Basics of air conditioning

Psychrometric chart and

Refrigeration cycle

2024

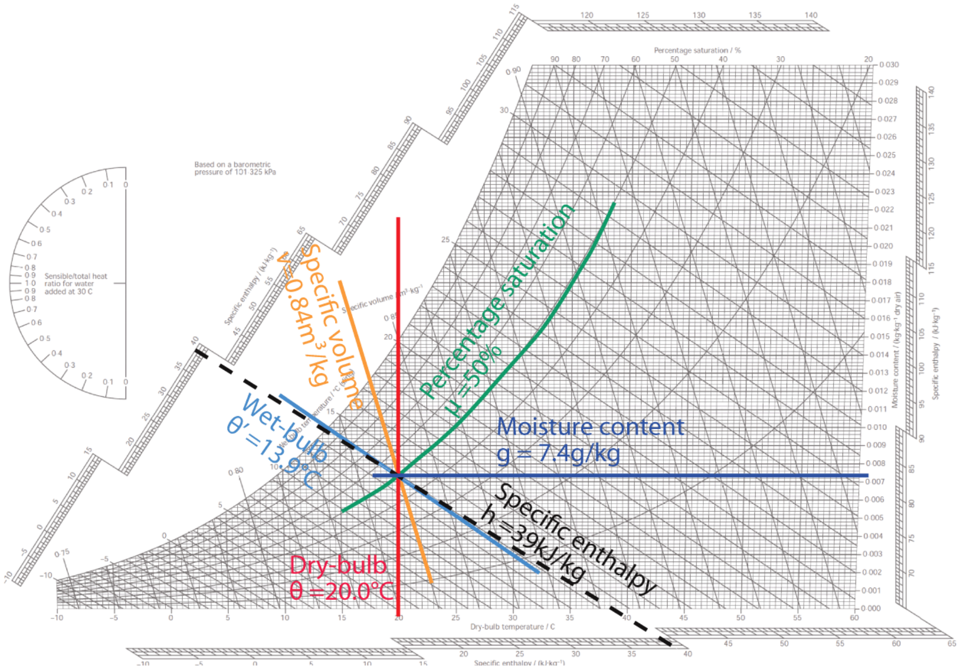
Prepared by Mechanical Engineer: **Dzhwar Ali Qadir**

Air conditioning:

Air conditioning is the process of removing heat from an enclosed space to achieve more comfortable interior environment and in some cases also controlling the humidity of internal air. Air conditioning can be achieved using a mechanical air conditioner or some other methods, including passive cooling or ventilate cooling. Air conditioning is a member of a family of systems and techniques that provide heating, ventilation, and air conditioning (HVAC). Heat pumps are similar in many ways to air conditioners, but use a reversing valve to allow them to heat and also cool an enclosed space.(1)

Air conditioners have three main components: a compressor, a condenser coil, and an evaporator coil. They also have a special chemical called refrigerant that loops through the system absorbing and removing heat. Working together these three components convert the refrigerant from gas to liquid and back to gas quickly.(2)

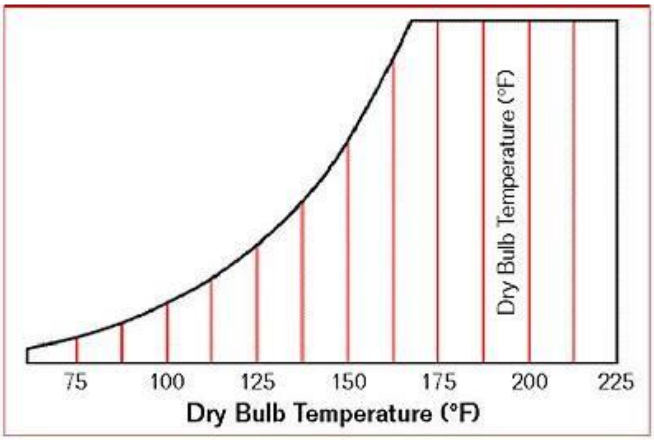
Psychrometric chart:



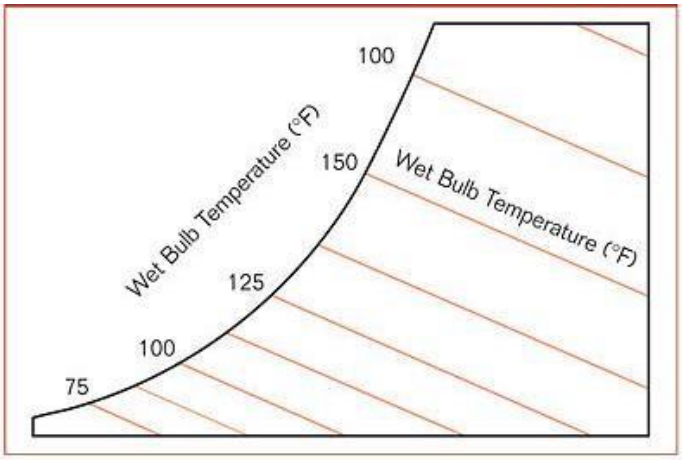
Psychrometric charts are complex graphs that can be used to determine the physical and thermodynamic properties of gas-vapour mixtures at a constant pressure. They are often used to determine the properties of moist air. This can be useful in the design of heating, ventilation and air-conditioning systems for buildings, and psychrometric charts often include a zone in the middle that represents the range of conditions that people find comfortable under different circumstances (such as summer and winter).(3)

Typically, the air properties represented on psychrometric charts are:

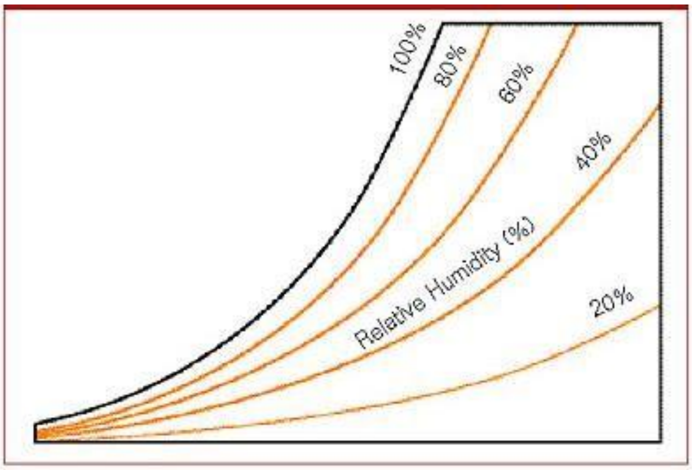
- **Dry-bulb temperature**: A measure of air temperature recorded by a thermometer exposed to the air but shielded from radiation and moisture.



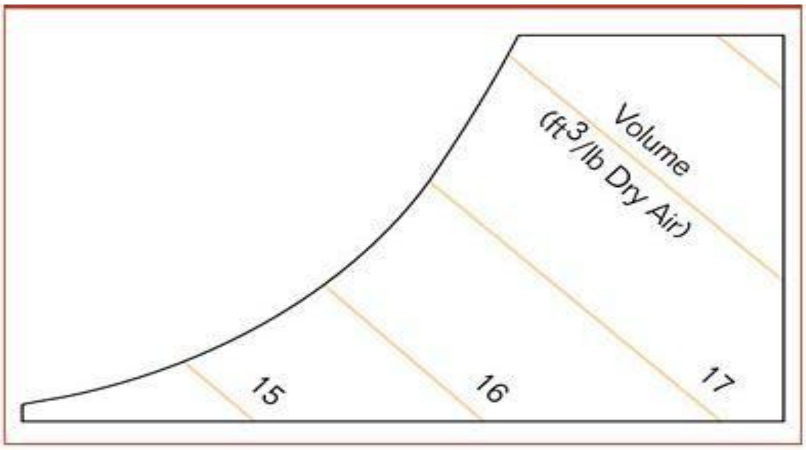
- **Wet-bulb temperature**: The temperature recorder by a thermometer that has its bulb wrapped in cloth and moistened with filtered (condensed) water. The rate of evaporation from the wet bulb, and so the temperature it records varies depending on the humidity of the air it is exposed to.



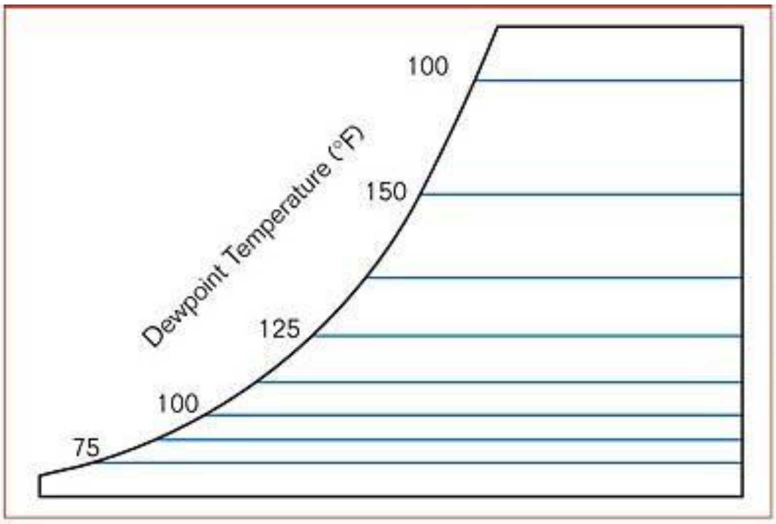
- **Relative humidity**: The ratio of the actual vapor pressure relative to the vapor pressure of saturated air at the same temperature, expressed as a percentage.



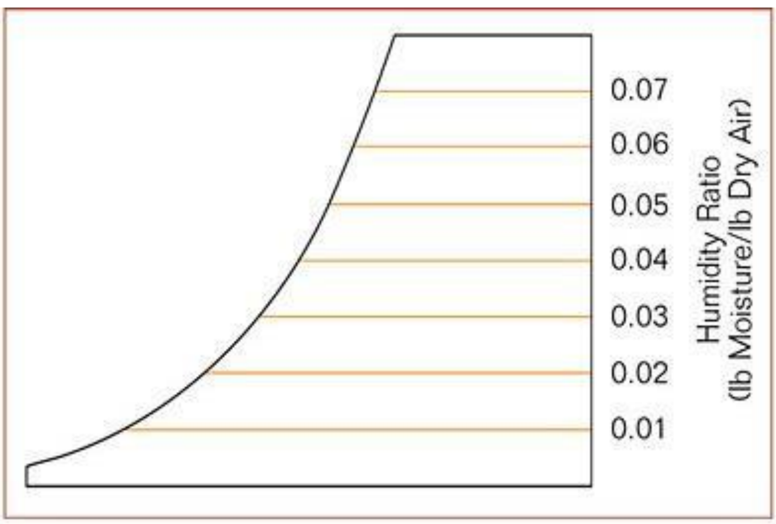
- **Specific volume**: The volume of a unit weight of dry air.



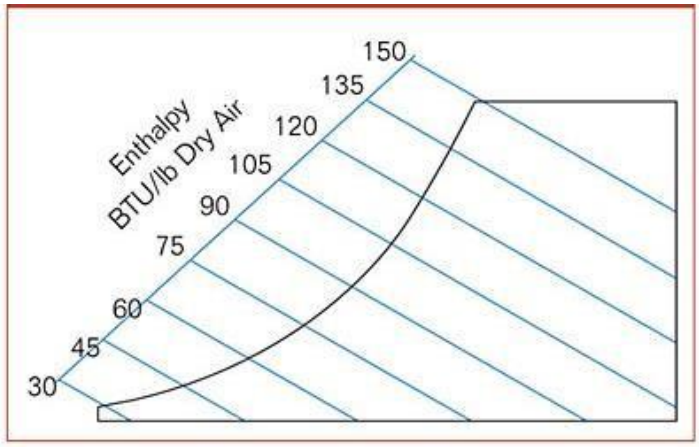
- **Dew point temperature**: The highest temperature at which water vapour will condense.



- **Humidity ratio**: The dry-basis moisture content of air expressed as the weight of water vapour per unit weight of dry air.



- **Enthalpy**: The energy content of air.



Atmospheric pressure varies with altitude and so a number of psychrometric charts are available for different atmospheric pressures, however, for altitudes of less than 600m the sea-level psychrometric chart is often considered adequate.(4)

Psychrometric process:

Sensible heating:

The term is used in contrast to a latent heat, which is the amount of heat exchanged that is hidden, meaning it occurs without change of temperature. For example, during a phase change such as the melting of ice, the temperature of the system containing the ice and the liquid is constant until all ice has melted. The terms latent and sensible are correlative .The sensible heat of a thermodynamic process may be calculated as the product of the body's mass (m) with its specific heat capacity (c) and the change in temperature (ΔT):

Calculation of heating load

$Q = ma\ (h2 - h1)$

$ma = \rho a * Va\ (Kg/s)$

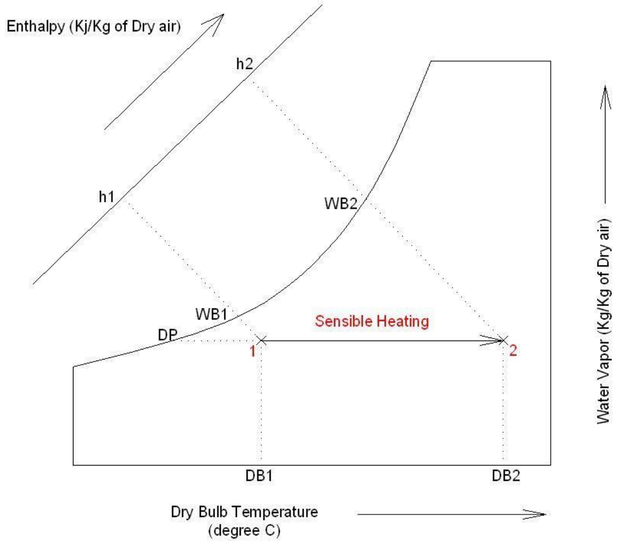
Va Volume flow rate of air m / s va.A

Va air velocity m/s (using pitot tube to measure)

$h1$ enthalpy of entering air kj/kg (from psychrometeric chart)

$h2$ enthalpy of exit air kj/kg (from psychrometeric chart)

To locate h1 and h2 dry bulb and wet bulb temperature should be measured for both entering and leaving air.



Sensible heat and latent heat are not special forms of energy. Rather, they describe exchanges of heat under conditions specified in terms of their effect on a material or a thermodynamic system, both sensible and latent heats are observed in many processes while transporting energy in nature. Latent heat is associated with changes of state, measured at constant temperature, especially the phase changes of atmospheric water vapor, mostly vaporization and condensation, whereas sensible heat directly affects the temperature of the atmosphere.

Sensible Cooling:

Sensible cooling process is opposite to sensible heating process. In sensible cooling process the temperature of air is decreased without changing its moisture content. During this process the sensible cooling, DB and WB temperature of the air decreases while latent of air, and the DP point temperature of the air remains constant. Sensible cooling of the air is important when the air conditioner by cooling coil. In the cooling coil the air is cooling by passing it over the evaporator coil or the cooling coil that carry the low temperature refrigerant. In some cases the cooling of air is also done to suit different industrial and comfort air-conditioning applications where large air conditioning systems are used.

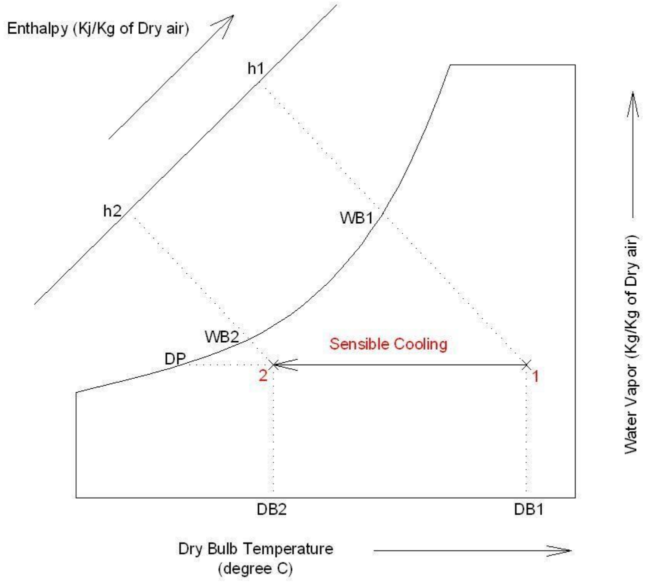
In general the sensible cooling process is carried out by passing the air over the cooling coil. This coil may be cooled by passing the refrigerant in evaporator pipes. The refrigerant wide used in air conditioning and refrigeration system.

Like the sensible heating, the sensible cooling process is also represented by a straight horizontal line on the psychrometric chart. The line starts from the initial DB temperature of air and ends at the final temperature extending towards the left (see the figure). The sensible cooling line is also constant DP temperature line.(5)

The heat transfer rate during this process is given by:

$QT = ma.(h1 - h2)$

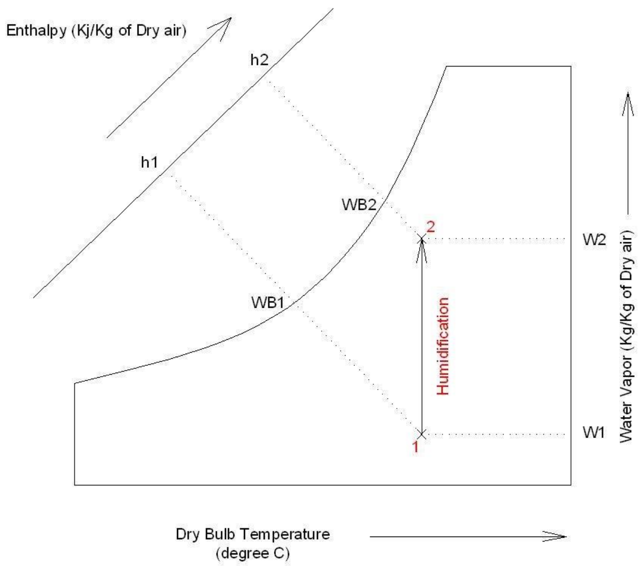
$QT = ma.\,(DBT1 - DBT2)$



Humidification:

Absolute humidity is the mass of water vapour in a volume of air divided by the mass of dry air. Relative humidity (RH) is a measure of the water vapour density of air compared to the water vapour density for saturated air at the same temperature and pressure (that is, the maximum amount of moisture that air can 'hold' at that temperature and pressure).

Relative humidity is expressed as a percentage. Typically, a relative humidity of 40% to 60% is appropriate in many buildings.



Dehumidification:

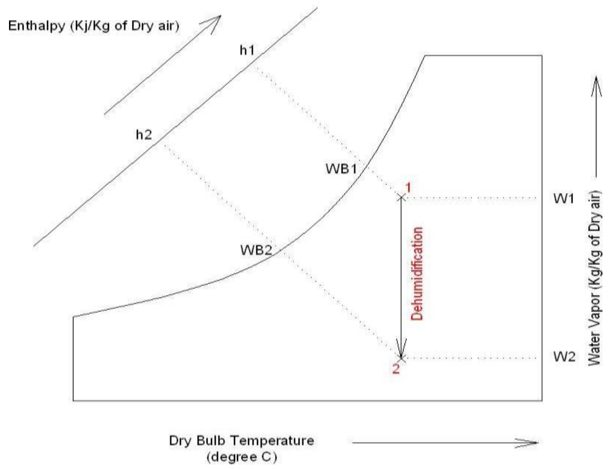
This process causes the relative humidity level and the dry bulb temperature of the air to increase. The wet bulb temperature and dew point temperature increase as well.

Humidity can be controlled by limiting sources of moisture, increasing ventilation or removing it through a process referred to as dehumidification. Dehumidification uses a device known as a dehumidifier to remove moisture from the warm, humid air before the air comes into contact with a cold surface, condenses and deposits the moisture onto the cold surface.

The dehumidification process is based on the refrigeration principle that gas under pressure heats up and when the pressure drops, so does the temperature of the gas. In a dehumidifier, a compressor delivers pressurized gas to the 'hot' coils, in turn, leading to the larger 'cold' coils, which allow the gas to expand. The cooled gas returns to the compressor for recycling.

This is achieved by drawing air from the room into the unit and passing it over cold coils upon which water vapour condenses and drips into a reservoir. The cold, but now dry air is drawn by a fan over heated coils before being returned to the room as additional convicted heat.

A device called a humidistat switches off the compressor when the humidity (moisture content) of the surrounding air has dropped to the required level.

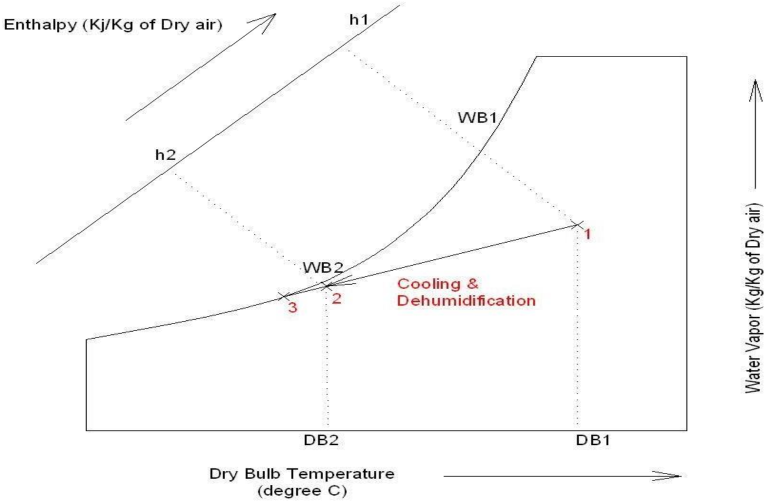


COOLING AND DEHUMIDIFICATION:

The process of humidification can be incorporated into air conditioning equipment. Moisture is added to the air by releasing a spray or stream of water that is kept at a temperature that is lower than the dry bulb temperature of the surrounding air. When that air comes into contact with the cooler stream of moisture, small droplets of water in the stream evaporate as they adjust to the warmer temperature of the surrounding air.

The water from the evaporated stream is absorbed along with its moisture content into the air to increase humidity levels. The cooler temperature from the evaporated stream can also be incorporated into the air, which decreases the temperature of the air.

Cooling and humidification techniques do not work in hot, humid conditions. They can only be used in places with hot, dry climates.



-By-pass factor of heating and cooling coils:

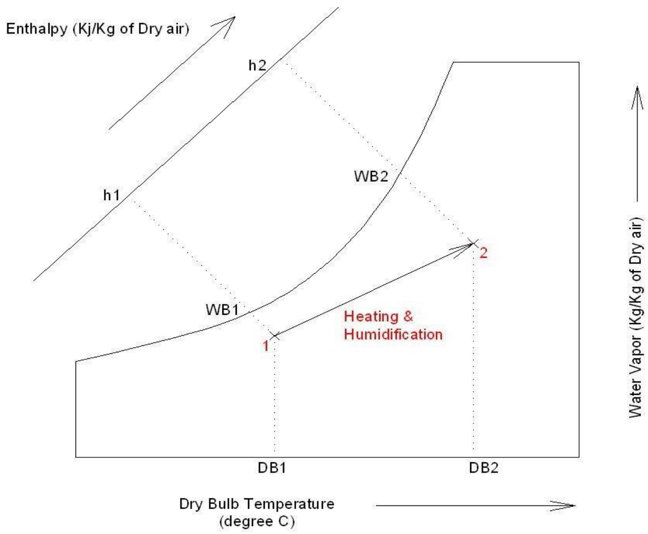
Bypass Factor:

In most cooling applications, the air leaving the cooling coil is not entirely saturated since some air does not come in contact with the cooling coil. The fraction of air that misses the coil is called the bypass factor, BF. The bypass factor can be determined from the temperature of water supplied to the cooling coil and from the states of incoming and exiting air. The inability of a coil to heat or cool the air to its temperature, it's due to the coil inefficiency and some amount of air just bypassing the coil without affecting by it.

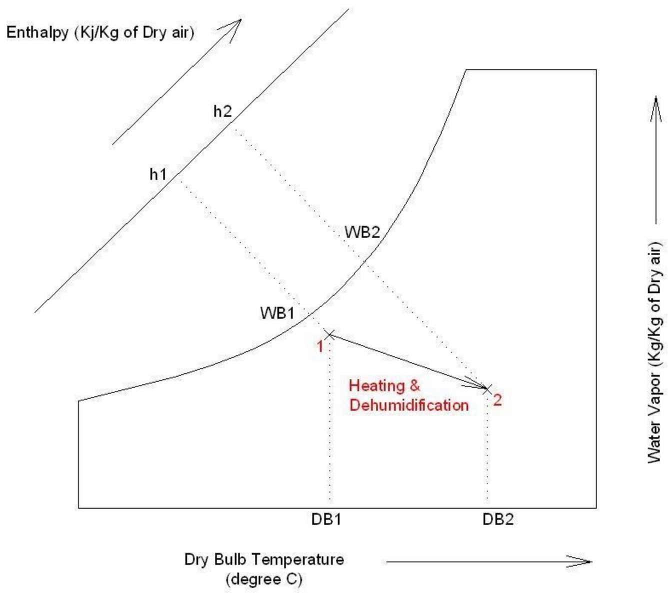
BF = (t2-t3) / (t1-t3)

HEATING AND HUMIDIFICATION:

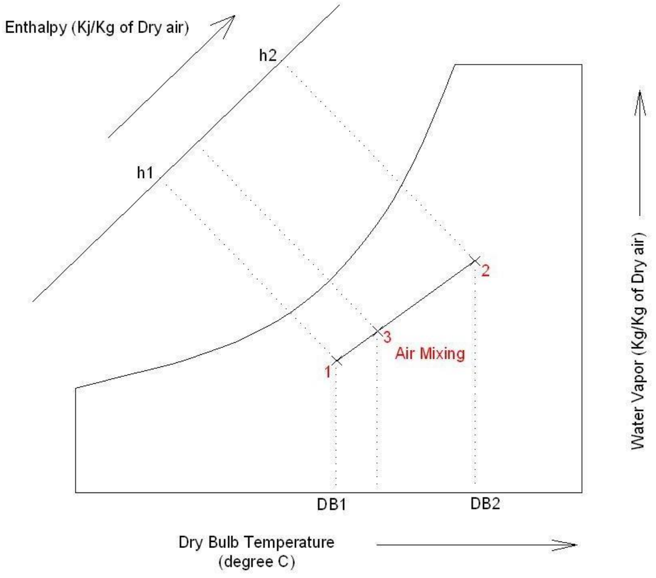
The process of humidification can be incorporated into heating systems and then activated when this equipment is being used to make the air warmer. This form of humidification increases the dry bulb temperature of the air as well as the humidity. Moisture is added to the air by releasing steam kept at a temperature that is higher than the dry bulb temperature of the surrounding air. When the surrounding air mixes with the warm steam, the moisture droplets in the steam evaporate as they adjust to the temperature of the surrounding air.



Heating and dehumidification: The act of removing moisture, water vapour, from the air while increasing its dry bulb (DB) temperature is referred to as the heating and dehumidification process.



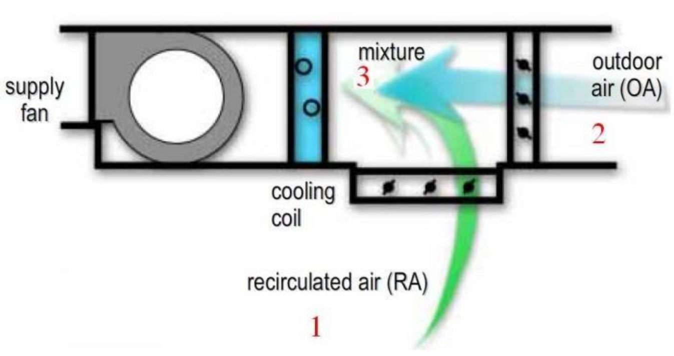
Air mixing:



Mixing of different air streams is quite common in AHU systems. Consider stream-1

And stream-2 of moist air are mixing in a mixing chamber and then flowing out of the

Mixing chamber as shown below:



Mass balance of dry air flow for the mixing chamber gives:

m1 + m2 = mm

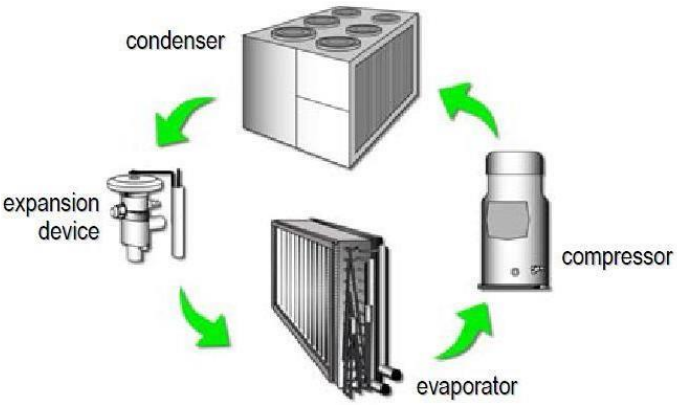
Where

m1 = mass flow rate of dry air for stream-1, kg dry air / s

m2 = mass flow rate of dry air for stream-2, kg dry air / s

mm = mass flow rate of dry air for mixed stream, kg dry air / s

Refrigeration Cycle



A typical refrigeration system consists of several basic components such as compressors, condensers, expansion devices and evaporators in addition to several accessories such as filters. It is essential to study the design and performance characteristics of individual components.

1-Compressor: Compression is the first step in the refrigeration cycle, and a compressor is the piece of equipment that increases the pressure of the working gas. Refrigerant enters the compressor as low-pressure, low-temperature gas, and leaves the compressor as a high-pressure, high-temperature gas.

2-Condensor:

The condenser, or condenser coil, is one of two types of heat exchangers used in a basic refrigeration loop. This component is supplied with high-temperature high-pressure, vaporized refrigerant coming off the compressor. The condenser removes heat from the hot refrigerant vapor gas vapor until it condenses into a saturated liquid state. After condensing, the refrigerant is a high-pressure, low-temperature liquid, at which point it's routed to the loop's expansion device.

3-Expansion valve:

These components come in a few different designs. Popular configurations include fixed orifices, thermostatic expansion valves (TXV) or thermal expansion valves and the more advanced electronic expansion valves (EEVs). But regardless of configuration, the job of a system's expansion device is the same - create a drop in pressure after the refrigerant leaves the condenser. This pressure drop will cause some of that refrigerant to quickly boil, creating a two-phase mixture.

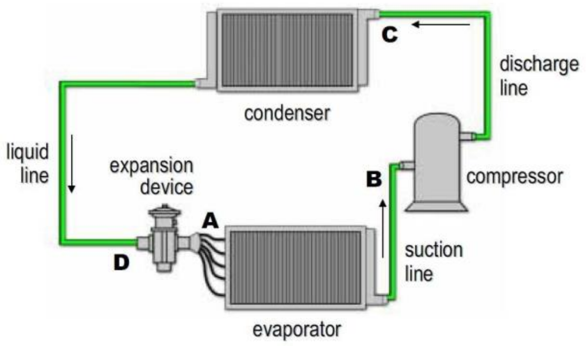
This rapid phase change is called *flashing*, and it helps the next piece of equipment in the circuit, *the evaporator*, to perform its intended function.

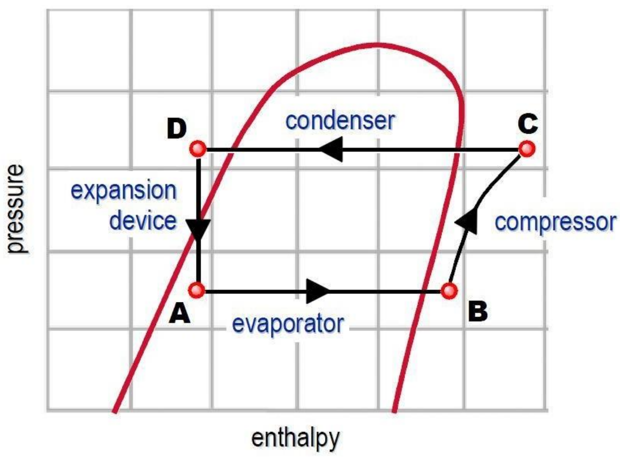
4-Evaporator:

The evaporator is the second heat exchanger in a standard refrigeration circuit, and like the condenser, it's named for its basic function. It serves as the end task of a refrigeration cycle, given that it does what we expect air conditioning to do – absorb heat.

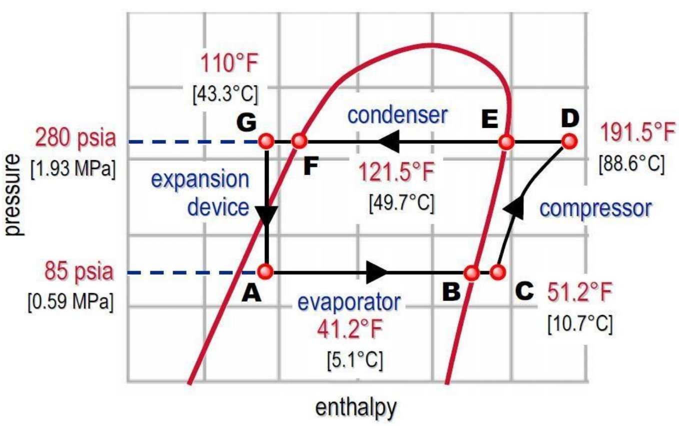
This happens when refrigerant enters the evaporator as a low temperature liquid at low pressure, and a fan forces air across the evaporator's fins, cooling the air by absorbing the heat from the space in question into the refrigerant.

After doing so, the refrigerant is sent back to the compressor, where the process restarts. And that, in a nutshell, is how a refrigeration loop works.





Refrigerant cycle pressure-enthalpy chart



Refrigeration cycle components

The most important & often the costliest component (typically 30 to 40 percent of total cost) of any vapor compression refrigeration system. The functions of a compressor is to continuously draw the refrigerant vapor from the evaporator so that a low pressure & low temperature can be maintained in the evaporator at which the refrigerant can boil extracting heat from the refrigerated space.(8)

The method of compression may be reciprocating, centrifugal, or rotary. The location of the power source also classifies compressors. Independent compressors are belt driven. Semi hermetic compressors have direct drive, with the motor and compressor in separate housings. The hermetic compressor has direct drive, with the motor and compressor in the same housing. Compressors can be classified according to its principles of working: (7)

A-**Positive Displacement Compressors**:

Positive displacement compressors draw in and capture a volume of air n a chamber. They then reduce the volume of the chamber to compress the air. Reciprocating piston compressors, rotary screw compressors, rotary vane compressors, and scroll compressors are all positive displacement compressors.

B-**Dynamic Displacement Compressors**:

Rather than physically reducing the volume of a captured pocket of air, dynamic displacement compressors instead speed up the air to high velocity, and then restrict the air flow so that the reduction in velocity causes pressure to increase. They are oil-free by nature, and some are oil-less. Dynamic compressors include axial and centrifugal types.

Types of compressors:

Compression can be achieved through a number of different mechanical processes, and because of that, several compressor designs are used in HVAC and refrigeration today. Other examples exist, but some popular choices are:

1. Reciprocating compressors

2. Scroll compressors

3. Rotary compressors

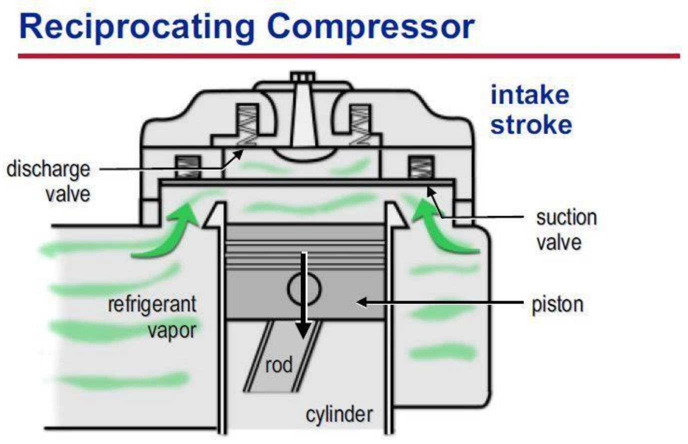
1-**Reciprocating compressor**:

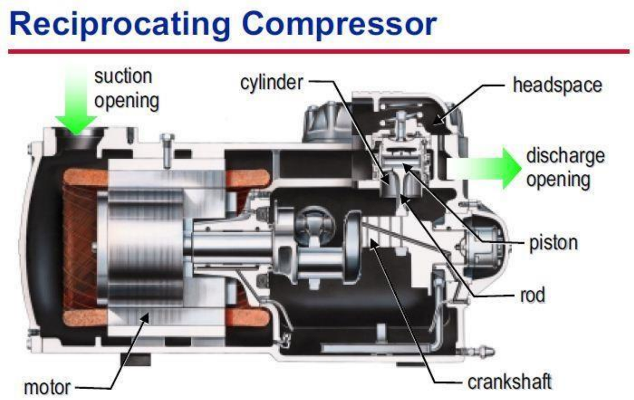
Reciprocating units have a piston in a cylinder. The piston acts as a pump to increase the pressure of the refrigerant from the low side to the high side of the system. A reciprocating compressor can have twelve or more cylinders.

The most commonly used reciprocating compressor is made for refrigerants R-22 and R-134a. These are for heating, ventilating and air conditioning, and process cooling. The most practical refrigerants used today are R-134a and R-22. However, R-134a, is gaining acceptance, in view of the CFC regulations world-wide. As a matter of fact, some countries only accept R-134a today.

Other environmentally acceptable refrigerants are R-404A and R-507. They are for low and medium-temperature applications. R-470C is for medium temperatures and air-conditioning applications. Recently, R-410A has gained acceptance as an environmentally acceptable substitute for R-22, but only for residential and small equipment. R-410A is not a drop-in refrigerant for R-22.

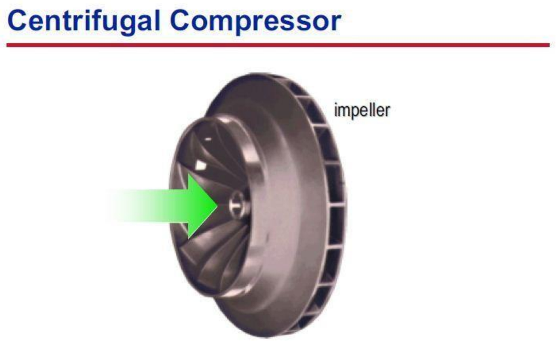
There are three types of reciprocating compressors: open drive, hermetic, and semi hermetic.



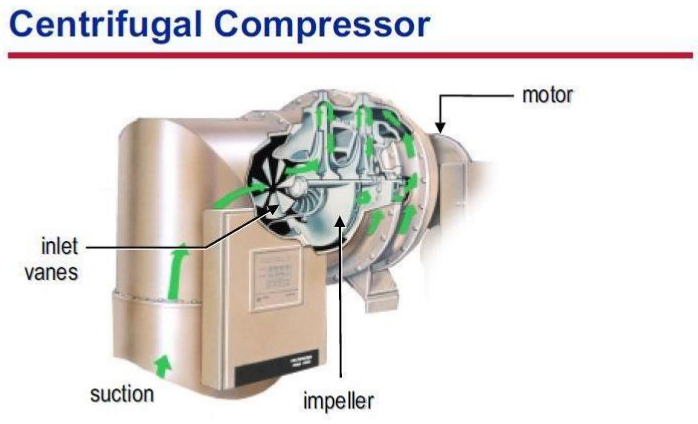


2-Centrifugal Compressor:

A centrifugal compressor is basically a fan or blower that builds refrigerant pressure by forcing the gas through a funnel-shaped opening at high speed. When the vanes restrict the flow of refrigerant, the turbine cannot do its full amount of work on the refrigerant. Thus, its capacity is limited. Most centrifugal machines can be limited to 10 to 25 percent of full capacity by this method. Some will



operate at almost zero capacity. However, another, though less common, method is to control the speed of the motor that is turning the turbine.



Scroll compressor: The scroll compressor is being used by the industry in response to the need to increase the efficiency of air-conditioning equipment.

Figures show how spiral-shaped members fit together. The two members fit together forming crescent-shaped gas pockets. One member remains stationary, while the second member is allowed to orbit relative to the stationary member.

This movement draws gas into the outer pocket created by the two members, sealing off the open passage. As the spiral motion continues, the gas is forced toward the center of the scroll form. As the pocket continuously becomes smaller in volume it creates increasingly higher gas pressures. At the center of the pocket, the high-pressure gas is discharged from the port of the fixed scroll member. During the cycle, several pockets of gas are compressed simultaneously. This provides a smooth, nearly continuous compression cycle.

This results in a 10 to 15 percent more efficient operation than with the piston compressors. A smooth,

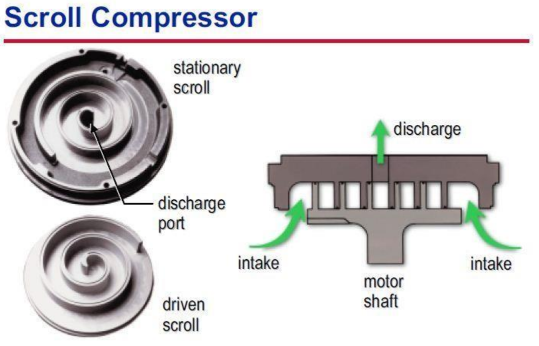
Continuous compression process means very low flow losses. No valves are required. This eliminates all valve losses. Suction and discharge locations are separate. This substantially reduces heat transfer between suction and discharge gas. There is no re expansion volume. This increases the compressor's heat pump capacity in low ambient operation. Increased heat pump capacity in low ambient temperatures reduces the need for supplemental heat when temperatures drop.

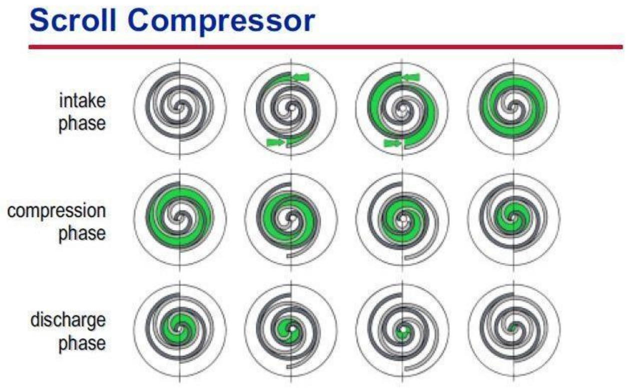
During summer, this means less cycling at moderate temperatures. It also allows better dehumidification to keep the comfort level high. When temperatures rise, the scroll compressor provides increased capacity for more cooling.

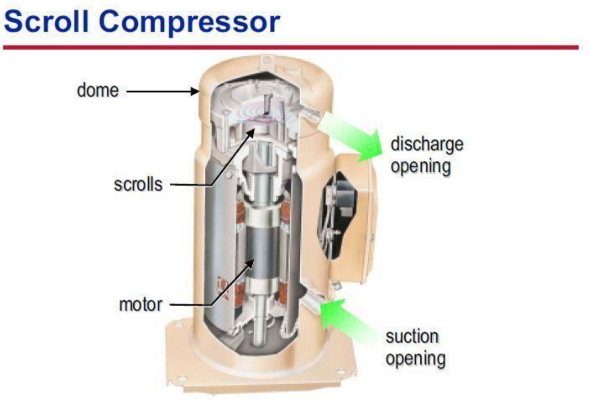
During the winter, the scroll compressor heat pumps deliver more warm air to the conditioned space than conventional models.

Strengths of scroll compressors:

- Efficient gas compression
- Low sound and vibration levels
- Fewer parts, smaller size, lighter weight, more per pallet
- No internal suspension system







Helical-rotary (screw) compressor:

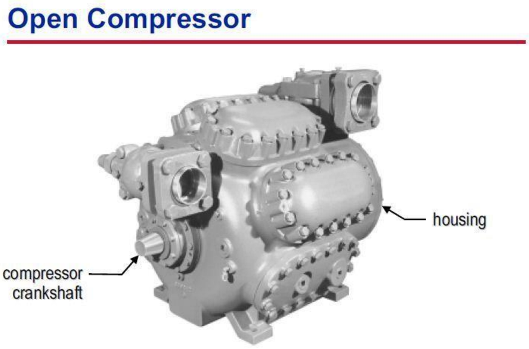
The rotary screw compressor is a true workhorse that makes many amazing feats of modern technology possible. The rotary screw compressor utilizes a positive displacement mechanism of intermeshing rotors, referred to as a rotary screw, air-end. These compressors are used commonly as replacements for automotive, industrial and commercial applications that require high pressure air in large volumes. Although less frequently, these compressors are also referred to as twins screw compressors, The process of compression in a rotary screw compressor is different than the process in a reciprocating piston compressor. The rotary screw air end produces compression in a continual sweeping motion. Unlike with the piston compressor, there is very little surge of flow or pulsation with these compressors. Rotary screw compressors also utilize rotors, which consist of two intermeshing helical shaped screws, to compress the air. The rotors in these compressors are precision machined to exceptionally tight tolerances to where the rotors nearly touch when meshing together and are within typically only a few thousandths of an inch in separation.

Screw compressors operate more or less like pumps, and have continuous flow refrigerant compared to reciprocals. Reciprocal have pulsations.Thise results in smooth compression with little vibration. Reciprocals, on the other hand, make pulsating sounds and vibrate. They can be very noisy

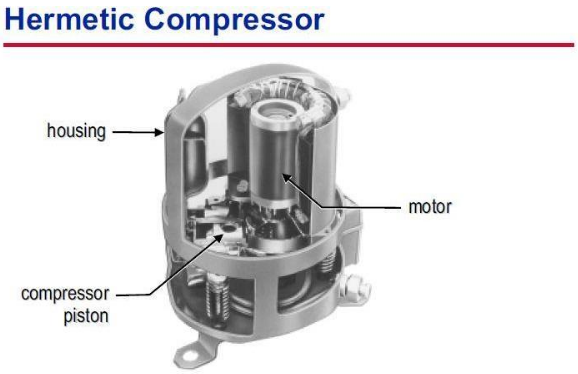
Screw compressors have almost linear capacity control mechanisms. That results in excellent part load performance. Due to its smooth operation, low vibration screw compressors tend to have longer life than reciprocals.

The compressor's ability for maintenance could be classified as below types:

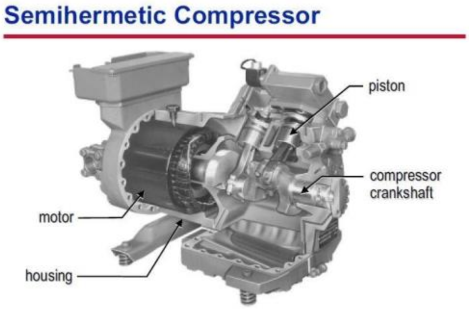
1-Open compressor



2-Hermetic compressor



3-Semihermetic compressor



Today, the vast majority of commercial compressors are reciprocal or screw-type compressors. Only the very largest commercial compressors use centrifugal force as their main operating principle. But there is another dimension to look at when you consider which kind of compressor you want to use.
You could consider this other dimension the architecture underlying your compressor technology.

The three different compressor architectures are:

- Hermetic
- Semi-Hermetic
- Open

Reciprocating compressors, screw compressors, and all other types can be found that conform to these three designs. Of course, certain technologies and applications are associated with certain approaches. Whichever architecture you choose, it will have a significant impact on how your system operates.
Likewise, it is very difficult to "start over" once you have chosen and deployed a compressor. With that in mind, it is important to make the right choice the first time. When it comes to refrigeration or HVAC systems at a large scale, that "right choice" is always an informed choice.

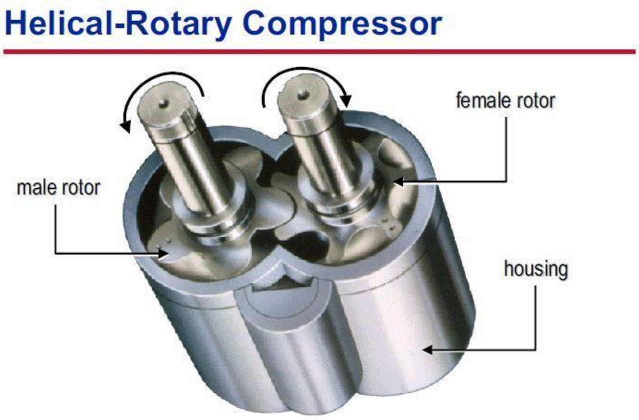
Hermetic compressor describes a style of compressor you are less likely to see in large industrial or commercial applications, but it is still used on occasion. A hermetic compressor is completely sealed away from the environment, with the casing welded shut. It cannot be accessed by any means.
On its own, "hermetic" usually means an airtight seal. In the context of a compressor, it refers to the way the compressor is completely separated from the external operating environment. You don't need to worry about spillage or infiltration of debris, which cuts down on flooding and slugging. However, there are serious drawbacks to a hermetic compressor that limit the way it is used, especially in demanding environments. Hermetic compressors are usually restricted to smaller systems. They are much more common in consumer goods, such as home refrigerators.

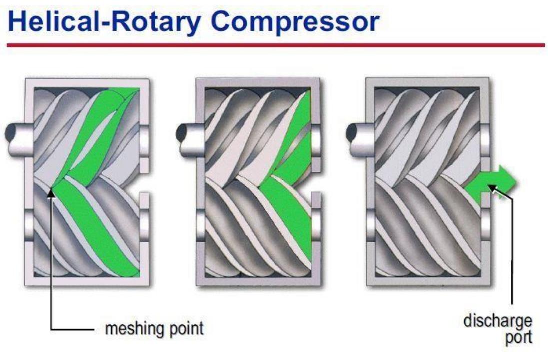
One of the most common places to see a hermetic compressor at a business is small refrigerated displays for grocery stores. These can be "chained together" to operate effectively even when one compressor underperforms or fails. The small, light hermetic compressor lends itself to this use. For situations where you need to maximize performance and efficiency, the hermetic compressor often gets passed over. In the event of a mechanical issue, it cannot be opened for service. A problem might be simple and easy to fix, but your only option is to replace the compressor completely.

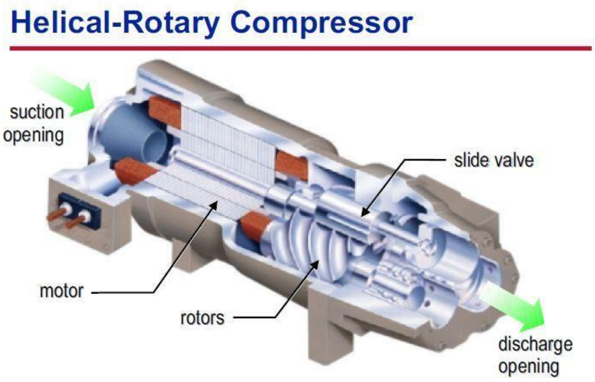
As with a hermetic compressor, a semi-hermetic compressor has both the compressor and the motor fully protected from the environment within a sealed shell. Unlike the hermetic compressor, though, semi-hermetic models are designed so they can be opened for diagnosis and periodic maintenance.

Maintenance truly is the key to extending the service life of a compressor and thus saving thousands of dollars in the long run. While no compressor will last forever, modern compressors can perform at full efficiency deep into their operational lifespan as long as they are getting the right maintenance.
With that in mind, the semi-hermetic compressor has displaced most other options as a common and reliable go-to for most approaches. This is even true when it comes to smaller reciprocating units that would have been designed as hermetic compressors in the past.

In an open compressor, the compressor itself and the motor are not protected from the elements in any way. While it is possible to service this kind of compressor, the environment must be carefully controlled or the compressor will fail due to dirt, debris, chemicals, and other contaminants.



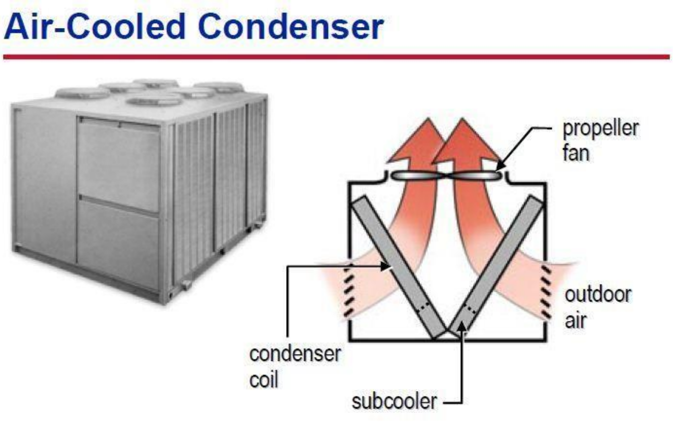




Condensers:

We have three types of condensers:

1-**Air cooled condensers**: using air as a medium of condensing, and we have two types:



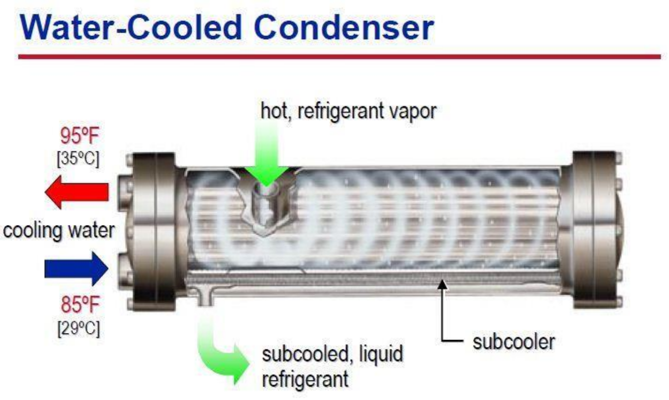
(a) Natural convection type
(b) Forced convection type

2-**Water cooled condenser**: use water as condensing medium.

(a)Shell and tube type

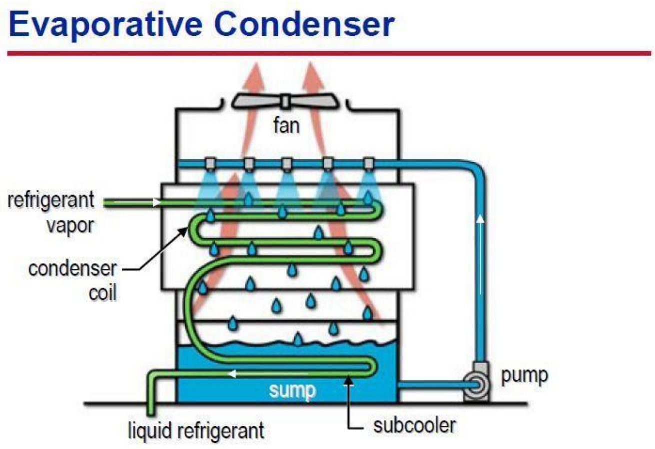
(b) Shell and coil type

(c) Double pipe type



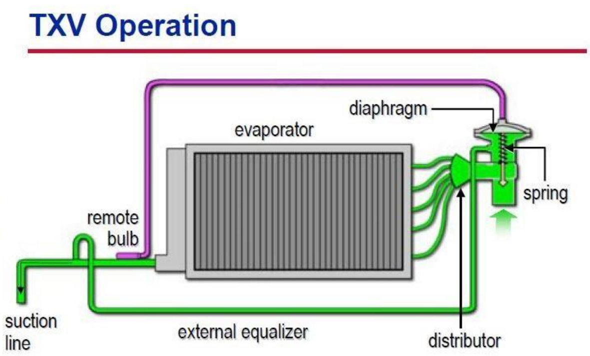
3- **Evaporative compressor**: Use both air and water as condensing medium:

(a) Induced type
(b) Forced type



Expansion device (Valve): The expansion valve work is to control the pressure between the condenser and the evaporator in a specific value to keep the refrigerant cycle working continuously, this metering device is used to control the amount of refrigerant released to the evaporator while expanding it in a process leading to pressure and temperature drop of the refrigerant, its located at the evaporator or the indoor unit of the air conditioning system.

The most famous expansion device is thermostatic expansion valve (TXV): It keeps the pressure deference between condenser and the evaporator and controlling the liquid gas entering the evaporator, and guarantees the evaporating of the liquid gas completely.



References:

1- Air conditioning and refrigeration ,Rex miller,state university of buffalo,newyork,Mark Miller industrial technology, the university of texas,MC,GrawiHill 2006.

2- https://jacobsheating.com/blog/air-conditioning-guide/#:~:text=Air%20conditioners%20have%20three%20main,and%20back%20to%20gas%20quickly

3- https://www.uomus.edu.iq/img/lectures21/MUCLecture_2021_1125739.pdf

4- https://www.designingbuildings.co.uk/wiki/Psychrometric_charts

5-https://www.uomus.edu.iq/img/lectures21/WameedMUCLecture_2021_92222268.pdf

6- Air-conditioning and mechanical ventilation (ACMV) systems, Singapore, Dr. Md Raisul Islam, 2014, ASHRAE Handbooks, p170-174

7-Air conditioning and refrigeration ,Rex miller,state university of buffalo,newyork,Mark Miller industrial technology, the university of texas,MC,GrawiHill 2006.P192-196

8-Lectures of air conditioning and refrigeration, prof Dr.Mushtaq esmael ,Mechanical Engineering Department, College of Engineering, Thi-Qar University.2020.