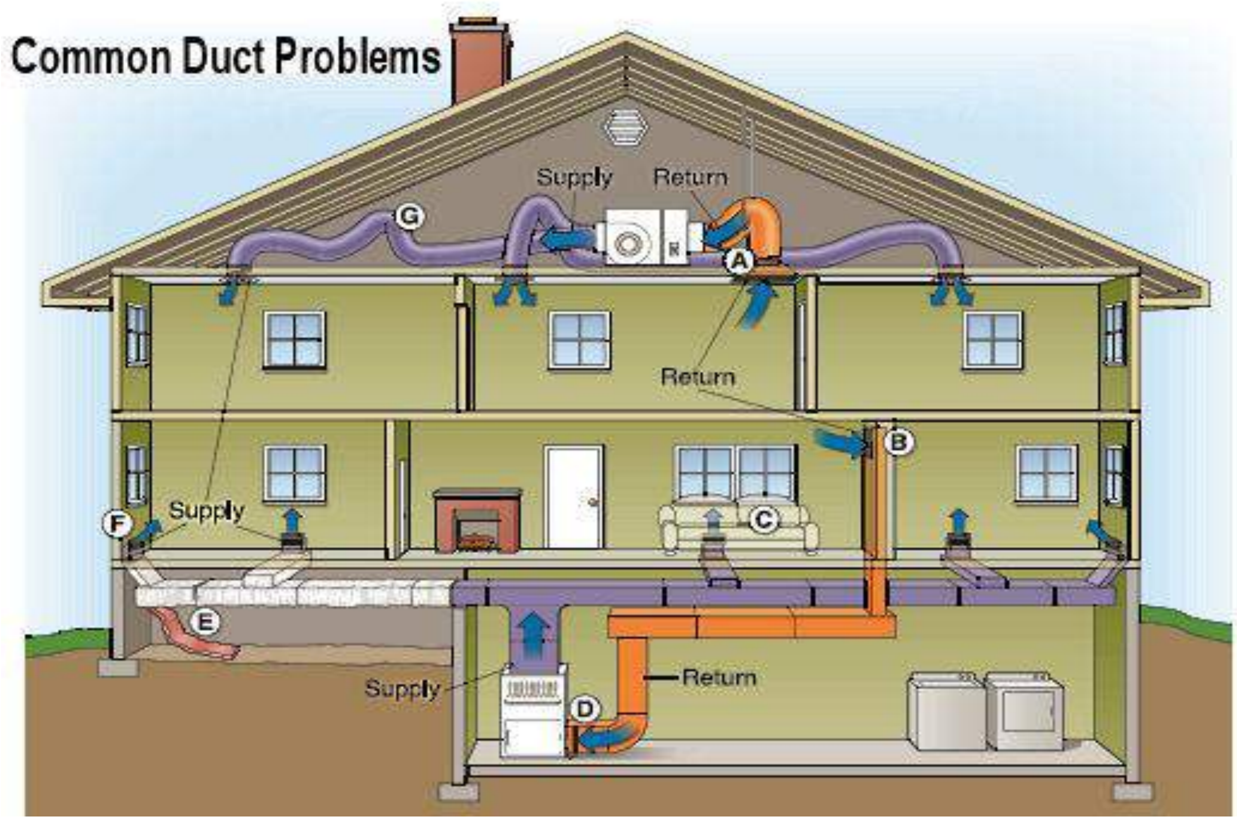
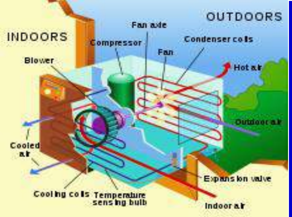
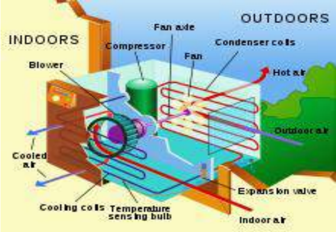
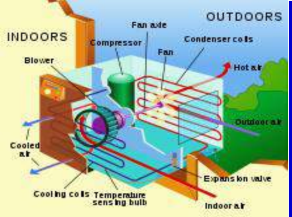




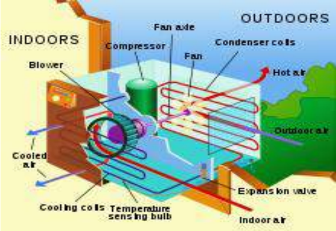
CENTRAL AIR CONDITIONING SYSTEM



- A Central air conditioning unit commonly is an air conditioning system that uses ducts to distribute cooled and dehumidified air to more than one room, or uses pipes to distribute chilled water to heat exchangers in more than one room and which is not plugged to a standard electrical outlet.
- The components of a central air conditioning unit are; the refrigerant, coil, the evaporator, the compressor, the condenser, the expansion device and the plenum.

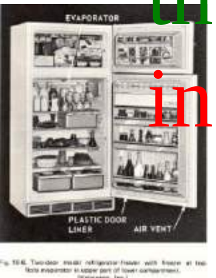


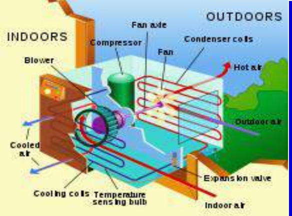
CENTRAL AIR-CONDITING SYSTEM



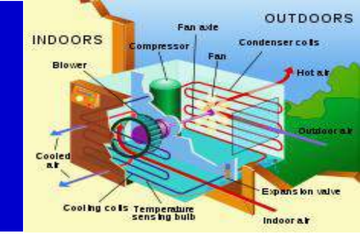
OPERATING SYSTEM OF CENTRAL AIR-CONDITIONER

- The centralized cooling system is outfitted by ducts for the distribution of air in all sections of the space to be cooled. The air is cooled by pipe lines that are chilled. The setup of the central cooling system automatically reduces the sound created by its operation as it is installed outside of our homes.





TYPES OF CENTRAL AC



- **•Field Erected Systems**

  These are usually used in large commercial structures. They may also be used to heat and cool various sections of a large building. Field erected systems frequently use chilled or heated liquid to transfer heating and cooling.

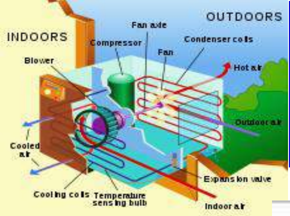
  •Central or Unitary Systems

  Central air conditioning systems are ideal for residential air conditioning. They are a complete, manufactured package ready for assembly. All internal wiring and piping has been done. The condensing unit is located away from the evaporator. There are three evaporator designs in use:

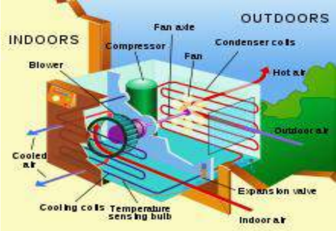
  •The A-type evaporator

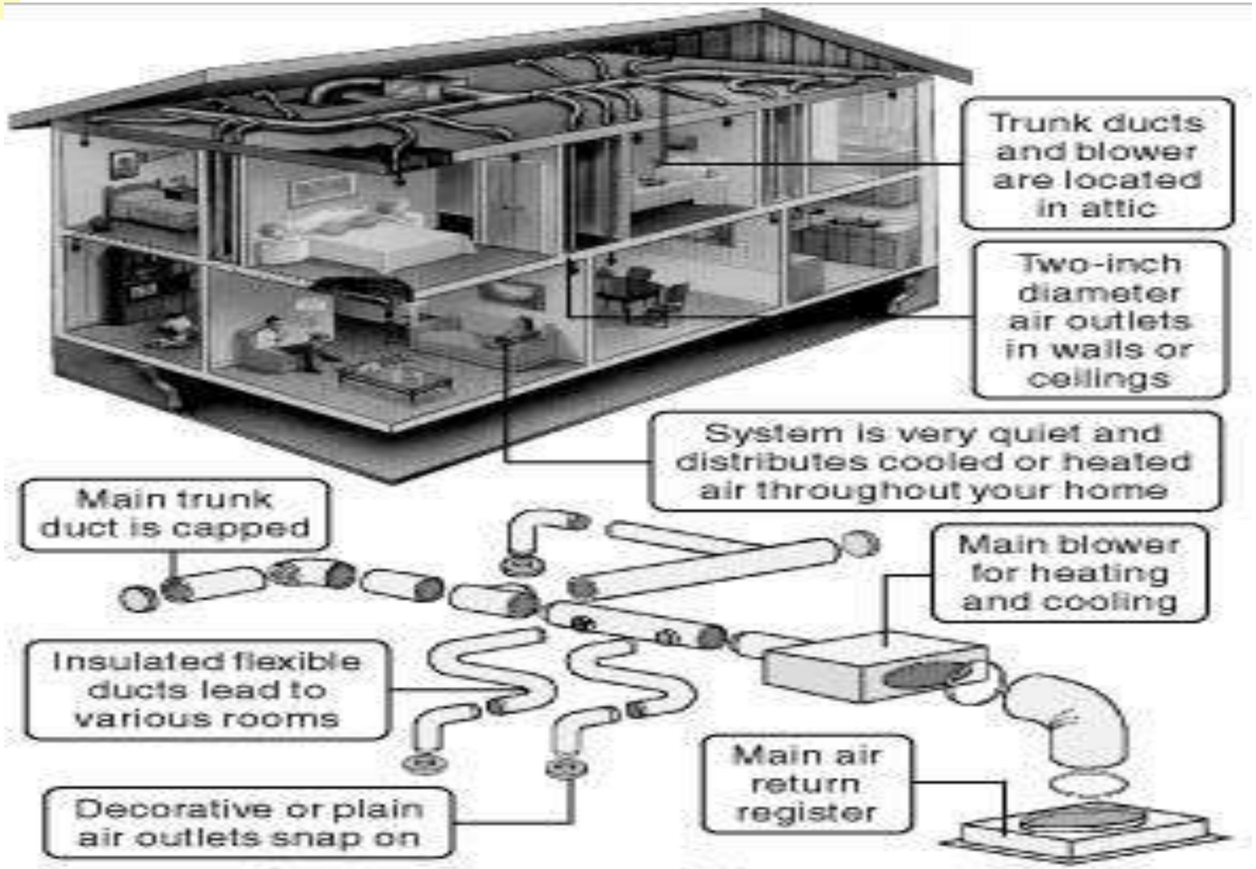
  •The slant-type evaporator

  •The flat-type evaporator for horizontal flow

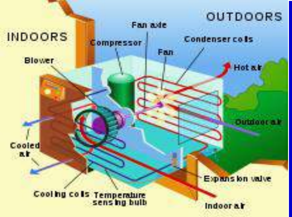


CENTRAL AIR CONDITIONING WITH DUCT

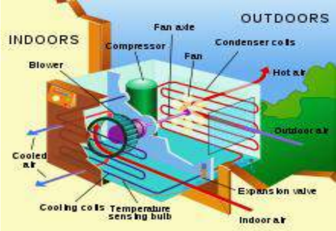




Components of a typical system



PRINCIPLE
OF
VAPOUR COMPRESSION REFRIGERATION SYSTEM



QUESTION?