Module - III

Refrigeration and Air conditioning

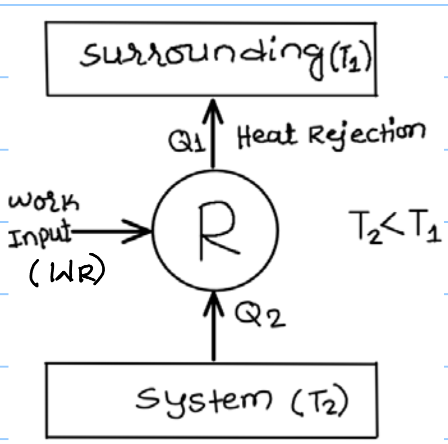
Refrigeration :

Refrigeration is defined as the process of reducing the temperature of a system/space/substance below that of the surrounding atmosphere and maintining this lower temperature within the boundary of a given system/space/substance by continuously extracting heat from it.

A substance, that extracts heat from the system and rejects it to the surrounding is called "Refrigerant".

The machine, that is employed to produce the refrigeration effect in general is called "Refrigerator".

Principle of operation of Refrigeration



- In the process of refrigeration, the heat is continuously removed from the system that is to be maintained at lower temperature and transferred to surrounding which is at a higher temperature.
- According to 2nd law of thermodynamics, the removal of heat from a low temperature and transferred to a high temperature is possible by supplying external work to the system under operation.

- Hence, a refrigerator needs external power for removing heat continuously from the desired space to maintain the temperature lower than the surrounding.
- The basic mechanism of the refrigeration is shown in above figure, in which T_1 and T_2 are the maximum and minimum temperature of the bodies respectively. 'R' is the refrigerator. 'Q_1' is the heat supplied to the hot body and 'Q_2' is the heat removed from the low temperature body, and 'W_R' is the work required to produce low temperature

Parts of Refrigerator

To accomplish task of producing the cooling effect, a refrigerator must consist, the following four main parts

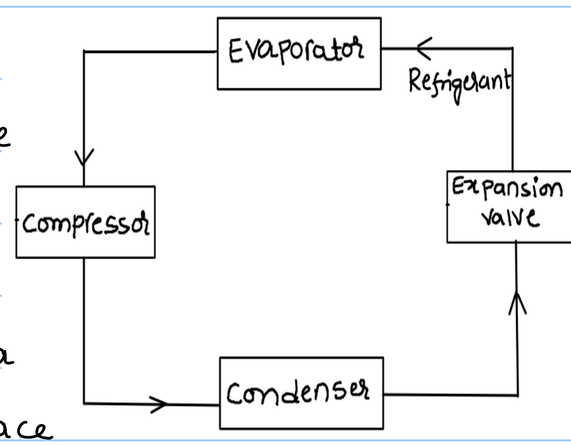
(i) Evaporator

(ii) Circulating sytem (Compressor or pump)

(iii) Condenser

(iv) Expansion device

(i) Evaporator:



An evaporator is component of the refrigeration system, in which heat is removed from the given space by the refrigerant. It consists of a coiled set of pipes inside the space in which substance have to be kept cool.

(ii) circulating system (compressor or pump):

The circulating system comprises of mechanical devices such as compressor or pump necessary to circulate the refrigerant. They increase the pressure and therefore, the temperature of the refrigerant also increases from given value to the higher value. Generally, these devices are driven by electric motors. The electrical energy input to the motor is the work input supplied to refrigerator.

(iii) condenser:

A condenser is a heat exchanging device in which the heat from the refrigerant is transferred/rejected to a medium of higher temperature, usually the atmospheric air. Here, refrigerant that is in vapour state gives of the latent heat to the air, and consequently condenses into liquid so that it can be circulated.

(iv) Expansion device or throttle valve:

It is the device that reduces the pressure and temperature of the liquid refrigerant before it is passed to the evaporator.

Properties of an ideal refrigerants

A refrigerant is a working fluid used to carry the heat in a refrigeration system.

The desirable properties of an ideal (good) rerfrigerant are classified into the following four main groups

(i) <u>Thermodynamic properties</u>

(a) **Boiling point:** An ideal refrigerant must have 'low boiling temperature' at atmospheric pressure, that is it should have the ability to turn into gas easily when it absorbs the heat. If the refrigerant has a high boiling temp-erature, the compressure will have to create too much of vacuum in order to lower the pressure to make vapourization happen.

(b) **Freezing point:** An ideal refrigerant must have 'very low freezing point', because the refrigerant should not freeze at low evaporator temperatures.

(c) **Evaporator and condenser pressure:** Both evaporator and condenser pressure should be 'slightly above the atmospheric pressure', so that the leakage of the refrigerant can be easily detected and avoid the entry of atmospheric air into the evaporator and condenser.

(d) **Latent heat of evaporation:** The latent heat of evaporation of the refrigerant 'must be very high', so that a minimum amount of refrigerant is sufficient to increase the refrigeration effect.

(e) **Critical temperature:** The critical temperature of the refrigerant 'must be high', ie the temperature above which the refrigerant gas (vapour) cannot be liquified, irrespective of how much pressure applied.

(ii) Physical properties

(a) Specific volume: The specific volume of the refrigerant 'must be very low' so that it reduces the size of the compressor required.

(b) Specific heat: An ideal refrigerant 'must have a low specific heat when it is in liquid state and high specific heat when it is in vapour state'. This helps to increase the refrigeration effect.

(c) Viscosity: The viscosity of the refrigerant at both liquid and vapour state 'must be very low' as it improves the heat transfer and reduces the pumping pressure.

(iii) Chemical properties (or safe working properties)

(a) Toxicity: An ideal refrigerant should be 'Non-toxic', because any leakage of the toxic refrigerant increases suffocation and poison the enviroment.

(b) Corrosiveness: An ideal refrigerant should be 'Non-corrosive' so that mettalic parts of the refrigerator are prevented from corrosion.

(c) Flammability: An ideal refrigerant should be 'Non-flammable and Non-explossive'.

(d) Chemical stability: An ideal refrigerant must have 'good chemical stability' ie must not decompose under operating condition.

(iv) Other properties:

(a) Odour: A good refrigerant must be 'odourless' because the food that is kept inside the refrigerator may loose its original taste.

(b) Availability: An ideal refrigerant 'should be easily available'.

(c) Cost: An ideal refrigerant must be available 'at low cost'.

(d) Action with lubricating oil: An ideal refrigerant 'must not react' when it mixes with the lubricating oil used in the compressor for lubricating the parts.

Types of Refrigerants

The most commonly used refrigerants are:

(i) Ammonia (NH_3)

* Normally employed in those refrigerator, which are operating under vapour absorption principle
* It has a high latent heat (1300 kJ/kg at $-15^\circ C$)
* It has a low specific volume ($0.509\ m^3/kg$ at $-15^\circ C$)
* It has a low boiling point temperature ($-33.3^\circ C$)
* It is environment freindly
* As it is highly toxic, flammable, irritating, corrosive and has the food desrying capacity. Hence it is unsuitable for domestic refrigerator
* It is widely used in cold storage, ice making plant

(ii) Carbon dioxide (CO_2)

* It is non-toxic and non-flammable
* It has a low boiling point temperature (−77.6°C)
* It is heavy, hence requires high operating pressure
* It has a low specific volume, so the plant size compact
* It is used in marines (ships), where space consideration is more important.

(iii) Sulphur dioxide (SO_2)

* one of the most commonly used refrigerant in the domestic / household refrigerator in olden days.
* It has a high boiling point (−10°C)
* It is colourless, suffocating and possesses irritating odour, hence rarely used or in use.

(iv) Freon −12 :

* It is non-flammable, non-explosive, non-corrosive and odourless. Hence, widely used / accepted refrigerant universally in domestic refrigerator.
* It has a boiling point of −29.8°C
* These refrigerant posing a major threat to the global environment, because it is has a role in the destruction of ozone layer

(v) Freon 22 :

* It is non-flammable, non-explosive, non-corrosive and odourless
* It has a boiling point of $-40.8^\circ c$ ($10^\circ c$ less than that of Freon 12)
* Hence, it is employed/used in domestic and large capacity plant air conditioners, food freezing, etc.
* Like Freon 12, These refrigerant posing a major threat to the global environment, because it also has a role in the destruction of ozone layer

Definition of the terms used in refrigeration.

(i) Refrigerating effect :

It is the amount of cooling produced by a refregeration system.

It is defined as the rate at which the heat is removed from the space to be cooled in a cycle.

It is also called 'capacity of refrigerator' and expressed in kW or kJ/s.

(ii) Ice making capacity :

Ice making capacity is the ability of a refrigerating system to make ice. In other words, It is the capacity of refrigerating system to remove heat from water (at room temperature) to make ice.

(iii) Ton of Refrigeration (TOR)

The unit of refrigeration or the capacity of the refrigeration system is expressed in terms of 'Ton of Refrigeration'.

It is defined as the amount of heat absorbed in order to produce one ton of ice in 24 hours from water, whose initial temperature is 0°c.

In SI units, the value of 1 TOR = 210 KJ/min or 3.517 KW.

(iv) Co-efficient of Performance (COP)

The performance of a refrigeration system is measured by a factor known as co-efficient of performance (COP). It is defined as the ratio of the amount of heat removed from a given space (desired output) to the work supplied to achieve the heat removal.

Higher the COP, the more efficient is device.

$$COP = \frac{\text{Desired out put}}{\text{work supplied}} = \frac{Q}{W}$$

where, Q = Heat removed in KJ/s or KW

W = work supplied or work done in KJ/s or KW.

(v) Relative co-efficient of Performance (Relative COP)

It is defined as the ratio of actual COP to the theoretical COP of a refrigerating system

$$\text{Relative COP} = \frac{\text{actual COP}}{\text{Theoretical COP}}$$

Types of Refrigeration system

There are two types of refrigeration system. they are

(i) vapour compression refrigerator (Domestic refrigerator)

(ii) vapour absorption refrigerator.

(i) Vapour compression refrigerator

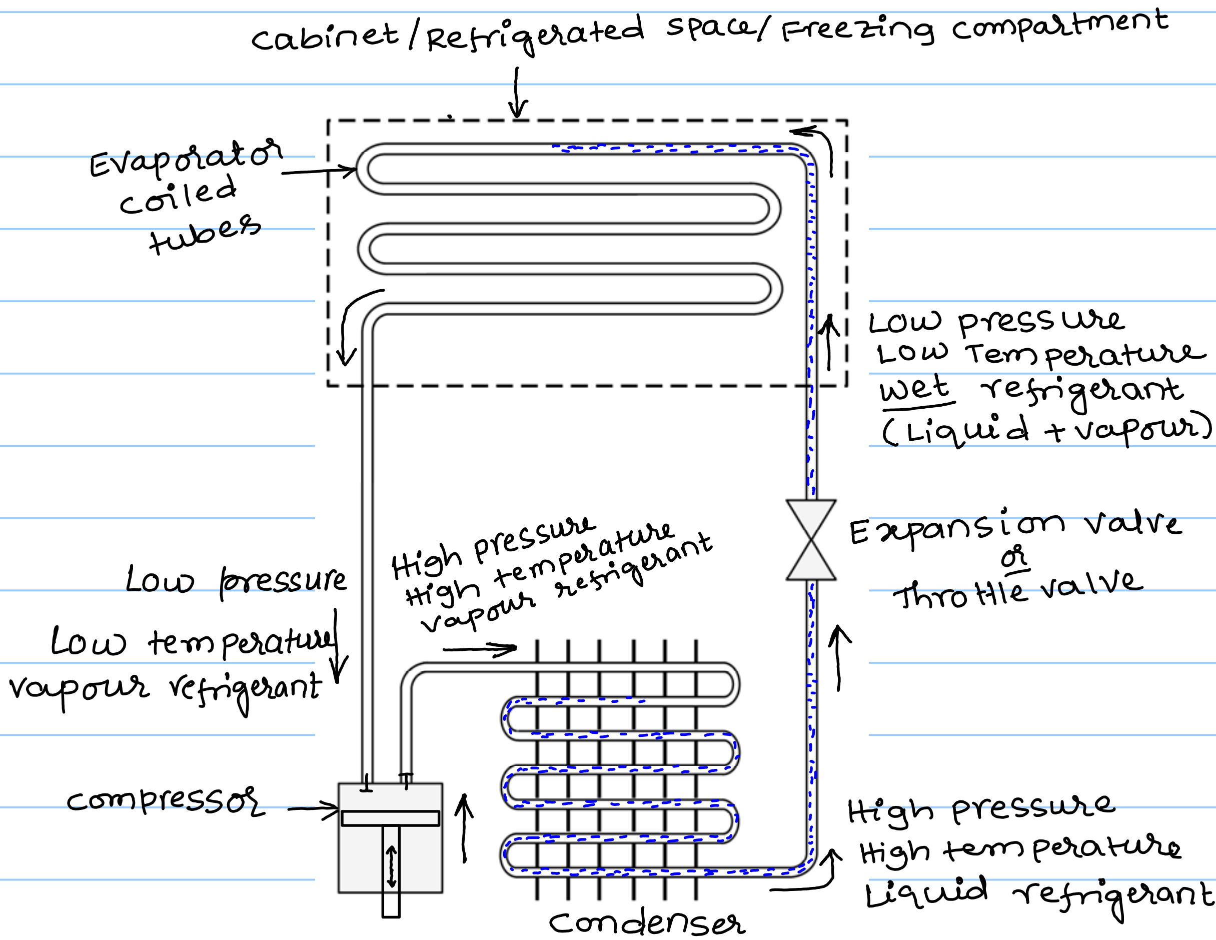


Figure shows the schematic (line diagram) of a vapour compression refrigerator system. The system consists of evaporator, compressor, condenser, and an expansion valve.

The low pressure and low temperature liquid refrigerant passing through the evaporator coils in the refrigerated space absorbs the heat and undergoes a change of phase from Liquid to vapour.

Further, the vapour which is at low pressure and low tempe-rature is drawn into the compressor, where it is compressed to high pressure and high temperature, this compressed vapour then enters the condenser.

In the condenser, the vapour refrigerant is cooled and condensed by giving its latent heat to surrounding atmosphere (mostly air). Then the high-pressure liquid refrigerant leaves the condenser. The high-pressure liquid refrigerant leaving the condenser then passes through the expansion valve (throttle valve) where it expands to a low pressure and temperature. Here the temperature of the refrigerant falls to a value that is less than that of the refrigerated space (freezing compartment) The low pressure – low temperature wet (Liquid + Vapour) refrigerant again enters the evaporator coils and cycle repeats.

One of the most commonly used refrigerant in vapour compression refrigeration system is "dichlorodifluoromethane" popularly known as 'Freon 12' or 'R12'. This refrigerant vapourises at −6.7°C in the evaporator under a pressure of 246.2 KPa and after compression to 909.2 KPa would condense at 37.8°C in the condenser.

(ii) Vapour absorption refrigerator

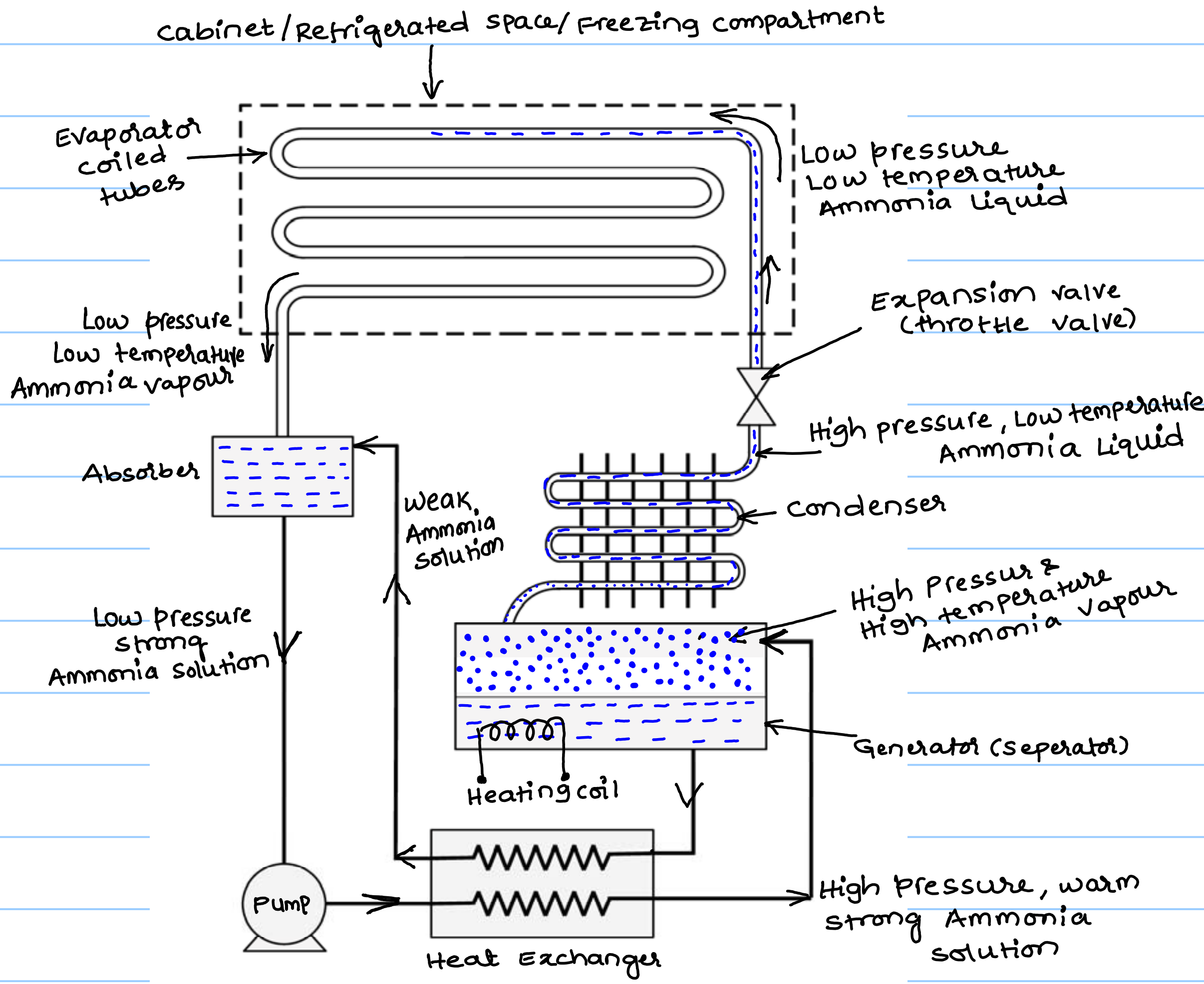


Figure shows Schematic of the vapour absorption refrigeration system.
The system consists of evaporator, absorber, pump, heat exchanger unit, generator, condenser and an expansion valve.
In this system ammonia is used as a refrigerant.
The low pressure and low temperature liquid ammonia passing through the evaporator coils in the refrigerated space absorbs the heat and undergoes a change of phase from Liquid to vapour.

Further, the ammonia vapour which is at low pressure and low temperature is then passed to the absorber.

In the absorber, the low pressure, low temperature ammonia vapour is dissolved in absorbent (water) and becomes strong ammonia solution at low pressure and is then pumped to a generator through the heat exchanger at high pressure.

The strong ammonia solution which is at high pressure becomes warm in the heat exchanger, as the hot weak ammonia solution flowing from the generator to the absorber transfers the heat.

Then, the warm strong ammonia solution is heated by using a heater in the generator. Here the vapour gets seperated from the solution and the resultant weak ammonia solution flows back to the absorber through heat exchanger.

High pressure, high temperature ammonia vapour is condensed to low temperature in a condenser by giving its latent heat to the surrounding (mostly air).

The high pressure, low temperature liquid ammonia then passes through the expansion valve, where it expands to a low pressure and temperature.

The low pressure, low temperature liquid ammonia again enter the evaporator and the cycle repeats.

** for your information

[Absorbent is a substance which absorb the large volumes of the vapour of a refrigerant even when it is cold and reduce it to the liquid and subsequently gives off its vapours when heated.

In most of the vapour absorption system, ammonia is used as a refrigerant and the cold water as 'Absorbent', because, ammonia readily dissolves in water]

comparision between vapour compression and vapour absorption refrigeration system.

Sl. No	Vapour compression refrigeration system	Vapour absorption refrigeration system
1	Refrigerant vapour is compressed	Refrigerant vapour is absorbed and heated
2	Works on mechanical energy (compressor)	Works on heat energy
3	Due to the presence of moving parts such compressor, the maintenance cost is high	As there are no moving parts, maintenance cost is less
4	The operation is noisy due to the presence of compressor.	The operation is quite as there are no moving parts in the entire system.
5	The design capacity of these system is limited, since the single compressor unit can produce upto1000 tons of refrigeration.	The design capacity of these system is well above 1000 tons.
6	Chances of refrigerant leakage is more due to high pressure working condition and wear of the reciprocating parts in the compressor.	There is no chance of refrigerant leakage in this type of system.
7	The COP is high and it decrease with increase in load	The COP is lower and it remains same at all loads
8	Freon is used as a refrigerant	Ammonia is used as a refrigerant
9	Most of the properties of the refrigerant is human friendly, hence widely used in domestic application.	Few properties of the refrigerant is not human friendly, hence not suitable for domestic application
10	Refrigerant vapours have to be compressed to vary high pressure, hence it requires more mechanical energy	The pump is only device and used for circulating the refrigerant, hence it requires less mechanical energy

Application of Refrigerator

(i) Used for food processing, preservation and distribution

(ii) Used in chemical and process industries

(iii) For storage of blood plasma, tissues, etc.

(iv) For manufacture and storage of drugs.

(v) For storage of vaccines, medicines in remote and rural areas.

(vi) For scientific use like storing of experimental samples in it.

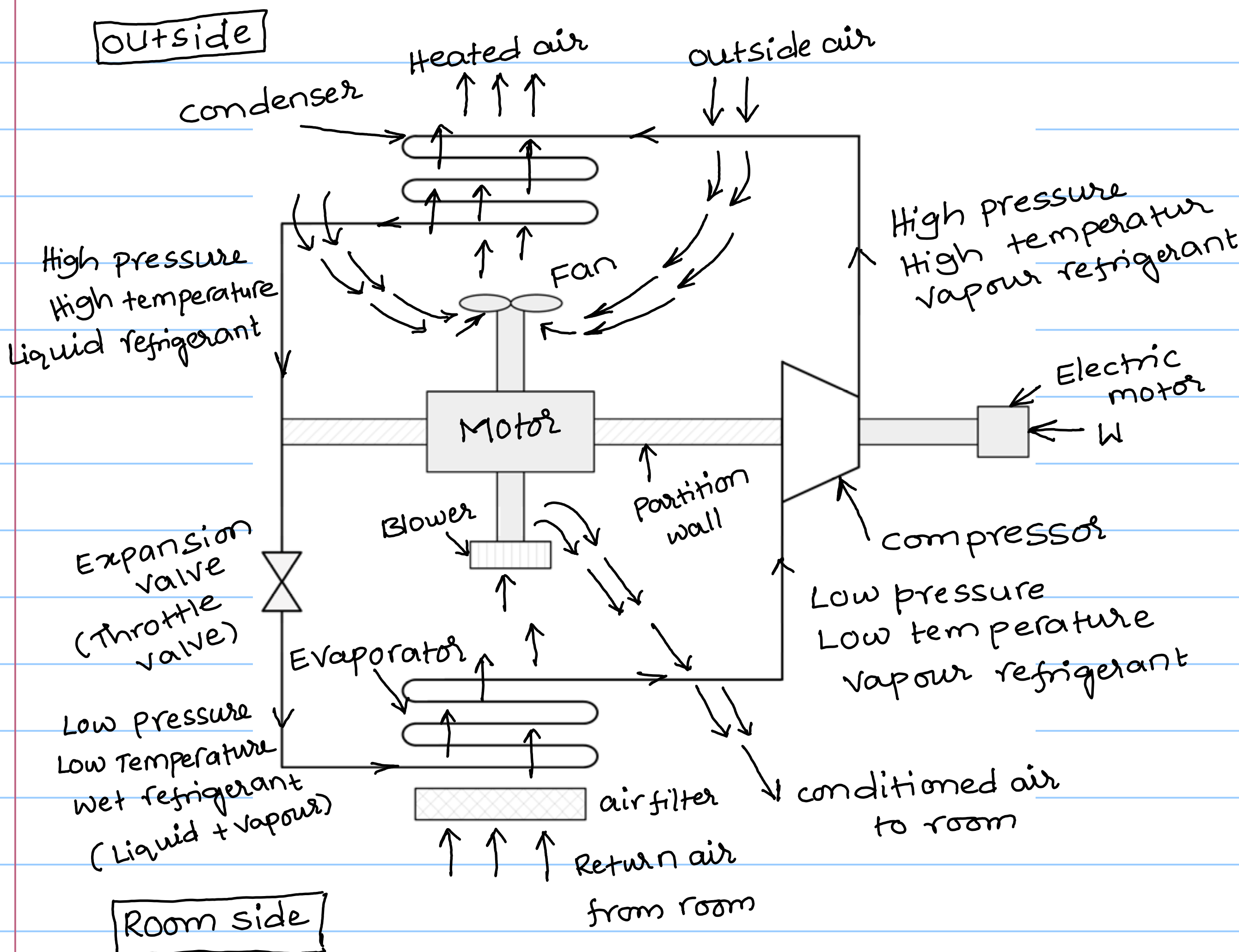
Air conditioning

Air conditioning is defined as the process of simultaneous control of temperature, humidity, cleanliness and air motion of the confined space.

Air conditioner (or Room air conditioner)

Air conditioner is a system or a device used to cool down the temperature of the confined space by removing the existing heat and moisture.

Working principle of air conditioning system



Construction:

Figure shows the line diagram of a window type room air conditioner. The unit consists of vapour compression refrigeration system (i.e evaporator, compressor, condenser, and an expansion valve), an air filter and a double shaft motor that drives a fan at one end and blower at the other end. The room side and the outdoor side of the unit are seperated by an insulated partition wall within the casing.

Working:

The blower sucks the warm air from the room through the air filter and the evaporator, The low pressure and low temperature liquid refrigerant passing through the evaporator coils absorbs the heat from the warm air and undergoes a change of phase from Liquid to vapour. Then the cooled air is sent back into the room by the blower which is driven by motor. This air mixes with the air present in the room, thereby bringing down the temperature and humidity level so as to maintain comfortable conditions.

Further, the vapour which is at low pressure and low tempe-rature is drawn into the compressor, where it is compressed to high pressure and high temperature, this compressed vapour then enters the condenser.

In the condenser, the vapour refrigerant is cooled and condensed by giving its latent heat to surrounding atmosphere (mostly air). Then the high-pressure Liquid refrigerant leaves the condenser. The high-pressure Liquid refrigerant leaving the condenser then passes through the expansion valve (throttle valve) where it expands to a low pressure and temperature. Here the temperature of the refrigerant falls to a value that is less than that of the set temperature (room temperature). The low pressure-low temperature wet (Liquid+Vapour) refrigerant again enters the evaporator coils where it absorbs the heat from the room and cycle repeats.

Applications of air conditioning

Air conditioning provides comfort for human beings and also a controlled environment for industrial activities.
Hence, application of air conditioning can be broadly devided into "comfort applications and process applications"

(i) comfort applications

(a) In residential buildings — single house and apartments
(b) Institutional buildings — offices, Hospitals, etc
(c) commercial buildings — shopping centers, mall etc
(d) Transportation — Aircraft, automobiles, bus, etc.,

(ii) process application

(a) Hospitals – in operation theatres
(b) clean rooms – MEMS & NEMS lab, pharamaceuticals etc.
(c) Textile factories
(d) Data centres
(e) Food cooking and processing areas.

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