Subject Code:21EEO304T
Subject Name: Energy Efficient Practices

Course Offered To: B.Tech 6th Semester Students

Dr. Priyea Ranjan

Assistant Professor (Research)

Mechanical Engineering Department

Unit-3

Energy Efficient Practices

- Energy efficiency in electrical utilities
- Compressed air system
- Energy saving opportunities in HVAC and refrigeration system
- Impact of Power Electronics in energy efficiency

Heating, Ventilation and Air Conditioning (HVAC) and refrigeration system

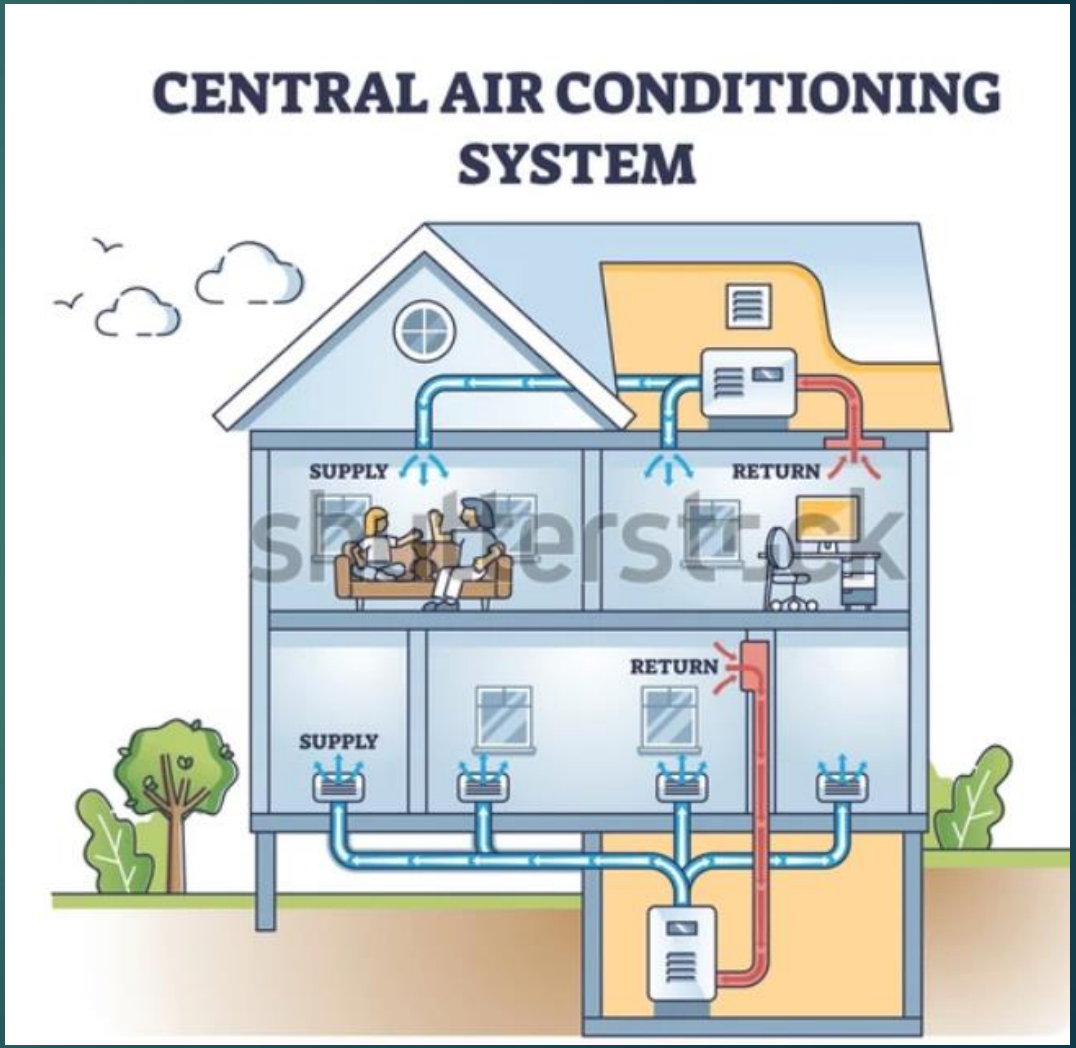
Heating, Ventilation and Air Conditioning (HVAC) refers to systems that control indoor climate by regulating temperature, humidity, and air quality in residential, commercial, and industrial buildings. It consists of:

Heating: Provides warmth using furnaces, boilers, or heat pumps.

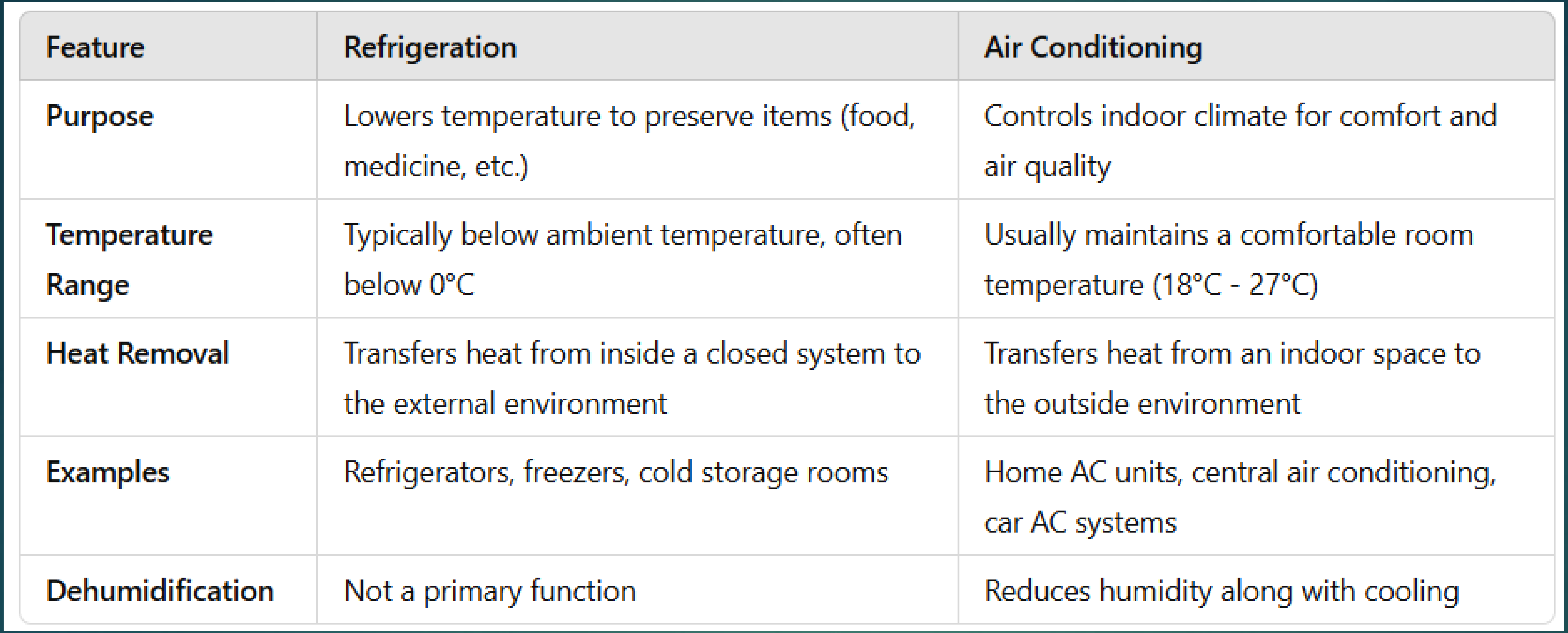
Ventilation: Ensures fresh air circulation by removing contaminants, odors, and excess moisture.

Air Conditioning (AC): The process of controlling temperature, humidity, and air quality in an enclosed space for comfort or industrial needs. It involves both cooling and dehumidification.

Refrigeration: The process of removing heat from a space or substance to lower its temperature and maintain it below the surrounding temperature. It is used in food preservation, industrial cooling, and medical applications.



Difference between Refrigeration and Air Conditioning



Feature	Refrigeration	Air Conditioning
Purpose	Lowers temperature to preserve items (food, medicine, etc.)	Controls indoor climate for comfort and air quality
Temperature Range	Typically below ambient temperature, often below 0°C	Usually maintains a comfortable room temperature (18°C - 27°C)
Heat Removal	Transfers heat from inside a closed system to the external environment	Transfers heat from an indoor space to the outside environment
Examples	Refrigerators, freezers, cold storage rooms	Home AC units, central air conditioning, car AC systems
Dehumidification	Not a primary function	Reduces humidity along with cooling

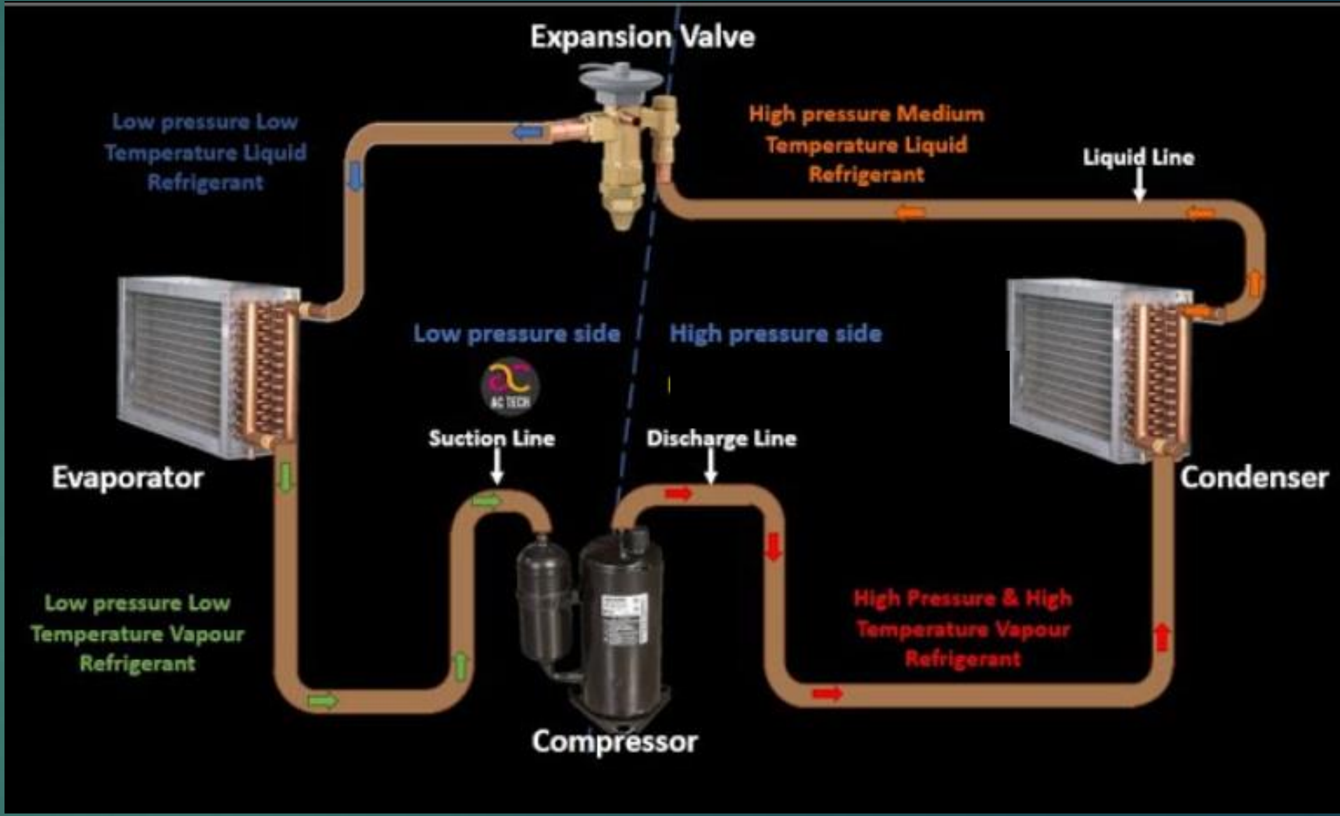
Types of refrigeration system

1. Vapour Compression Refrigeration System (VCRS)
2. Vapour Absorption Refrigeration System (VARS)

Vapour Compression Refrigeration system (VCRS)

- It consist of mainly 4 components
- ➢ Compressor
- ➢ Condenser
- ➢ Expansion Valve
- ➢ Evaporator

- Refrigerant is a type of substance which is able to absorb the heat from the space to be cooled.
- From compressor suction line we have refrigerant with low pressure and using compressor it is converted into high pressure refrigerant.
- Now the refrigerant has converted into high pressure and high temperature vapour.
- It is passed through condenser and condenser decreases temperature of refrigerant with minimum pressure drop. By decreasing temperature the vapour refrigerant converts into liquid refrigerant.
- Now refrigerant has converted into high pressure and low temperature liquid refrigerant.



Vapour Compression refrigeration system

Coefficient of Performance (COP) = Cooling effect/ Work Input

- It is passed through expansion valve, where the reduction in pressure takes place from high pressure to low pressure.
- Now refrigerant has converted into low pressure and low temperature liquid refrigerant.
- It is passed through evaporator, where the evaporator absorbs the heat from load and convert from liquid refrigerant to vapour refrigerant by absorbing heat
- Similarly the whole cycle is repeated.

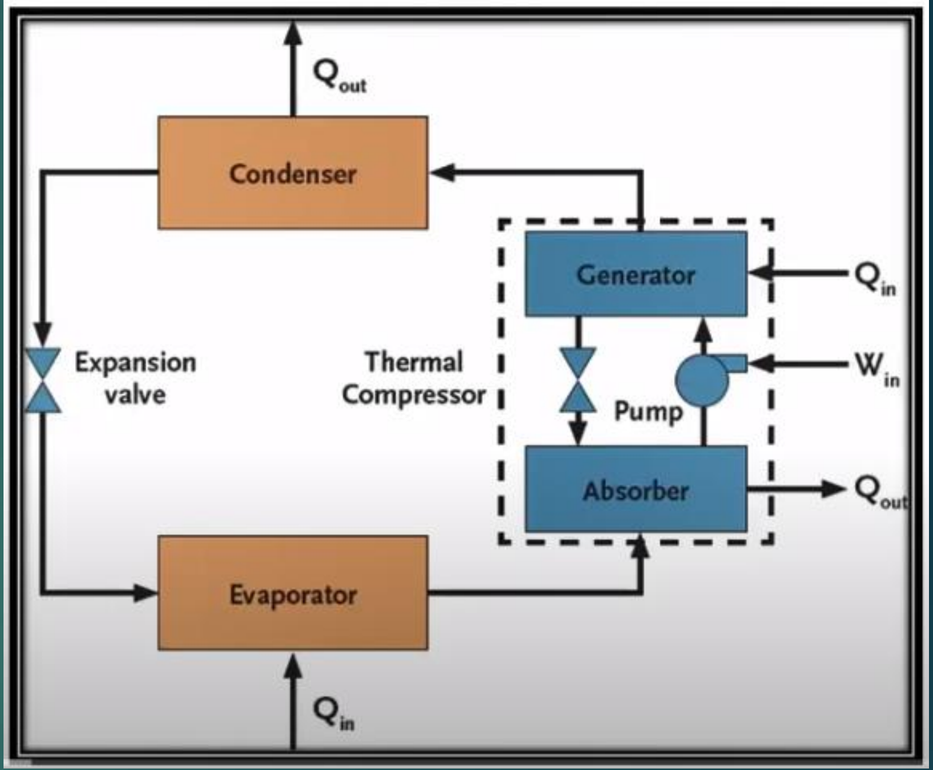
- Unit of Refrigeration: It is defined as the amount of heat required to extract from 1 Tonne of water at 0° C in order to convert it into ice at 0°C in a day or 24 hrs. It is represented as 1 TR.
- 1 TR = 3.5 kW

Vapour Absorption Refrigeration System (VARS)

- It is a type of system, in which instead of compressor we have 4 different elements- Generator, Absorber, Pump and Non-return Path.

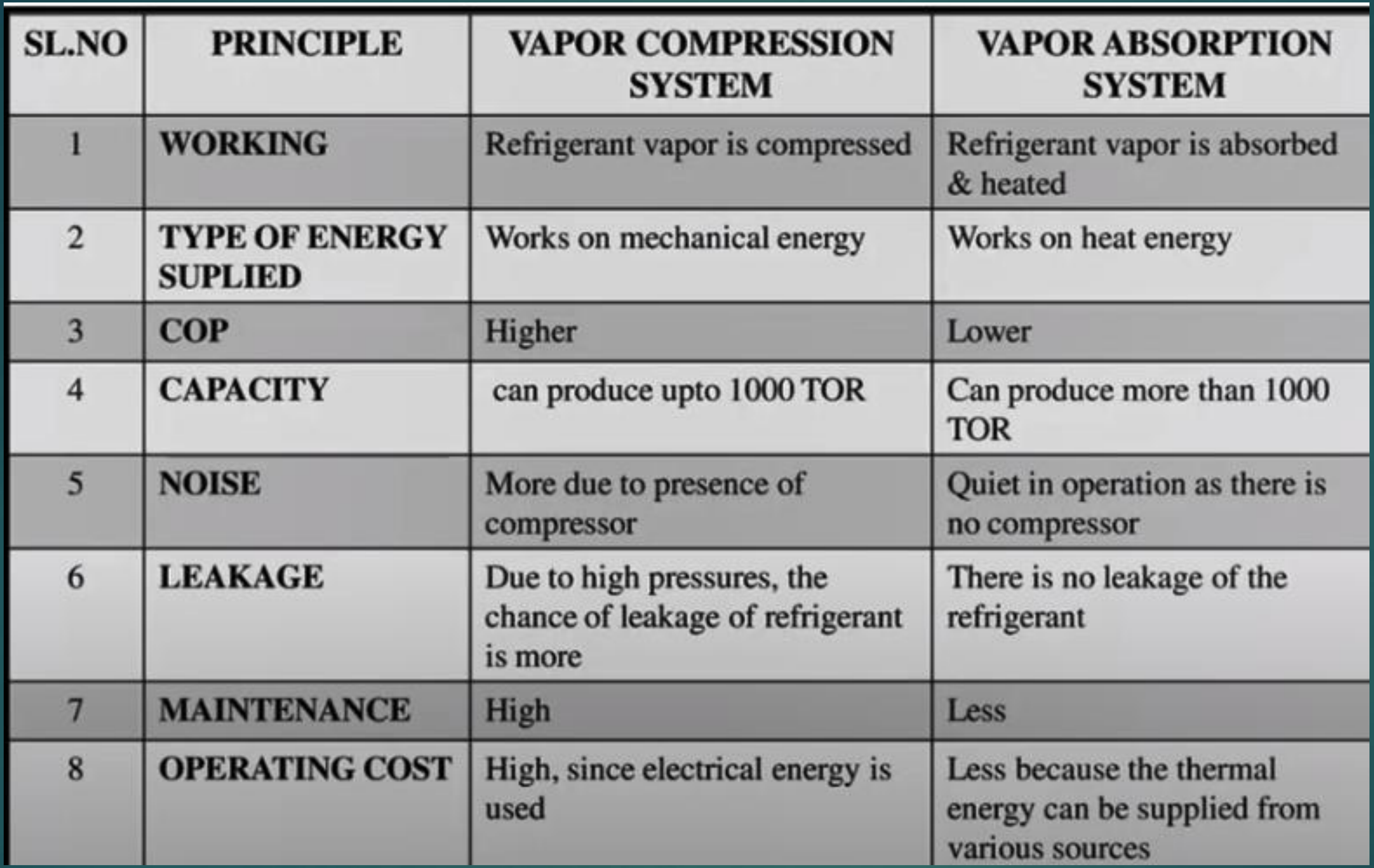
- From the previous one, three components are common - Condenser, Expansion valve and Evaporator.

- At the inlet of evaporator, refrigerant - (Saturated liquid). As it passes through the evaporator it absorbs the heat from surrounding so that it can convert from **Saturated liquid** to **Saturated vapor**.
- Now it is supplied to the Absorber which contains water. The vapor of refrigerant and water get mixed with each other after which converts it in pure liquid mixture of ammonia and water.
- The mixture of ammonia and water is pumped to the generator. In generator, heat (Q_{in}) is supplied which causes the evaporation of refrigerant (ammonia) and separated from water. It happens due to the difference of their boiling point. The refrigerant will separate first and leaving water.
- Superheated vapor will enter into the condenser while water flows back to the absorber via valve. The water releases Q_{out} heat in absorber and again mixed with new refrigerant.



Common refrigerant-
1. Ammonia-Water (for low-temperature applications)
2. Lithium Bromide-Water (for air conditioning)

Difference between VCRS and VARS



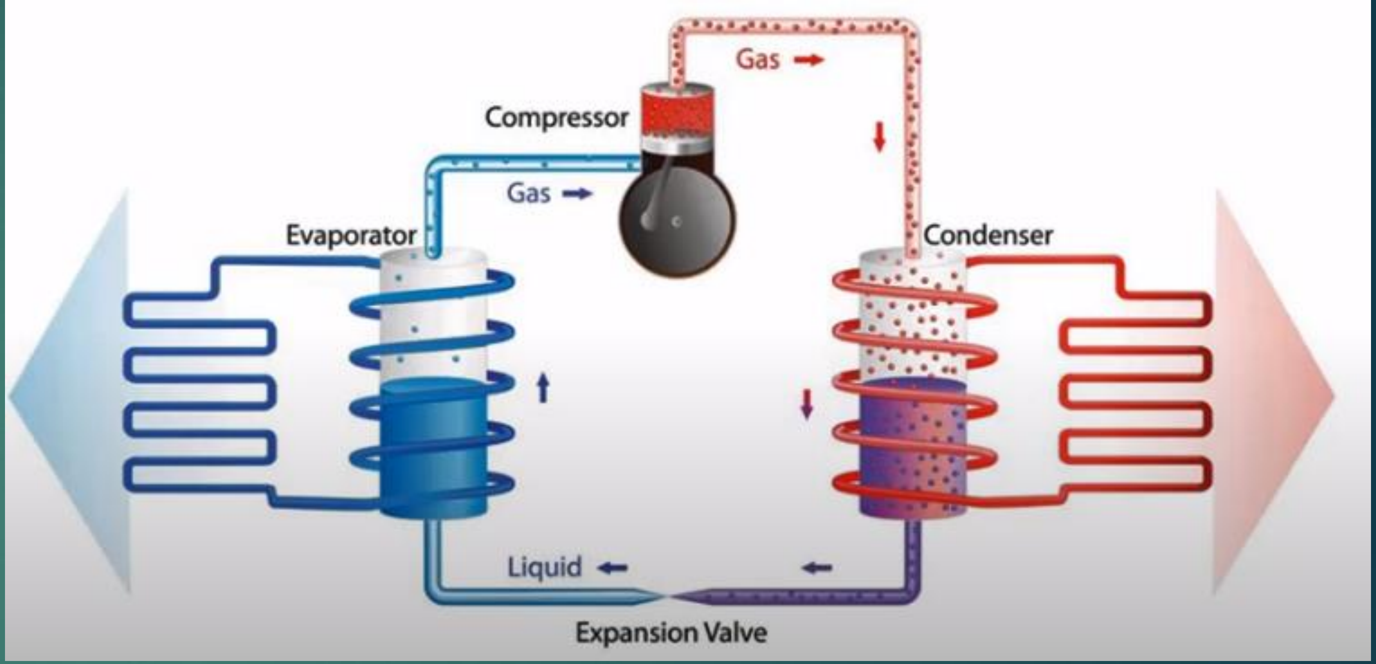
SL.NO	PRINCIPLE	VAPOR COMPRESSION SYSTEM	VAPOR ABSORPTION SYSTEM
1	**WORKING**	Refrigerant vapor is compressed	Refrigerant vapor is absorbed & heated
2	**TYPE OF ENERGY SUPLIED**	Works on mechanical energy	Works on heat energy
3	**COP**	Higher	Lower
4	**CAPACITY**	can produce upto 1000 TOR	Can produce more than 1000 TOR
5	**NOISE**	More due to presence of compressor	Quiet in operation as there is no compressor
6	**LEAKAGE**	Due to high pressures, the chance of leakage of refrigerant is more	There is no leakage of the refrigerant
7	**MAINTENANCE**	High	Less
8	**OPERATING COST**	High, since electrical energy is used	Less because the thermal energy can be supplied from various sources

- TOR- ton of refrigeration,
- COP- Coefficient of Performance is a ratio of useful heating or cooling provided to work (energy) required.

Heat Pump

From construction point of view, heat pump and refrigerator are similar, but basic difference is -
In refrigerator, we use it for cooling application while in heat pump we use it for heating application.

Evaporator: The heat pump absorbs heat from the outside air (even when it's cold outside) using a refrigerant. The refrigerant evaporates and turns into a gas.
Compressor: The gas is compressed, which increases its temperature and pressure.
Condenser: The high-pressure, high-temperature gas is then passed through a condenser inside the building. Here, it releases the heat into the indoor space, warming it up.
Expansion Valve: The refrigerant then passes through an expansion valve, where it cools down and turns back into a liquid, ready to start the cycle again.



Schematic diagram of heat pump

Air Conditioner

An air conditioner (AC) works by removing heat from the indoor air and expelling it outside, thus cooling the indoor environment.

Working of AC

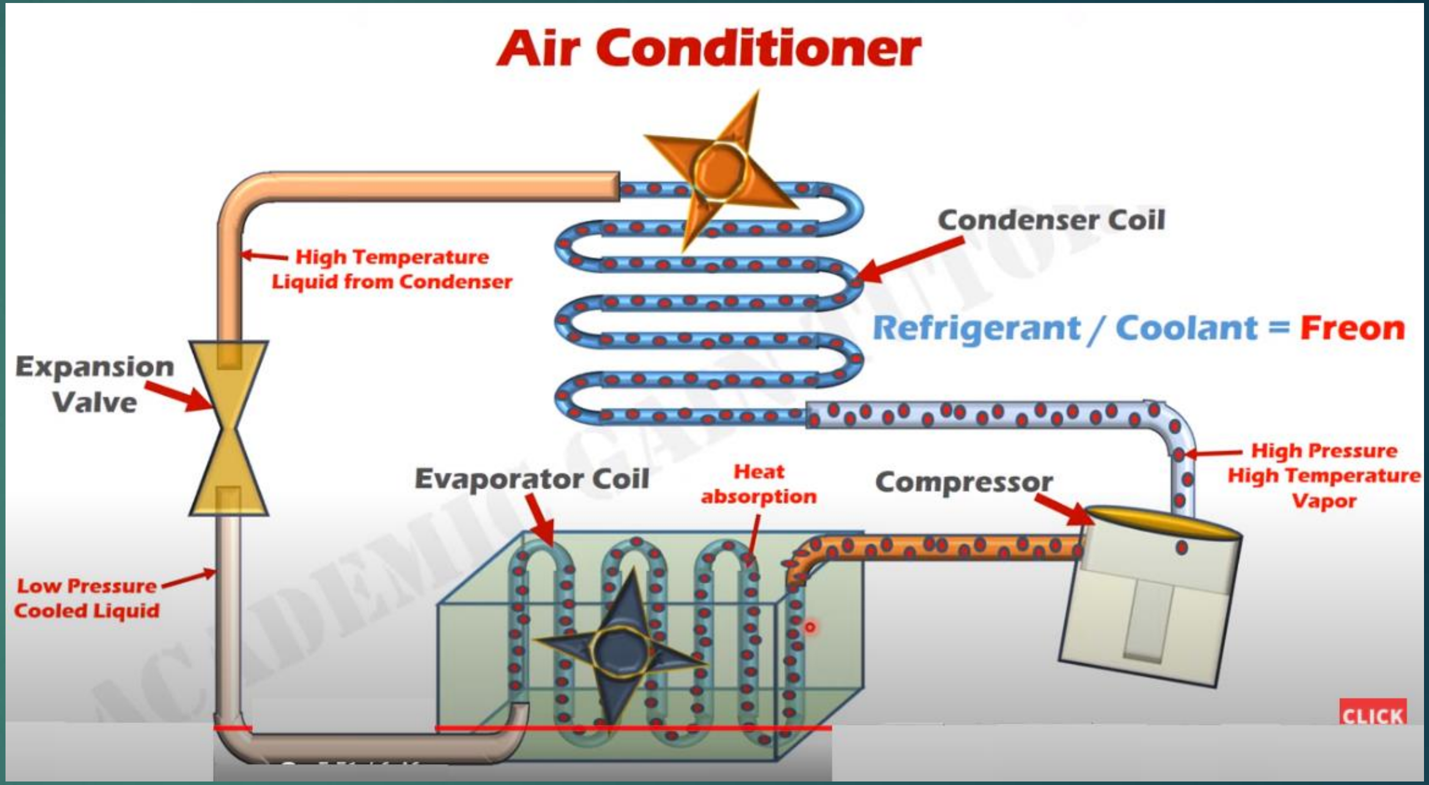
Evaporation: Inside the air conditioner, a liquid refrigerant absorbs heat from the indoor air and evaporates, turning into a gas. This occurs in the evaporator coil, which is located inside the air handler or indoor unit.

Compression: The refrigerant gas is then compressed by the compressor, which increases its temperature and pressure. This happens in the outdoor unit.

Condensation: The high-pressure, high-temperature gas passes through the condenser coil in the outdoor unit. Here, it releases the absorbed heat to the outside air and condenses back into a liquid.

Expansion: The liquid refrigerant then flows through an expansion valve, where it experiences a drop in pressure.

The whole cycle is again repeated.

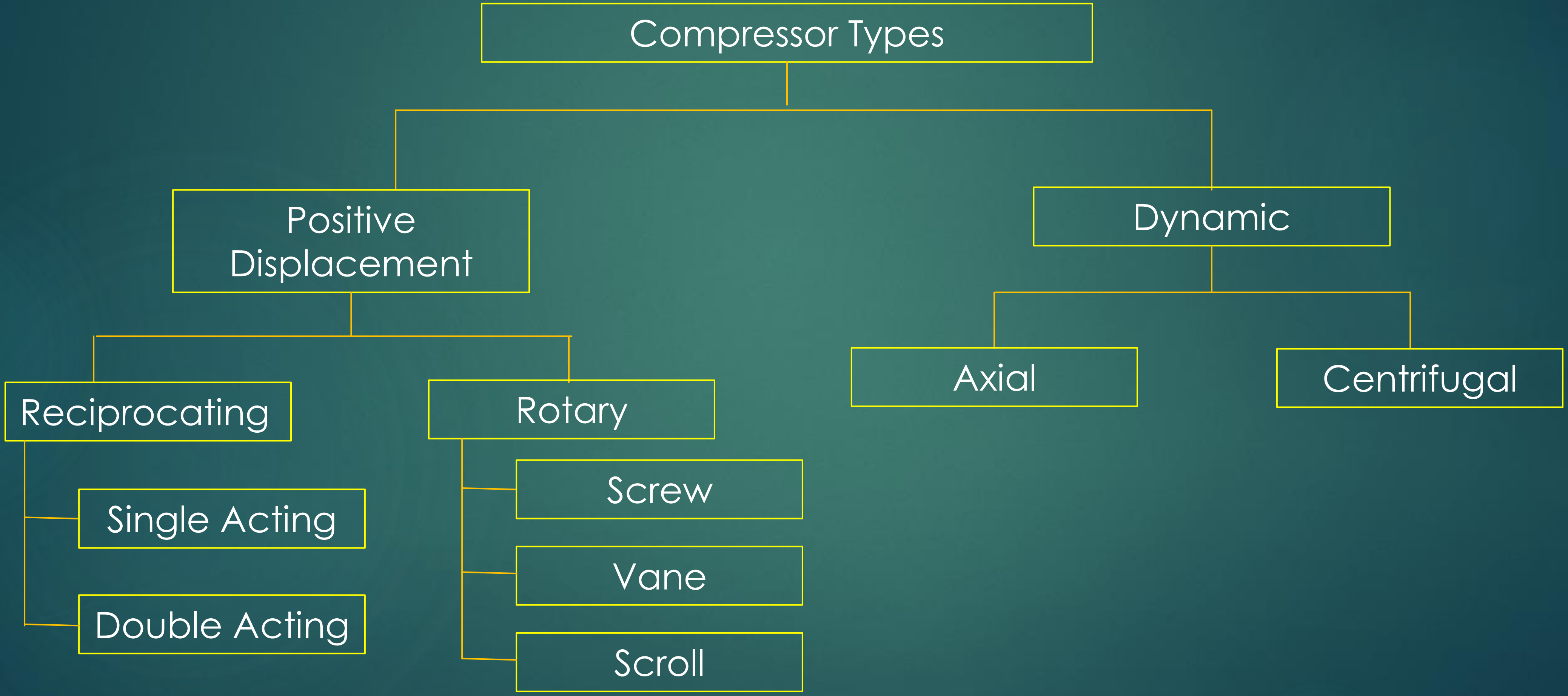


Air Conditioning System

Common refrigerants used: R-22, R-410A, R-290

Compressor

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. Compressors are widely used in various industries, including refrigeration, air conditioning, and industrial processes.



Compressor Types

Positive Displacement

Dynamic

Reciprocating

Rotary

Axial

Centrifugal

Single Acting

Double Acting

Screw

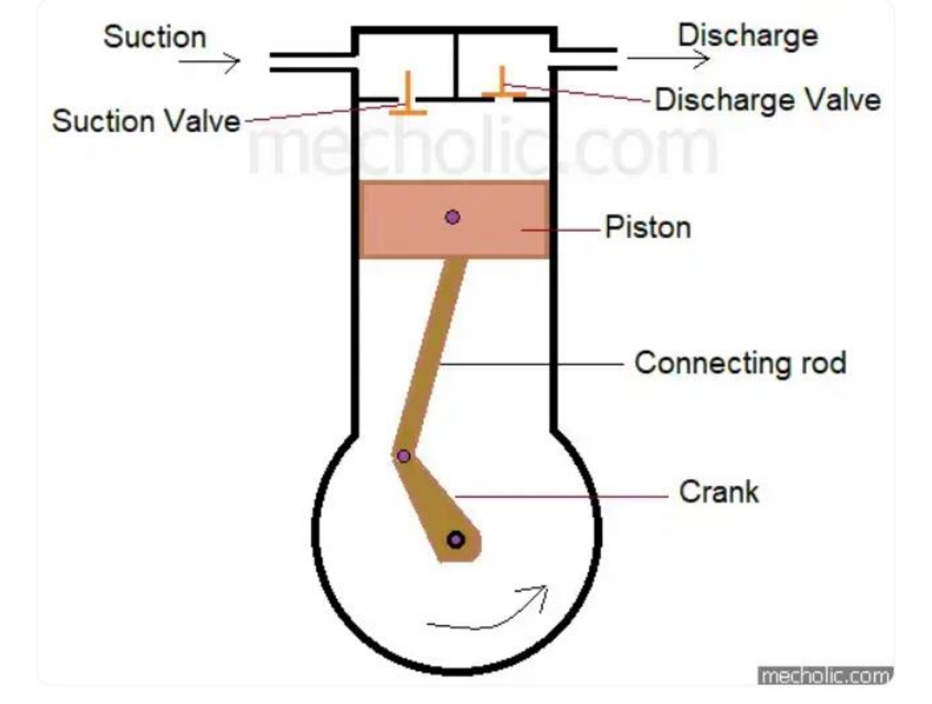
Vane

Scroll

Reciprocating Compressors

These compressors use a piston-cylinder mechanism to compress the gas. The volume of air is drawn into a cylinder and compressed by piston and then discharged into the discharge line. They are commonly used in small-scale applications and can handle high pressures.

- When the piston moves down, the pressure inside the cylinder is reduced.
- When the cylinder pressure is reduced below atmospheric pressure, the inlet valve opens.
- Atmospheric air is drawn into the cylinder till the piston reaches the bottom dead centre.
- The delivery valve remains closed during this period.
- When the piston moves up, the pressure inside the cylinder increases.
- The inlet valve is closed, since the pressure inside the cylinder is above atmospheric.
- The pressure of air inside the cylinder is increased steadily.
- The outlet valve is then opened and the high pressure air is delivered through the outlet valve in to the delivery pipe line.
- Maximum pressure generated in reciprocating air compressor is 30 bar.



Reciprocating Compressor

Applications:

Manufacturing & Production: Powers **pneumatic tools, paint sprayers, and assembly lines**.

Petrochemical and Oil & Gas Industry: Used for compressing natural gas, hydrogen, and other process gas

Rotary air compressor

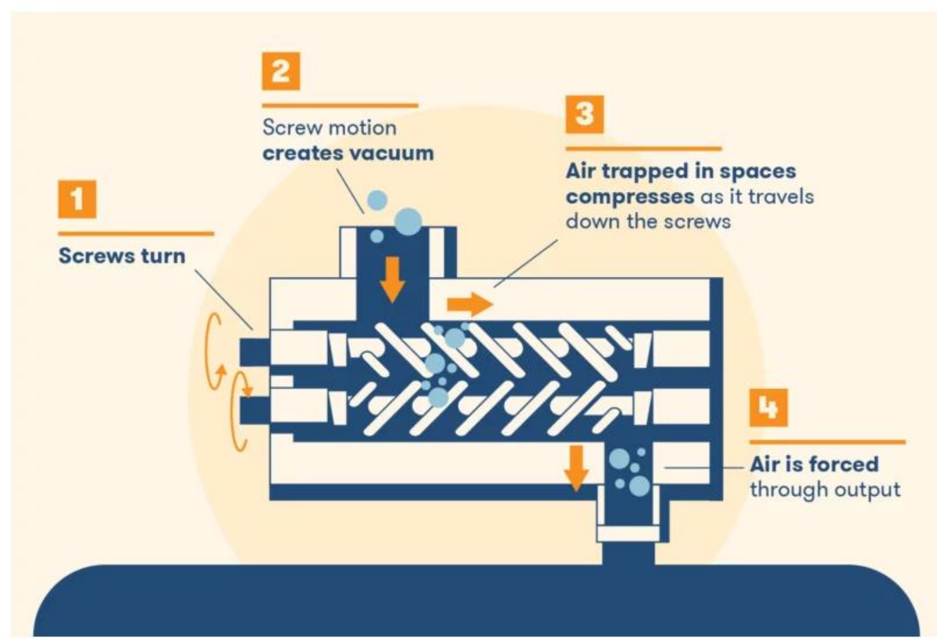
A **rotary air compressor** is a type of positive displacement compressor that compresses air by trapping it between rotating components and reducing its volume.

Working Principle

- It consists of two meshing helical rotors (screws) inside a casing.
- As the rotors turn, air enters the compressor through an inlet valve.
- The air gets trapped between the rotors and is compressed as the space between the rotors decreases.
- Compressed air exits through the outlet at high pressure.
- The maximum generated pressure is 15-30 bar.

Applications

- Manufacturing industries
- Automotive repair shops
- Food processing



Centrifugal Air Compressor

A **centrifugal air compressor** is a type of dynamic compressor that increases air pressure by converting kinetic energy into potential energy using a high-speed rotating impeller.

Working

The centrifugal air compressor operates based on the principles of **centrifugal force** and **dynamic compression**. The working process involves the following steps:

1. Air Intake:

Ambient air enters the compressor through an inlet.

2. Compression Process:

The air moves into a high-speed rotating **impeller** (which may rotate at thousands of RPM).

The impeller blades accelerate the air outward, increasing its **kinetic energy**.

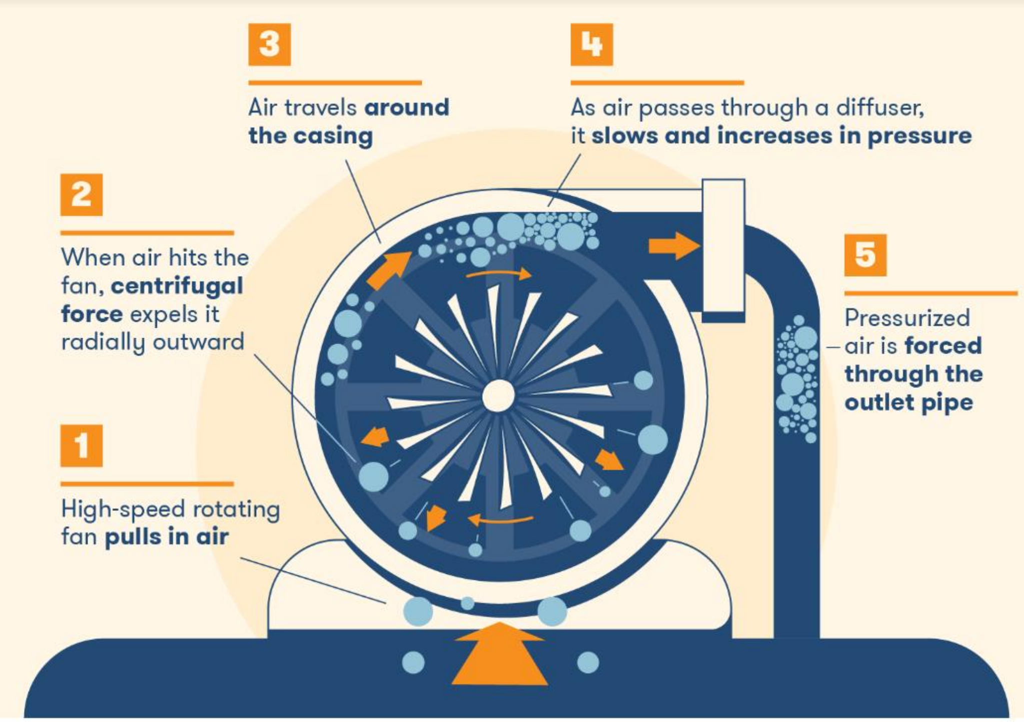
The air then enters the **diffuser**, where its velocity decreases while pressure increases (conversion of kinetic energy into pressure energy).

3. Multiple Stages (if needed):

In high-pressure applications, multiple impellers and diffusers are arranged in series to achieve further compression.

4. Air Discharge:

The compressed air exits through a volute casing, which further aids in pressure buildup before being delivered for use. The maximum generated pressure is 40-60 bar.



Applications

Power Plants – Used for combustion air in gas turbines.

Chemical and Petrochemical Industries – For process air and cooling.

Axial Air Compressor

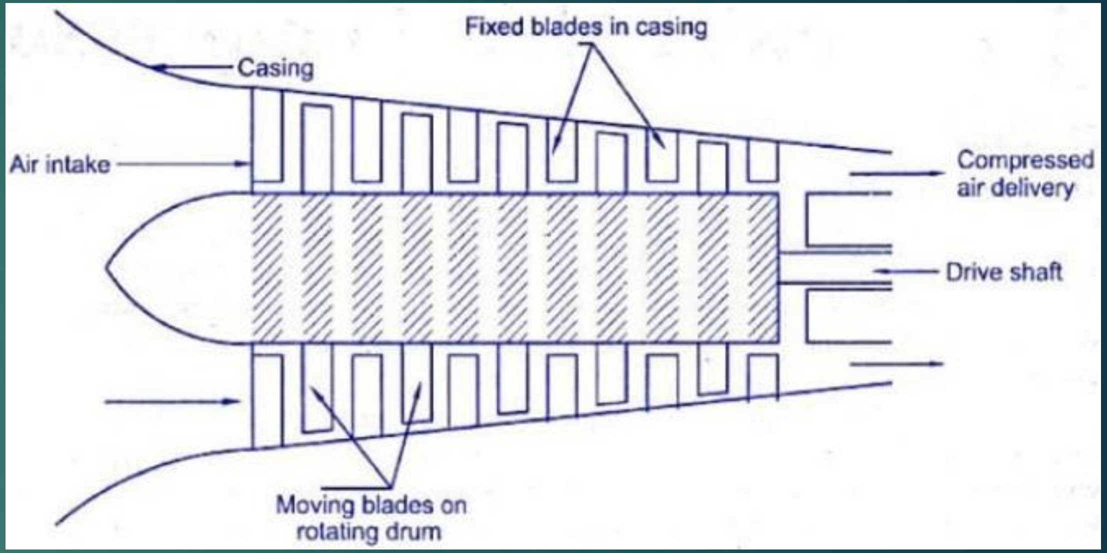
An **axial compressor** is a type of dynamic compressor that compresses air through a series of rotating and stationary blades arranged in stages along the axis of the airflow.

The axial compressor operates on the principle of **gradual pressure increase through multiple stages**. The process involves the following steps:

1. Air Intake:
Ambient air enters the compressor **in parallel to the axis of rotation**.

2. Compression Process (Multi-stage Compression):
The compression process occurs in multiple stages, each consisting of:
Rotating Blades (Rotor Blades) – These accelerate the air, increasing its velocity.
Stationary Blades (Stator Blades) – These slow down the air, converting **kinetic energy into pressure energy**.
This alternating **rotor-stator arrangement** continues over several stages, gradually increasing the air pressure while maintaining a smooth and continuous flow.

3. Air Exit (Discharge):
The compressed air is discharged at high pressure and is sent to the combustion chamber (in jet engines) or used for industrial applications.



Schematic of an axial compressor

Maximum pressure generated in axial air compressor is 30-50 bar

Applications

Jet Engines & Aircraft Turbines – Essential for propulsion in gas turbine engines.

Industrial Applications – Large-scale air compression in oil refineries and chemical plants.

Aerospace & Defense – Rocket engines and high-speed propulsion systems.

Axial Compressor

Scroll Compressor

A **scroll compressor** is a type of **positive displacement compressor** that compresses air or refrigerant using two interleaved **spiral-shaped scrolls** (one stationary and one orbiting).

Working

1. Air Intake

- One scroll remains **stationary**, while the other moves in an **orbiting motion** (without rotating).
- This motion creates **pockets of air** between the scrolls.

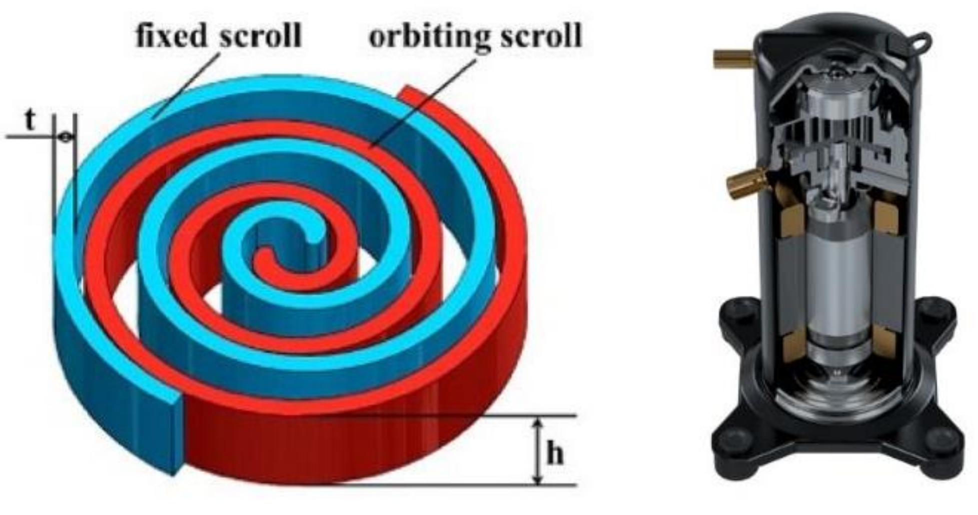
2. Compression Process

- As the orbiting scroll moves, the **air pockets get smaller**, reducing volume and increasing pressure.
- This process happens gradually in multiple stages, making compression **smooth and continuous**.

3. Air Discharge

- When the air reaches the **center of the scroll**, it is at **high pressure** and is discharged.
- The process repeats continuously without pulsation, ensuring **steady airflow and minimal noise**.

- Maximum generated pressure is up to 10 bar.

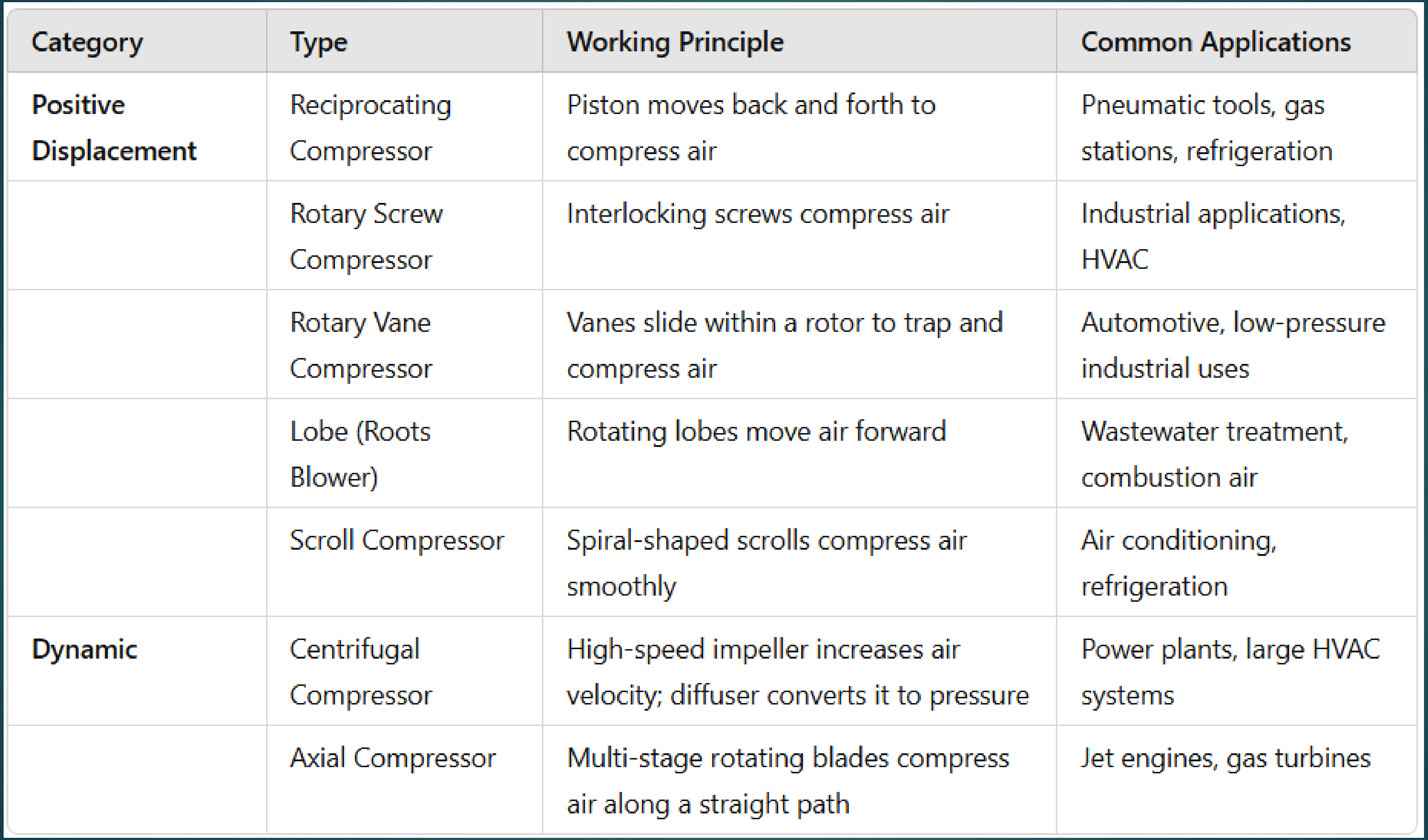


Scroll Compressor

Applications:

- ◈ Air Conditioning (HVAC)
- ◈ Refrigeration Systems
- ◈ Medical Air Compressors
- ◈ Industrial Air Supply

Summary of Compressors



Category	Type	Working Principle	Common Applications
Positive Displacement	Reciprocating Compressor	Piston moves back and forth to compress air	Pneumatic tools, gas stations, refrigeration
	Rotary Screw Compressor	Interlocking screws compress air	Industrial applications, HVAC
	Rotary Vane Compressor	Vanes slide within a rotor to trap and compress air	Automotive, low-pressure industrial uses
	Lobe (Roots Blower)	Rotating lobes move air forward	Wastewater treatment, combustion air
	Scroll Compressor	Spiral-shaped scrolls compress air smoothly	Air conditioning, refrigeration
Dynamic	Centrifugal Compressor	High-speed impeller increases air velocity; diffuser converts it to pressure	Power plants, large HVAC systems
	Axial Compressor	Multi-stage rotating blades compress air along a straight path	Jet engines, gas turbines

Condenser

A **condenser** works by removing heat from a hot vapor (usually refrigerant or steam), causing it to condense into a liquid. This heat is transferred to air or water, which then carries the heat away.

Heat Transfer Process:

1. **Hot vapor enters the condenser coils** from the compressor.
2. **Cooling medium (air or water) absorbs heat** from the vapor.
3. **Vapor cools and condenses** into a high-pressure liquid.
4. The liquid refrigerant or condensate is then sent to the next stage of the system (expansion valve or boiler feed pump).

Types of Condensers

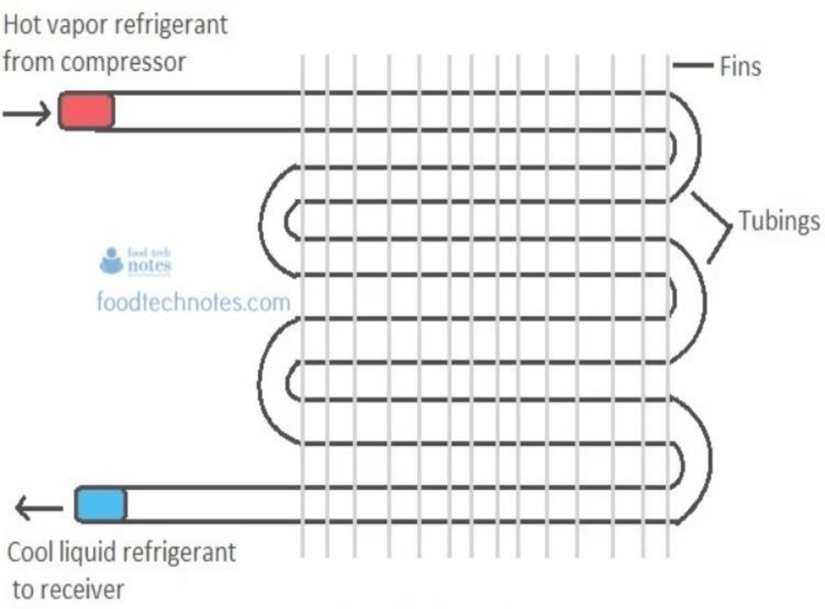
(a) Air Cooled Condensers

An **air-cooled condenser** is a type of **heat exchanger** that removes heat from a refrigerant or steam using ambient air instead of water. These condensers are commonly used in **HVAC systems, refrigeration units, power plants, and industrial applications** where water availability is limited.

Working

Hot refrigerant vapor from the compressor enters the condenser coils. **Air is blown over the coils** using fans, absorbing heat from the refrigerant. **Heat is rejected into the atmosphere**, causing the refrigerant to condense into a high-pressure liquid.

The **liquid refrigerant exits** the condenser and continues to the expansion valve in the refrigeration cycle.



Air cooled condenser

The **liquid refrigerant exits** the condenser and continues to the expansion valve in the refrigeration cycle.

(b) **Water Cooled Condensers:** A **water-cooled condenser** is a heat exchanger that removes heat from a refrigerant by transferring it to water. It is commonly used in industrial cooling, HVAC (heating, ventilation, and air conditioning) systems, and refrigeration units.

Working

1. Hot Refrigerant Enters the Condenser

The high-pressure, high-temperature **refrigerant vapor** enters the condenser from the compressor.

This refrigerant carries heat absorbed from the evaporator and compression process.

2. Heat Transfer to Water

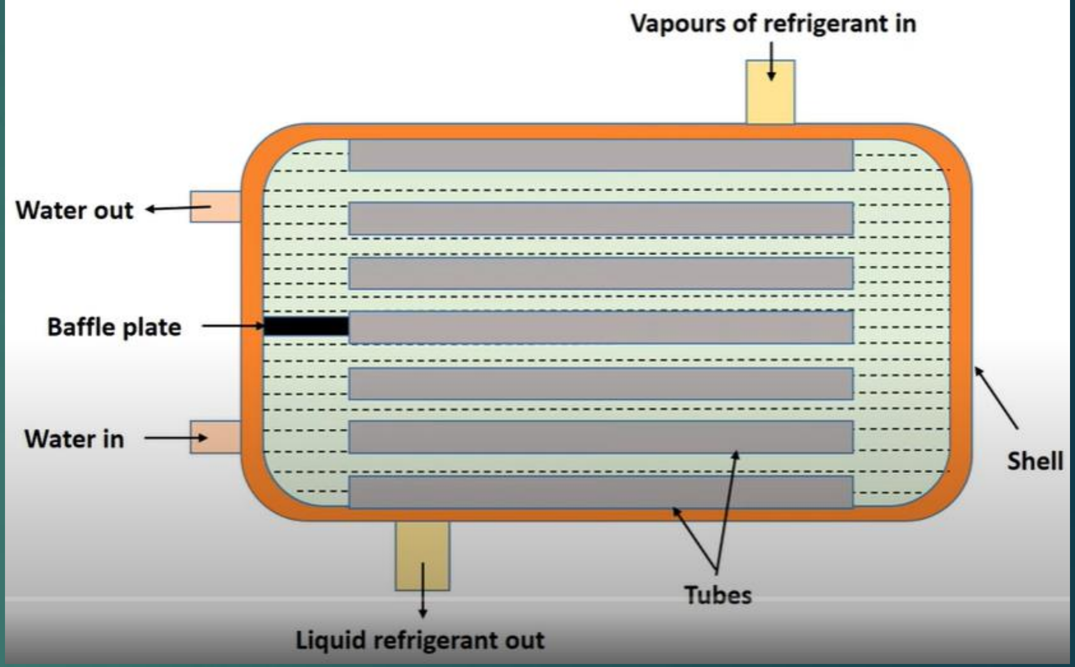
Cool **water circulates** through the condenser tubes or shell.

The refrigerant releases heat to the water, causing it to cool down and **begin condensing** into a liquid.

3. Condensation of Refrigerant

As the refrigerant loses heat, it gradually **changes from vapor to liquid**.

This liquid refrigerant is now at high pressure and is ready for expansion and further cooling.



Water cooled condenser

4. Removal of Heated Water
The now **heated water** is either discharged or **recirculated through a cooling tower** to be cooled and reused.
In closed-loop systems, water is cooled before re-entering the condenser.
5. Liquid Refrigerant Moves to Expansion Valve
The high-pressure **liquid refrigerant exits** the condenser and moves toward the expansion valve.
The expansion valve reduces its pressure and temperature before it enters the evaporator to **absorb heat** again, completing the cycle.

(C) **Evaporative type condenser**

An **evaporative condenser** is a heat exchanger that combines **air-cooled** and **water-cooled** condensation methods. It enhances cooling efficiency by using **water spray and air movement** to remove heat from the refrigerant. This type of condenser is widely used in **power plants, industrial cooling systems, and HVAC applications** due to its water-saving and high-efficiency properties.

Working

Step 1: Hot Refrigerant Enters the Condenser Coils

- The **high-pressure, high-temperature refrigerant gas** from the compressor enters the condenser coil.

Step 2: Water is Sprayed Over the Coils

- A **pump-driven water spray system** continuously sprays **cool water** over the condenser coils.

Step 3: Air Flow Enhances Cooling

- A **blower or fan** draws air across the coils, helping in heat transfer.
- The combination of **air movement and water spray** improves heat dissipation.

Step 4: Evaporation Lowers Temperature

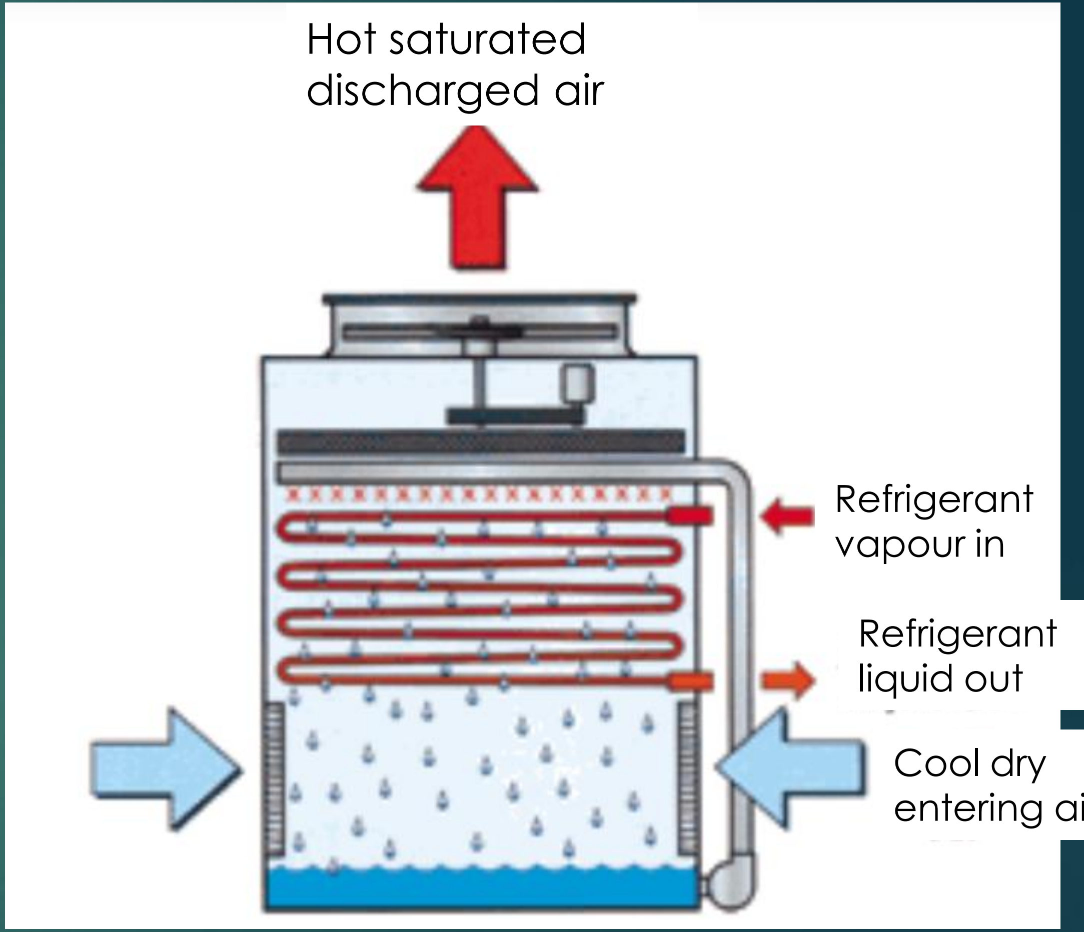
- As part of the sprayed water **evaporates**, it absorbs heat from the refrigerant.
- The **latent heat of vaporization** removes a significant amount of heat, allowing the refrigerant to condense into a liquid.

Step 5: Refrigerant Condensation

- As the heat is removed, the refrigerant changes from a **gas to a high-pressure liquid** inside the condenser coil.
- The condensed liquid refrigerant then moves toward the expansion valve and evaporator to continue the refrigeration cycle.

Step 6: Water Recirculation and Drift Control

- The remaining **unevaporated water** is collected in a basin and **recirculated** using a pump.



Evaporative Condenser

Cooling Tower

A **cooling tower** is a specialized heat exchanger used to remove excess heat from industrial processes, HVAC systems, and power plants by transferring heat from hot water to the surrounding air. This helps in maintaining **optimal operating temperatures** for equipment and improves energy efficiency.

Step 1: Hot Water Enters the Cooling Tower

- Heated water from an industrial process, power plant, or HVAC system **flows into the cooling tower**.
- The hot water is sprayed or distributed over the **fill media** (plastic or wooden slats) to **increase surface area for cooling**.

Step 2: Airflow Enhances Cooling

- **Air enters** the tower either naturally (in natural draft) or through **fans** (in mechanical draft).
- The airflow **increases heat transfer** by carrying heat away from the water droplets.

Step 3: Evaporation Cools the Water

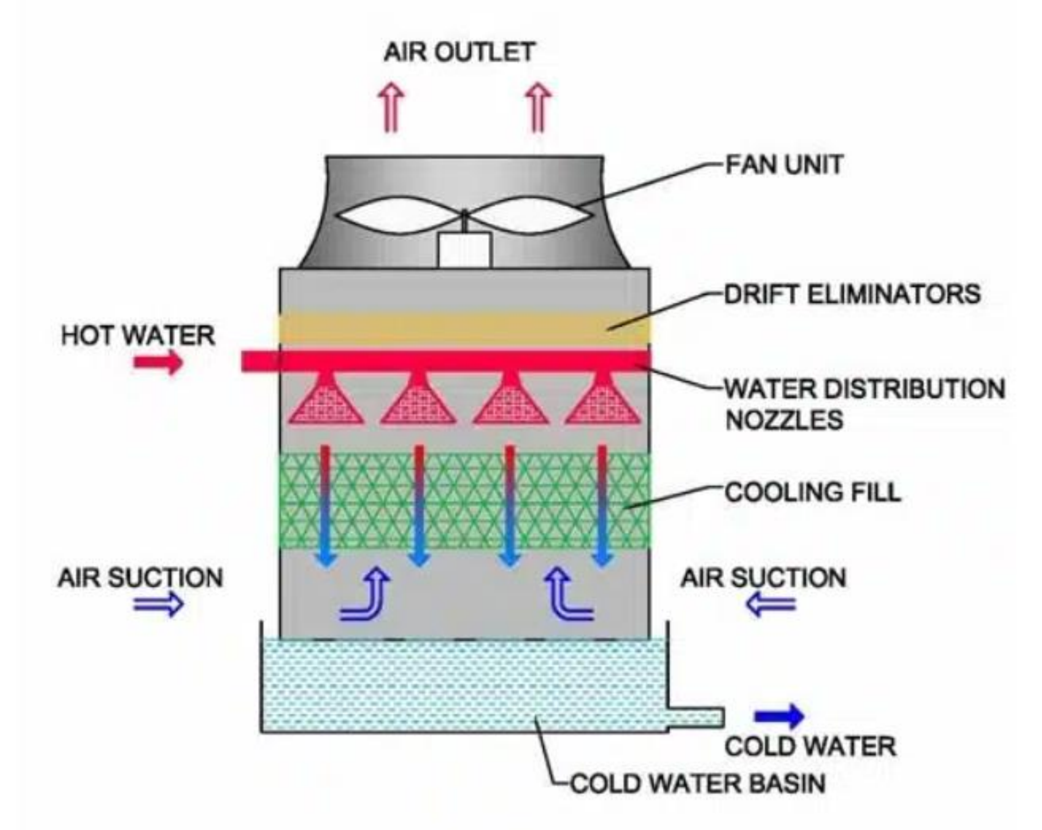
- A **small portion of water evaporates**, absorbing heat in the process.

Step 4: Cooled Water is Collected and Reused

- The cooled water **collects at the bottom basin** of the cooling tower.
- A pump **recirculates** this cooled water back to the system for reuse.

Step 5: Heat is Released into the Atmosphere

- The removed heat is **released into the atmosphere** through rising warm air.
- Some water droplets escape with the airflow, but **drift eliminators** reduce water loss.



Schematic of Cooling Tower

Step 6: Water Treatment and Replenishment
- Since **some water is lost due to evaporation**, new water (make-up water) is added.
- **Chemical treatment** is required to prevent **corrosion, scaling, and biological growth** like algae.

- A **drift eliminator** in a cooling tower is a component designed to reduce water loss by capturing and redirecting water droplets that escape with the air exhaust. It helps improve water efficiency and minimizes environmental and health concerns related to airborne water droplets.

Energy saving opportunities in HVAC and refrigeration system

HVAC (Heating, Ventilation, and Air Conditioning) and refrigeration systems are among the **largest energy consumers** in buildings and industries. Improving energy efficiency in these systems reduces **operational costs, extends equipment life, and minimizes environmental impact**.

1. Proper system Designing and Sizing

Oversized systems waste energy due to frequent cycling, while undersized systems work harder and wear out faster.

Proper sizing ensures efficient operation and optimal energy use.

Energy-Saving Strategies:

Load Calculation – Conduct a detailed heating and cooling load calculation before selecting equipment.

Proper Ductwork and Piping Design – Well-insulated and sealed ducts/pipes **reduce heat loss** and improve airflow.

2. Use High-Efficiency Equipment

Modern, high-efficiency HVAC and refrigeration units consume **20-50% less energy** than older models.

Energy-Saving Strategies:

Upgrade to Energy-Efficient Compressors – Use **scroll, screw, or magnetic bearing chillers** that consume less power.

Choose High-Efficiency Heat Exchangers – Plate-and-frame heat exchangers improve heat transfer efficiency.

3. Optimize Refrigeration and Cooling Systems

Poorly maintained refrigeration systems **waste energy and reduce cooling efficiency**.

Energy-Saving Strategies:

Proper Refrigerant Charge – Too much or too little refrigerant lowers efficiency.

Use Low- Global Warming Potential (GWP) Refrigerants – Newer refrigerants provide better efficiency with a lower environmental impact. Ex- R-290, R-600a etc.

Regular Coil Cleaning – Dirty coils reduce heat exchange efficiency, increasing energy use.

4. Improve Airflow and Ventilation Efficiency

Poor airflow reduces system performance and increases energy use.

Energy-Saving Strategies:

Demand-Controlled Ventilation (DCV) – Adjusts airflow based on occupancy, saving up to **30% on ventilation costs**.

Install Variable Frequency Drives (VFDs) on Fans – Allows motors to run at optimal speeds, reducing energy waste.

Seal and Insulate Ductwork – Leaky ducts can waste up to **20% of conditioned air**.

5. Implement Smart Controls and Automation

Manual operation leads to unnecessary energy use. **Smart systems optimize energy usage automatically**.

Energy-Saving Strategies:

Programmable Thermostats – Automatically adjust temperature settings based on schedules.

Energy Management Systems (EMS) – Monitors and controls HVAC and refrigeration operations to improve efficiency.

Building Management Systems (BMS) – Integrates HVAC, lighting, and other systems for better energy optimization.

6. Reduce Cooling and Heating Loads

The lower the heat gain/loss in a building, the less the HVAC system needs to work, reducing energy consumption.

Energy-Saving Strategies:

Improve Building Insulation – Proper insulation reduces heating/cooling demand.

Install Energy-Efficient Windows and Doors – **Double-glazed windows** and tight seals prevent heat loss/gain.

Optimize Internal Heat Sources – Reduce heat-generating appliances inside buildings.

7. Utilize Renewable Energy Sources

Renewable energy sources **reduce reliance on grid electricity**, lowering operating costs.

Energy-Saving Strategies:

Solar-Assisted HVAC Systems – Use solar energy to **power air conditioning and ventilation**.
Heat Recovery Systems – Capture waste heat from compressors for space heating or water preheating.

8. Perform Regular Maintenance and Monitoring

Poorly maintained systems **consume up to 25% more energy** than well-maintained ones.

Energy-Saving Strategies:
Clean Filters Regularly – Dirty filters block airflow, reducing efficiency.
Check for Refrigerant Leaks – Leaks lower cooling capacity and increase power consumption.
Inspect for Faulty Valves and Dampers – Stuck valves cause compressors to run longer than necessary.

9. Use Free Cooling Techniques

Free cooling reduces the load on mechanical refrigeration, saving energy.

Energy-Saving Strategies:
Economizer Systems – Use **cool outside air** instead of mechanical cooling when ambient conditions allow.
Thermal Storage Systems – Store cooling energy in **ice or chilled water tanks** for later use.

Impact of Power Electronics on Energy Efficiency

Power electronics plays a crucial role in **enhancing energy efficiency** across various industries by enabling precise control over electrical energy conversion, distribution, and utilization. It is widely used in **HVAC systems, motor drives, renewable energy systems, industrial automation, and electric vehicles**, leading to significant reductions in energy consumption and operational costs.

Key Areas Where Power Electronics Improves Energy Efficiency

1. Motor Drives and Industrial Automation

Variable Frequency Drives (VFDs):

Control the speed of AC motors based on demand, reducing energy waste.

Can improve efficiency by **30-50%** in HVAC, pumps, and fans.

Soft Starters:

Reduce inrush current during motor startup, improving efficiency and extending motor life.

Ex- A **centrifugal pump with a VFD** can operate at partial load rather than running at full speed all the time, reducing energy consumption.

2. Renewable Energy Systems (Solar, Wind, and Energy Storage)

MPPT (Maximum Power Point Tracking) in Solar Inverters:

Ensures that solar panels operate at their most efficient power output.

Increases efficiency by **10-25%** compared to fixed voltage operation.

Grid-Tied Inverters:

Convert DC power from renewable sources into high-quality AC power for the grid.

Energy Storage Systems (ESS):

Power electronics help efficiently charge and discharge **batteries** (e.g., lithium-ion).

Ex- In a **solar farm**, inverters optimize power conversion, minimizing losses and improving energy output.

3. Power Conversion and Smart Grids

High-Efficiency Converters (AC-DC, DC-DC, DC-AC):

Used in **power supplies, electric vehicles, and telecom systems** to minimize energy losses. Modern **Silicon Carbide (SiC) and Gallium Nitride (GaN) semiconductors** reduce switching losses, improving efficiency.

Smart Grids & Energy Management:

Power electronics enable real-time load balancing, reducing transmission losses and optimizing energy distribution.

Ex- A **smart grid** with advanced inverters can automatically adjust power flow, reducing energy wastage.

4. Electric Vehicles (EVs) and Transportation

High-Efficiency Motor Controllers:

Control **traction motors** to optimize acceleration and regenerative braking.

Battery Management Systems (BMS):

Ensure efficient battery usage, extending lifespan and reducing energy waste.

5. HVAC & Refrigeration Systems

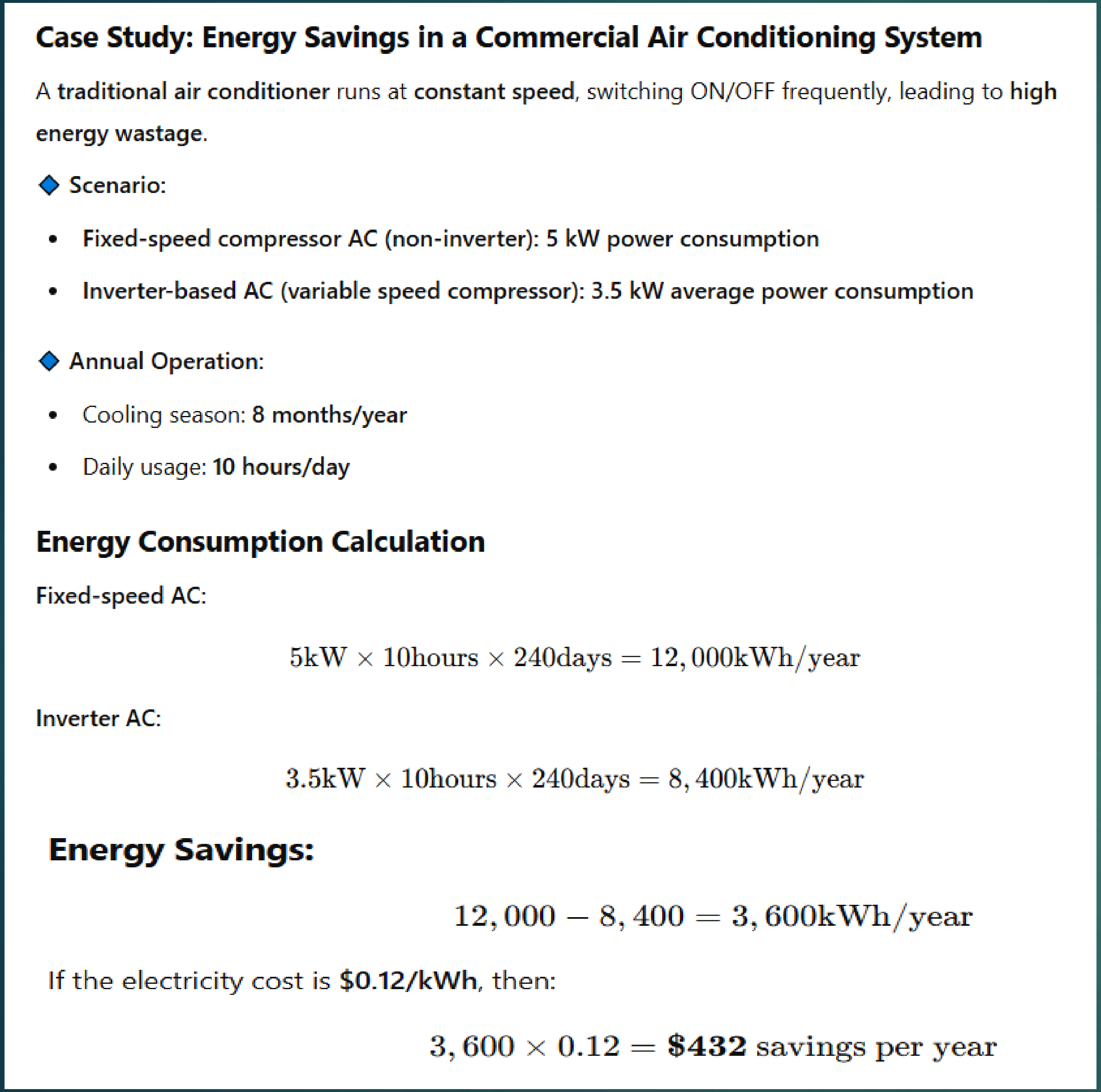
Inverter-Based Compressors:

Adjust compressor speed to match cooling/heating demand, saving **30-40%** energy.

Electronic Expansion Valves (EEVs):

Precisely control refrigerant flow, improving system efficiency.

Ex- A **modern air conditioner with an inverter compressor** consumes much less energy than a traditional fixed-speed AC.



Case Study: Energy Savings in a Commercial Air Conditioning System

A **traditional air conditioner** runs at **constant speed**, switching ON/OFF frequently, leading to **high energy wastage**.

◆ Scenario:

- **Fixed-speed compressor AC (non-inverter): 5 kW power consumption**
- **Inverter-based AC (variable speed compressor): 3.5 kW average power consumption**

◆ Annual Operation:

- Cooling season: **8 months/year**
- Daily usage: **10 hours/day**

Energy Consumption Calculation

Fixed-speed AC:

$$5\text{kW} \times 10\text{hours} \times 240\text{days} = 12,000\text{kWh/year}$$

Inverter AC:

$$3.5\text{kW} \times 10\text{hours} \times 240\text{days} = 8,400\text{kWh/year}$$

Energy Savings:

$$12,000 - 8,400 = 3,600\text{kWh/year}$$

If the electricity cost is **$0.12/kWh**, then:

$$3,600 \times 0.12 = \mathbf{\$432} \text{ savings per year}$$

Efficiency Improvement: Up to **30% reduction in power consumption**.
Payback Period: 2–3 years (based on extra cost of inverter-based AC).

Thank You