Basic Mechanical Engineering
(Credit: 3.00)

EEE 1207

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Refrigeration and Air conditioning systems

Refrigeration

- Refrigeration is the process of removing heat from an enclosed space, or from a substance, and moving it to a place where it is unobjectionable.
- Purpose of Refrigeration: The primary purpose of refrigeration is lowering the temperature of the enclosed space or substance and then maintaining that lower temperature.
- Applications of Refrigeration: Following are the major applications of refrigeration–
    - Ice making
    - Preservation and Transportation of Perishables.
    - Special Industrial Process
    - Air cooling

Classification of refrigeration system

- Vapour Compression Refrigeration System (VCRS)
- Vapour Absorption Refrigeration System (VARS)
- Solar Energy based Refrigeration System
- Air Cycle Refrigeration System
- Steam and Vapour Jet Refrigeration System
- Thermoelectric Refrigeration System
- Vortex Tube Refrigeration System
- Low Temperature Refrigeration System
- Electrolux Refrigeration System
- Magnetic Cooling Refrigeration System

Units of Refrigeration:

A tonne (TR) of refrigeration is defined as the amount of refrigeration effect produced by the uniform melting of one tonne (1000 kg) of ice from and at 0°C in 24 hours.

Since the latent heat of ice is 335 kJ/kg, therefore one tonne of refrigeration,

$$1TR = 1000 \times 335 \text{ kJ in 24 hours}$$

$$= (1000 \times 335) / (24 \times 60)$$

$$= 232.6 \text{ KJ/min}$$

In actual practice, one tonne of refrigeration is taken as equivalent to 210 kJ/min or 3.5 kW i.e. 3.5 KJ/sec.

Vapor Compression Refrigeration System

The Vapor Compression Refrigeration system uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. All such systems have four components:

1. Compressor (Generally a Reciprocating Compressor)
2. Condenser (It condenses the high pressure gaseous refrigerant and acts as storage tank)
3. Expansion Device (Also called a throttle valve. May be a globe valve or simply a capillary tube)
4. Evaporator (Also termed as cooling coil. It is generally a copper coil with high surface area)

Vapor Compression Refrigeration System

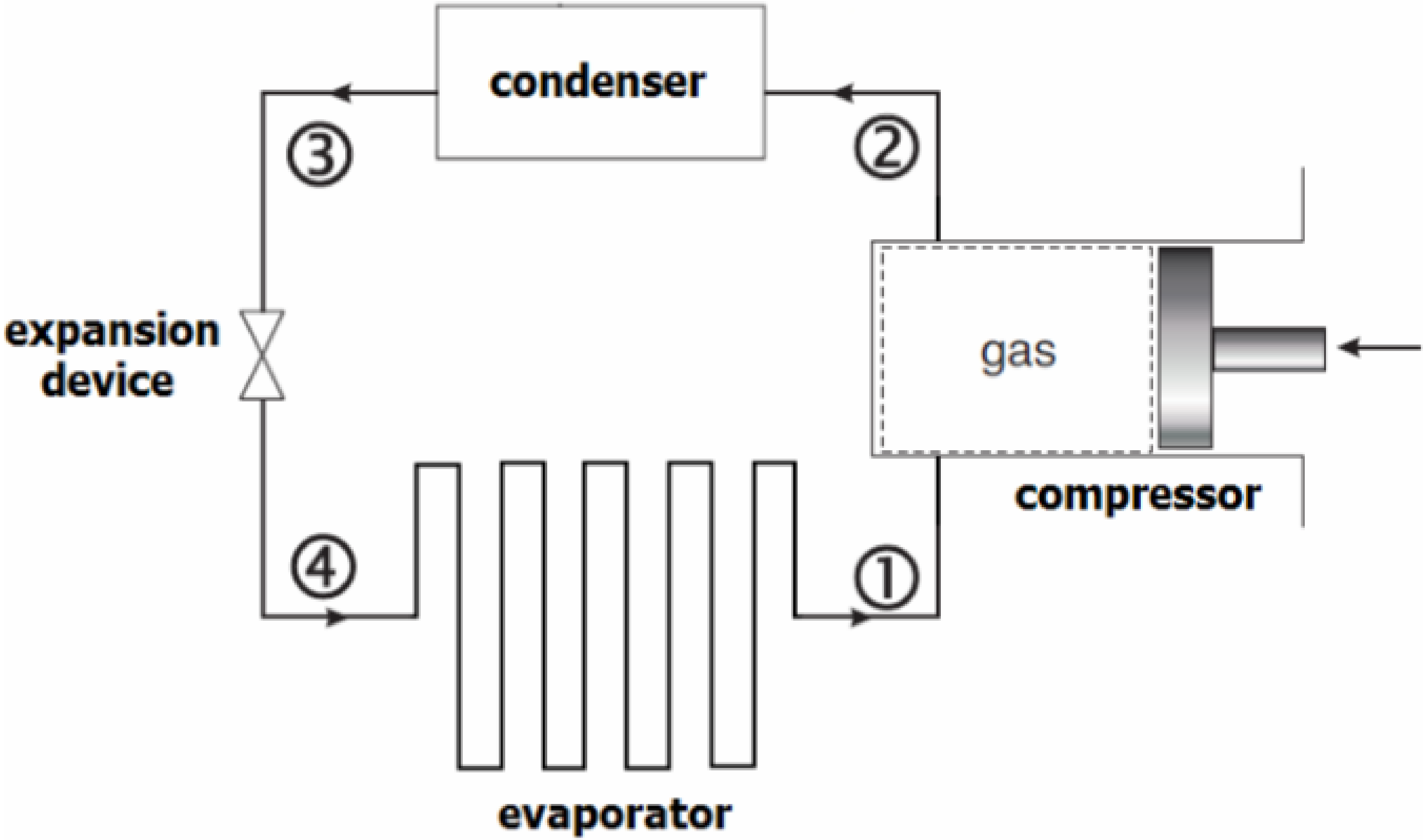


Fig.: Schematic Diagram for Vapor Compression Refrigeration System

Vapor Compression Refrigeration System

Process:

• Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapor (holding as much water or moisture as can be absorbed) and is compressed to a higher pressure, resulting in a higher temperature as well.

• The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor (a vapor that is obtained by raising the temperature of a substance above the saturation temperature while maintaining a constant pressure) and it is at a temperature and pressure at which it can be condensed with typically available atmospheric air.

• That hot vapor is routed through a condenser where it is cooled and condensed into a liquid by flowing through a coil or tubes with relatively cooler atmospheric air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by the atmospheric air.

Vapor Compression Refrigeration System

Process:

The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion device where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapor refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated.

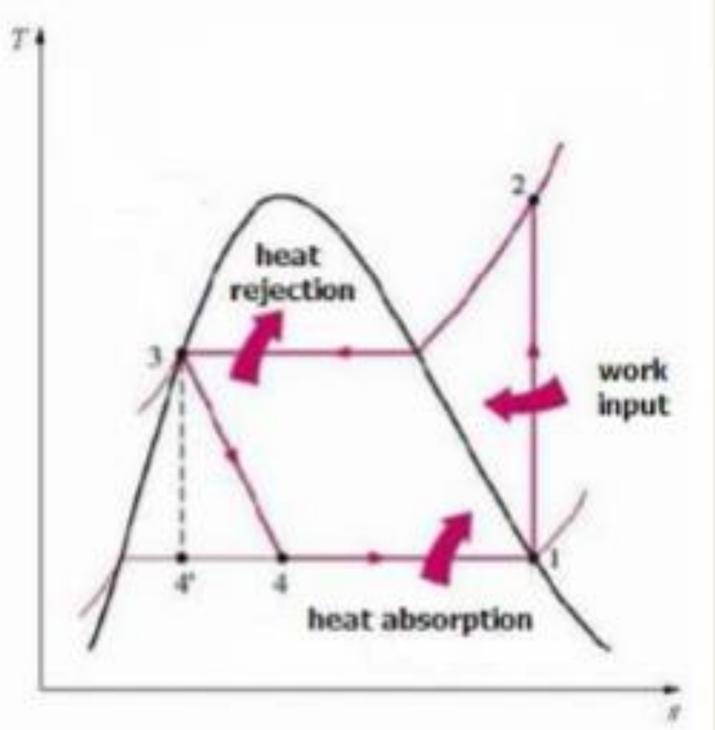
Vapor Compression Refrigeration System

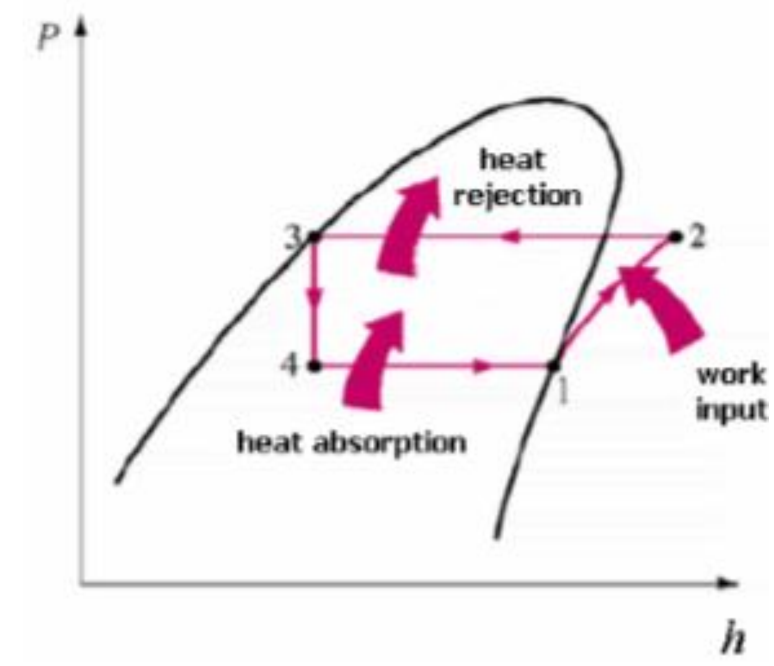
Process:

- The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapor mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser.
- To complete the refrigeration cycle, the refrigerant vapor from the evaporator is again a saturated vapor and is routed back into the compressor.

Vapor Compression Refrigeration System

Thermodynamic Analysis





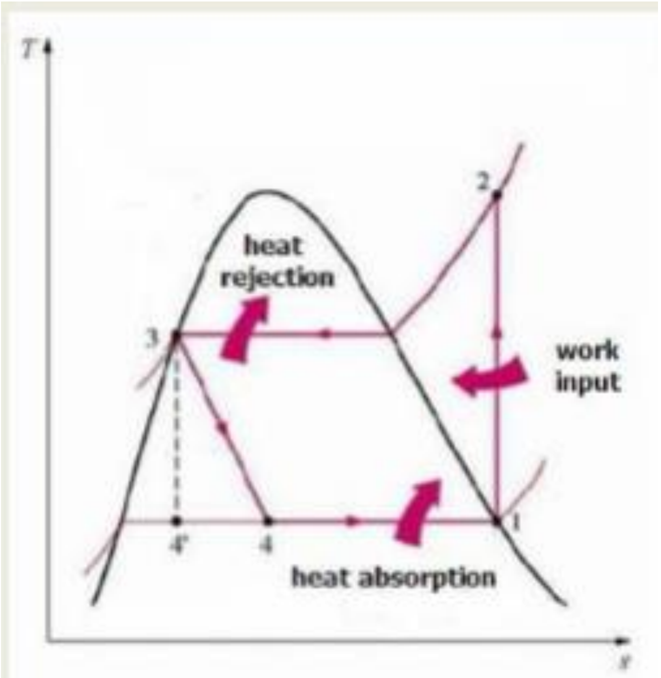
Process **Description**

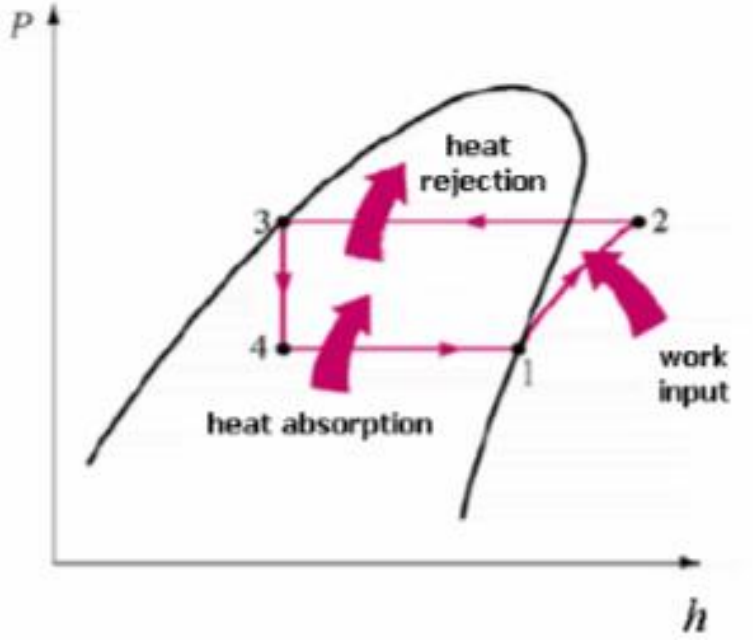
1–2: A reversible, adiabatic(isentropic) compression of the refrigerant. The saturated vapor at state 1 is superheated to state 2.

2–3: An internally, reversible, constant pressure heat rejection in which the working substance is de-superheated and then condensed to a saturated liquid at 3. During this process, the working substance rejects most of its energy to the condenser cooling water

Vapor Compression Refrigeration System

Thermodynamic Analysis



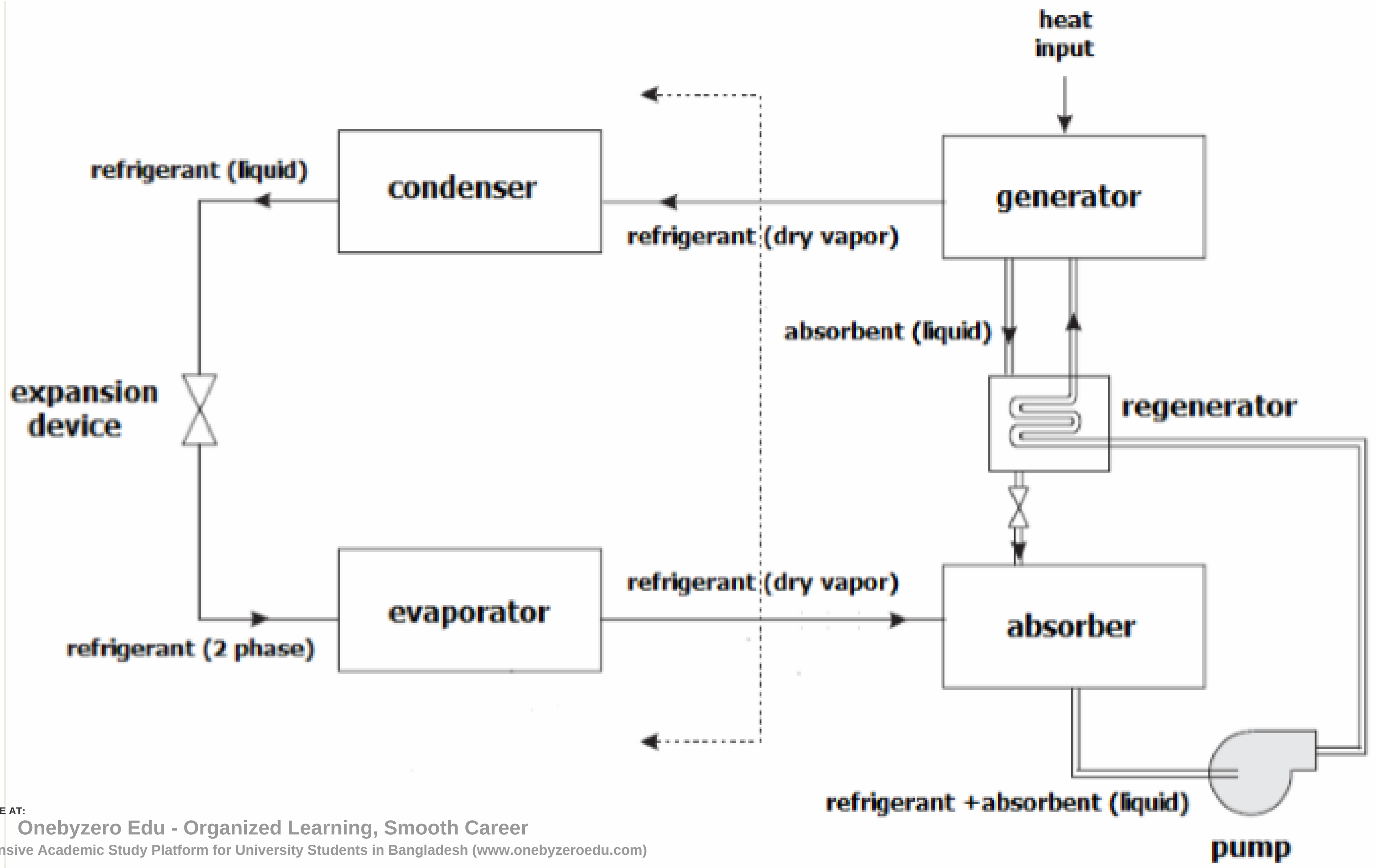


Process **Description**

3 – 4: An irreversible throttling process in which the temperature and pressure decrease at constant enthalpy.

4– 1: An internally, reversible, constant pressure heat interaction in which the working fluid is evaporated to a saturated vapor at state point 1. The latent enthalpy necessary for evaporation is supplied by the refrigerated space surrounding the evaporator. The amount of heat transferred to the working fluid in the evaporator is called the refrigeration load.

Vapor Absorption Refrigeration System



Vapor Absorption Refrigeration System

Process:

In a vapor absorption refrigeration system, the refrigerant circulates through the condenser, expansion valve and evaporator same as in the vapor compression refrigeration system. The compressor is replaced by an absorber, pump, generator, regenerator and a valve.

In the absorber, dry refrigerant vapor is absorbed by a liquid absorbent. The process is exothermic and the absorption is inversely proportional to the temperature i.e. the cooler the better. A pump raises the solution to the pressure of the generator. In the generator, the refrigerant is driven out of the solution by the addition of heat (endothermic reaction) and it is passed back to the condenser. Sometimes a regenerator is used to recover some of the thermal energy from the absorbent solution passed back to the absorber. This energy is transferred to the solution pumped to the generator. This reduces the heat input required to vaporize the solution in the generator.

Vapor Absorption Refrigeration System

Advantages of Vapor Absorption Refrigeration System

- In a vapor absorption refrigeration system, the working fluid is pumped to higher pressure as a liquid whose specific volume is less than that of a gas as in the vapor compression refrigeration system compressor. Hence the work input is much less.
- There are considerable savings in power input because a pump is used instead of a compressor. Although sometimes this is weighed off against the cost of extra hardware in a vapor absorption refrigeration system.
- In this system, heat is added to the process to retrieve the refrigerant vapor from the liquid solution. The refrigeration process is driven by heat and this thermal energy often comes from the exhaust gasses of several other systems (boiler flue gas, gas turbine exhaust or engine exhaust). Thus the system can utilize waste heat.

Vapor Absorption Refrigeration System

Common Refrigerant –Absorbent Combinations

Refrigerant	Absorbent
Ammonia (NH_3)	Water (H_2O)
Water (H_2O)	Lithium Bromide (LiBr) Lithium Chloride (LiCl)

COP : The coefficient of performance or COP of a refrigeration system is the ratio of the refrigeration effect (amount of heat removed from the reservoir) to the supplied work.

$$COP = \frac{|\Delta Q|}{\Delta W}$$

A refrigeration system operating at a COP of 2.0 removes 2.0 units of heat for each unit of energy consumed (e.g. such an air conditioner consuming 1 kWh of electrical energy would remove heat from a building's air at a rate of 2kWh).

Refrigerants

A refrigerant is a compound used in a refrigeration cycle that reversibly undergoes a phase change from a gas to a liquid.

Refrigerant Types:

Primary Refrigerant: Refrigerants, such as Dichlorodifluoromethane (R-12), Mono-chloro-difluoro-methane (R-22), and Refrigerant 502 (R-502), are called PRIMARY REFRIGERANTS because each one changes its state upon the application or absorption of heat, and, in this act of change, absorbs and extracts heat from the area or substance.

Secondary refrigerant: SECONDARY REFRIGERANTS are substances, such as air, water, or brine. Though hot refrigerants in themselves, they have been cooled by the primary refrigeration system; they pass over and around the areas and substances to be cooled; and they are returned with their heat load to the primary refrigeration system.

Refrigerants

Desirable Properties of Refrigerants

The important properties of refrigerants that relate to the overall performance of a refrigeration system are given below–

- A high critical temperature is desirable as it is impossible to condense the refrigerant at a temperature above the critical, no matter how much the pressure is increased.
- A refrigerant should have a low boiling temperature; otherwise it would become necessary to operate the compressor at high vacuums with the resulting lowered efficiency and capacity.
- The freezing point of the refrigerant should be lower than the lowest operating temperature of the cycle to prevent blockage of refrigerant pipelines.
- Low refrigerant densities are usually preferable, since they permit the use of small suction and discharge lines without excessive pressure drops.

Refrigerants

Desirable Properties of Refrigerants

- A high latent heat of vaporization is desirable because it is usually associated with a high refrigerating effect per unit mass of refrigerant circulated.
- A refrigerant should have low volume per unit mass when in gaseous state. This not only reduces the size of the equipment but also means higher compressor efficiency.
- The refrigerant should have a lower viscosity and high values of thermal conductivity.
- The refrigerant should be chemically stable in operating conditions
- The refrigerant should have no chemical reaction with the lubricating oil.
- The refrigerant should be nontoxic, non corrosive and inert.

Air Conditioning Systems

Air Conditioning Systems

Air conditioning is the cooling and dehumidification of indoor air for thermal comfort. In a broader sense, the term can refer to any form of cooling, heating, ventilation, or disinfection that modifies the condition of air. An air conditioner (often referred to as AC) is an appliance, system, or mechanism designed to stabilize the air temperature and humidity within an area (used for cooling as well as heating depending on the air properties at a given time), typically using a refrigeration cycle but sometimes using evaporation, commonly for comfort cooling in buildings and motor vehicles.

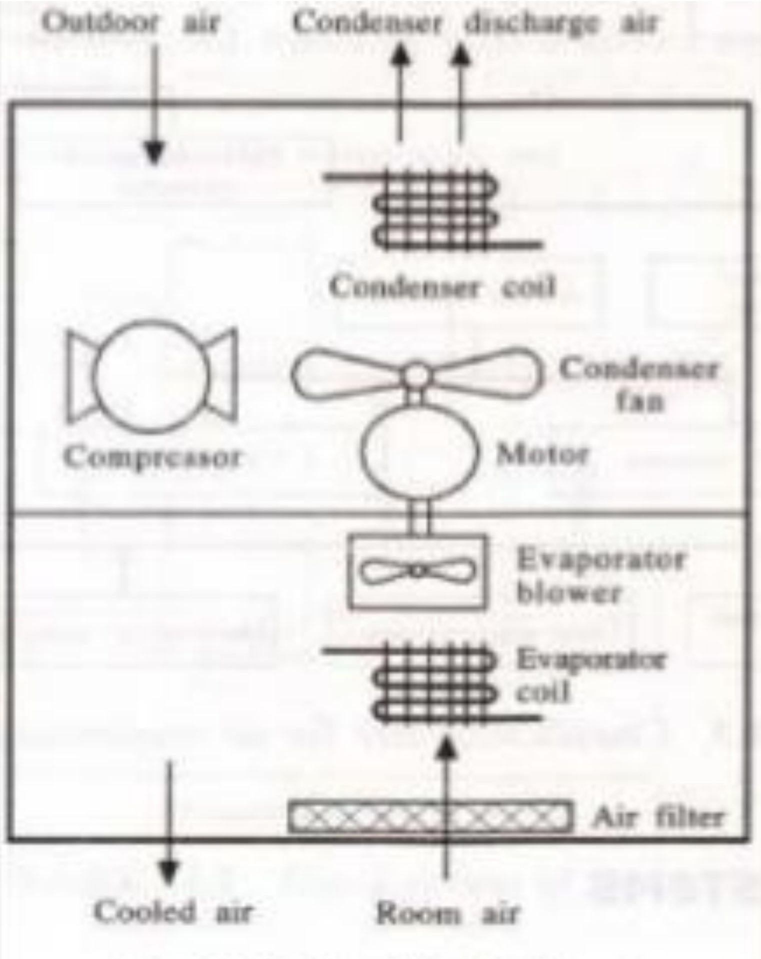


Fig.: Self Contained Air Conditioner

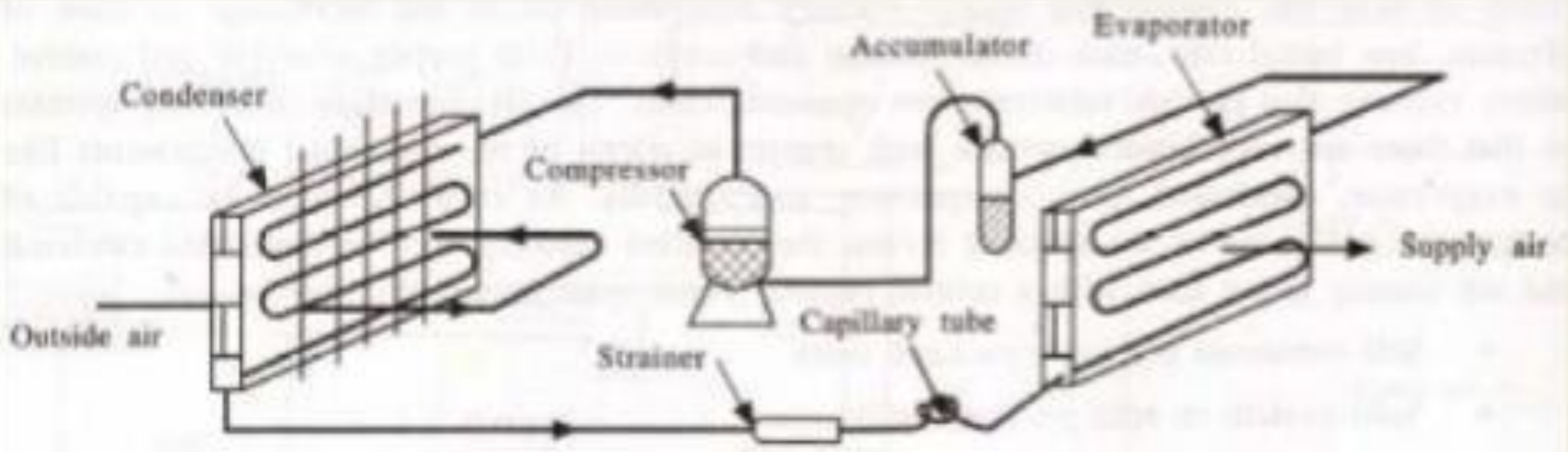


Fig.: Refrigeration Circuit in a Self Contained Air Conditioner

History

In 1902, the first modern electrical air conditioning unit was invented by Willis Carrier in Buffalo, New York.

After graduating from Cornell University, Carrier found a job at the Buffalo Forge Company.

There, he began experimenting with air conditioning as a way to solve an application problem for the Sackett-Wilhelms Lithographing and Publishing Company in Brooklyn, New York.

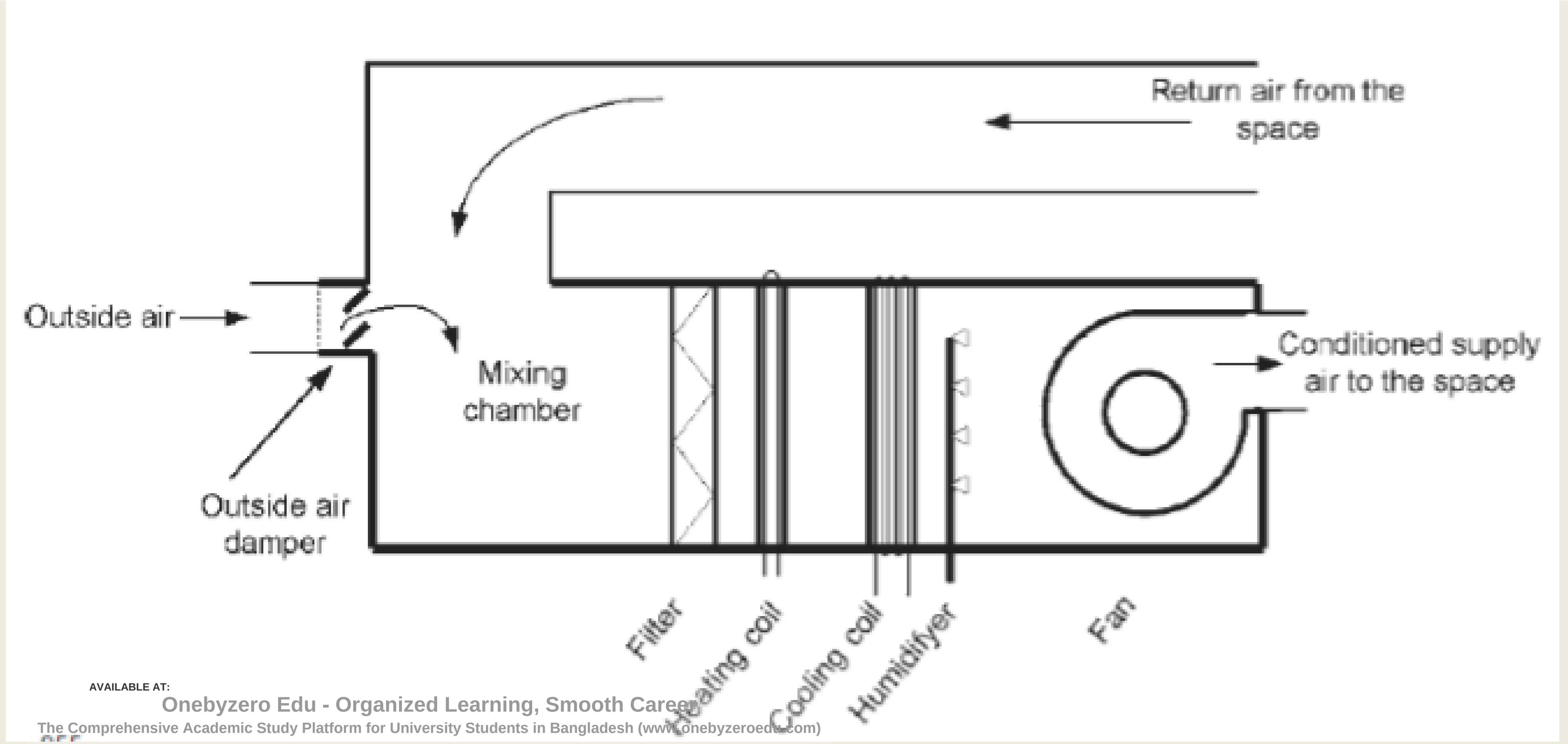
The first air conditioner, designed and built in Buffalo by Carrier, began working on 17 July 1902.

Willis Carrier

Equipments Used in an Air Conditioning System

1. Circulation fan: The main function of this fan is to move air to and from the room.
2. Air conditioning unit: It is a unit which consists of cooling and dehumidifying processes for summer air conditioning or heating and humidification processes for winter air conditioning.
3. Supply duct: It directs the conditioned air from the circulating fan to the space to be air conditioned at proper point.
4. Supply outlets: These are grills which distribute the conditioned air evenly in the room.
5. Return outlets: These are the openings in a room surface which allow the room air to enter the return duct.
6. Filters: The main function of the filters is to remove dust, dirt and other harmful bacteria from the air.

Basic Air-Conditioning System



Classification of Air Conditioning System

The air conditioning systems may be broadly classified as follows:

1. According to the purpose-

(a) Comfort air conditioning system

(b) Industrial air conditioning system

2. According to season of the year-

(a) Winter air conditioning system

(b) Summer air conditioning system

(c) Year-round air conditioning system

3. According to the arrangement of equipment-

(a) Unitary air conditioning system

(b) Central air conditioning system

Comfort vs. Industrial Air-conditioning

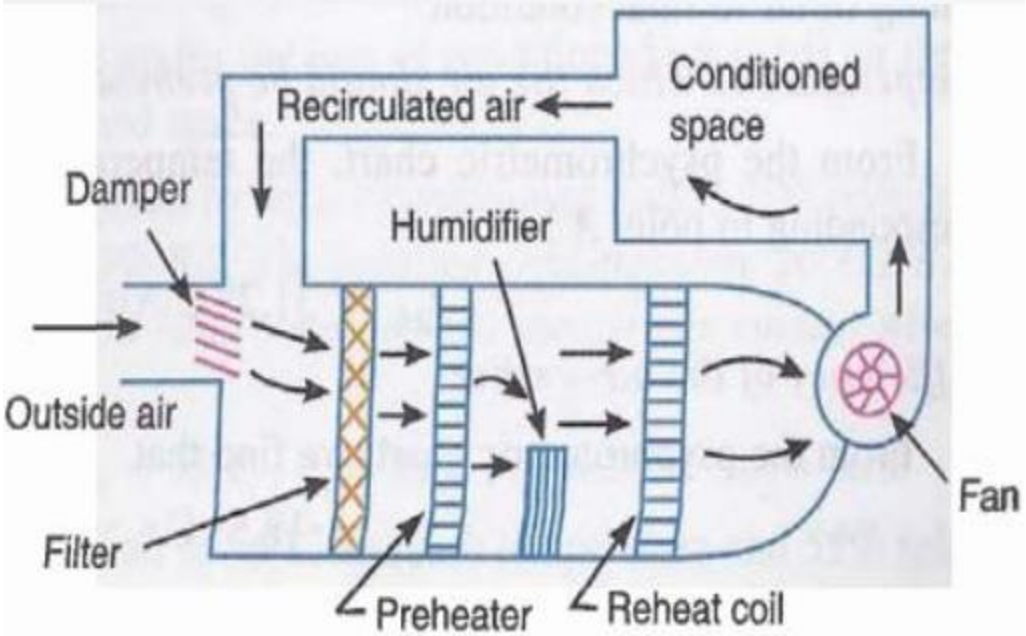
Comfort air-conditioning is for human comfort. It involves control of space temperature, humidity, air-motion and cleaning/filtering of air.

Industrial air-conditioning does not have the primary function of conditioning air for human comfort. This type of air conditioning system is used in textile mills, paper mills, machine-parts manufacturing plants, tool rooms, photo-processing plants etc.

Winter Air Conditioning System

In winter air conditioning, the air is heated, which is generally accompanied by humidification.
The outside air flows through a damper and mixes up with the recirculated air. The mixed air passes through a filter to remove dirt, dust and other impurities.

The air now passes through a preheat coil in order to prevent the possible freezing of water and to control the evaporation of water in the humidifier.



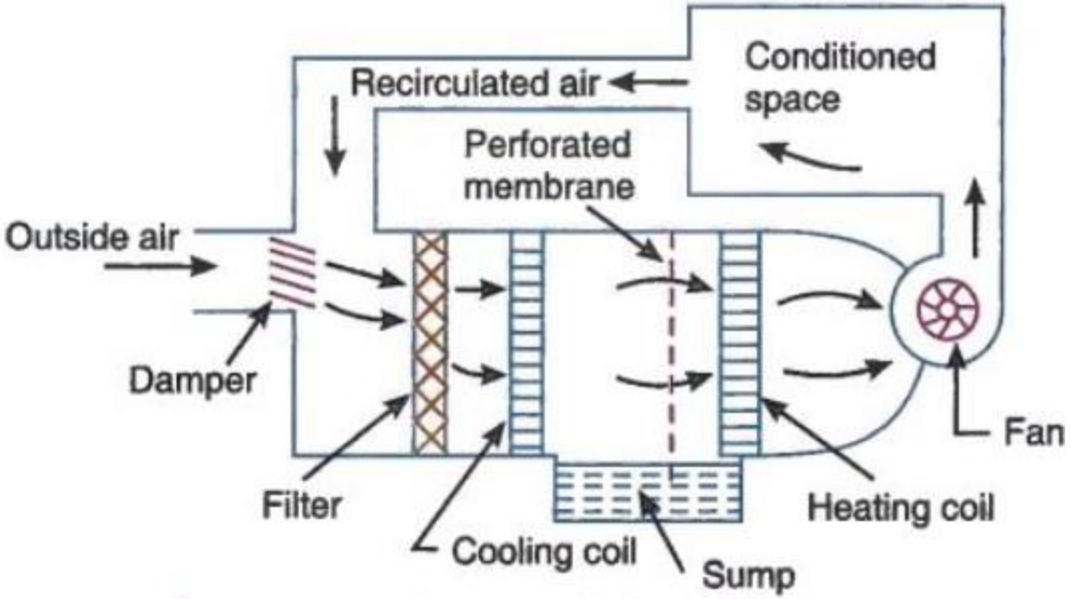
Winter air conditioning system

After that, the air is made to pass through a reheat coil to bring the air to the designed dry bulb temperature. Now, the conditioned air is supplied to the conditioned space by a fan. From the conditioned space, a part of the used air is exhausted to the atmosphere by the exhaust fans or ventilators. The remaining part of the used air (known as recirculated air) is again conditioned.

Summer Air Conditioning System

Here the air is cooled and generally dehumidified.

The outside air flows through the damper, and mixes up with recirculated air The mixed air passes through a filter to remove dirt, dust and other impurities. The air now passes through a cooling coil. The coil has a temperature much below the required dry bulb temperature of the air in the conditioned space.

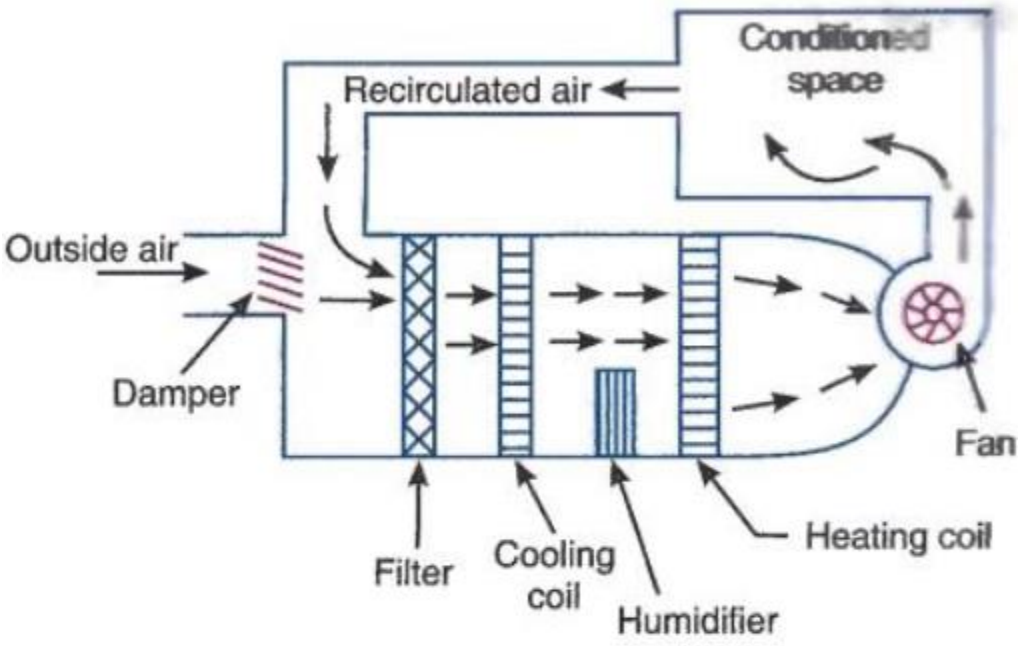


Summer air conditioning system

The cooled air passes through a perforated membrane and loses its moisture in the condensed form which is collected in a sump. After that, the air is made to pass through a heating coil which heats up the air slightly. This is done to bring the air to the designed dry bulb temperature and relative humidity. Now the conditioned air is supplied to the conditioned space by a fan. A part of air is exhausted and the rest is recirculated.

Year-Round Air Conditioning System

The year-round air conditioning system should have equipment for both the summer and winter air conditioning.
The outside air flows through the damper and mixes up with the recirculated air. The mixed air passes through a filter to remove dirt, dust and other impurities.
In summer air conditioning, the cooling coil operates to cool the air to the desired value.
The dehumidification is obtained by operating the cooling coil at a temperature lower than the dew point temperature.



Year-round air conditioning system

In winter, the cooling coil is made inoperative and the heating coil operates to heat the air. The spray type humidifier is also made use of in the dry season to humidify the air.

Air Conditioning Systems

Zoned A/C System

- In many buildings there is a variety of spaces with different users and varying thermal loads. When a system is designed to provide independent control in different spaces, each space is called a **Zone.**
- Zoning leads 4 broad categories of A/C system:
  - Unitary, refrigeration-based systems
  - All-air systems
  - Air-and-water systems
  - All-water systems

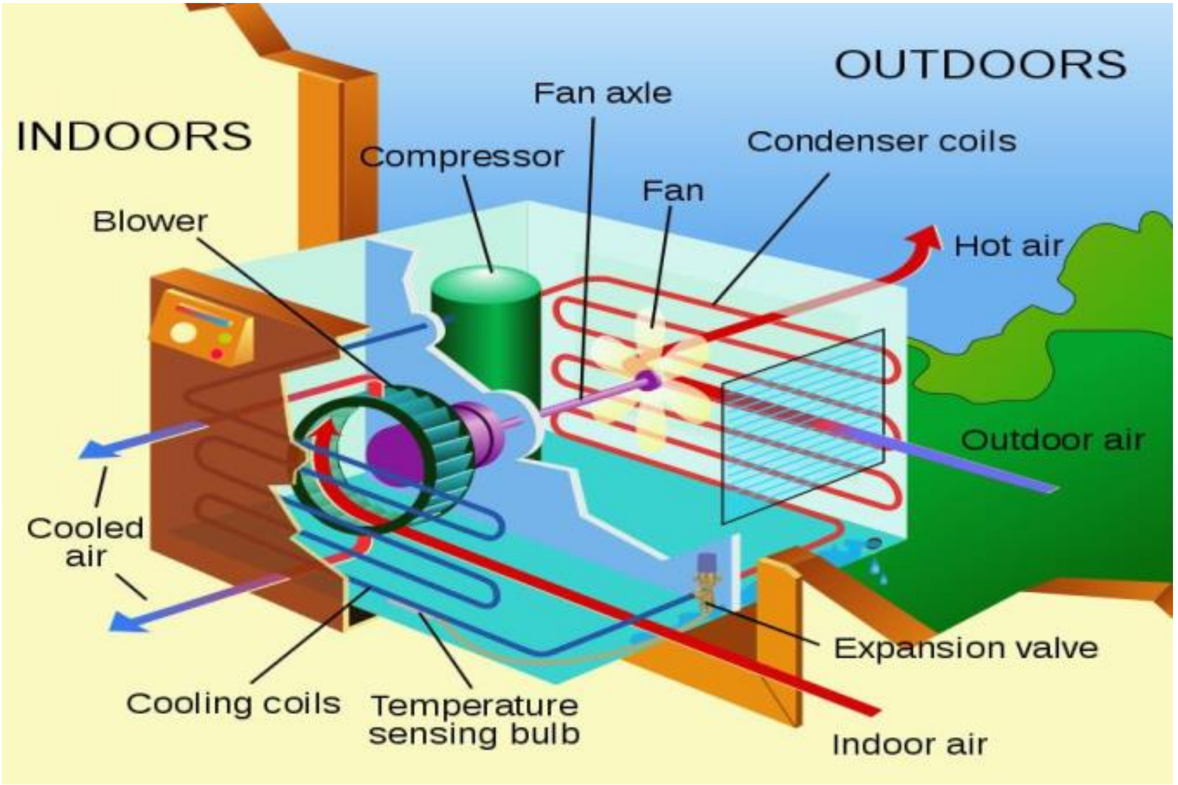
Air Conditioning Systems

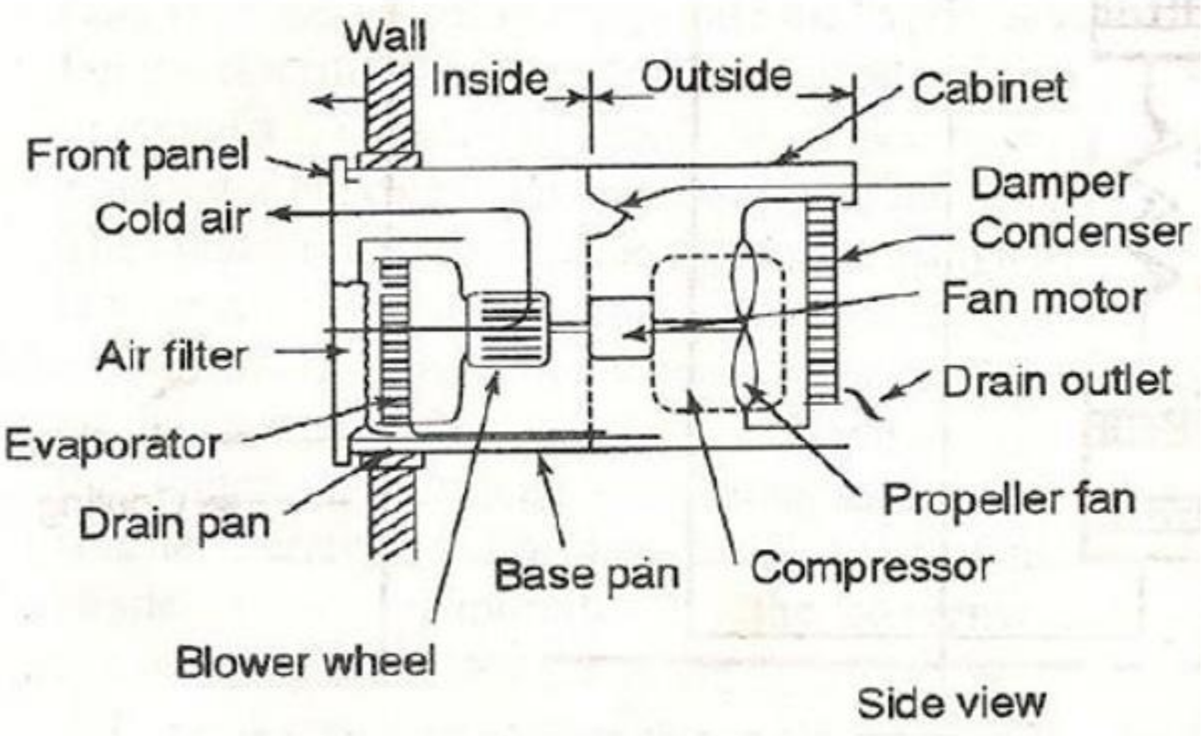
1. Unitary, Refrigeration-based systems
   a. Single Package Units
   b. Split Package Units

Air Conditioning Systems

Single Package Units

Window Air Conditioner

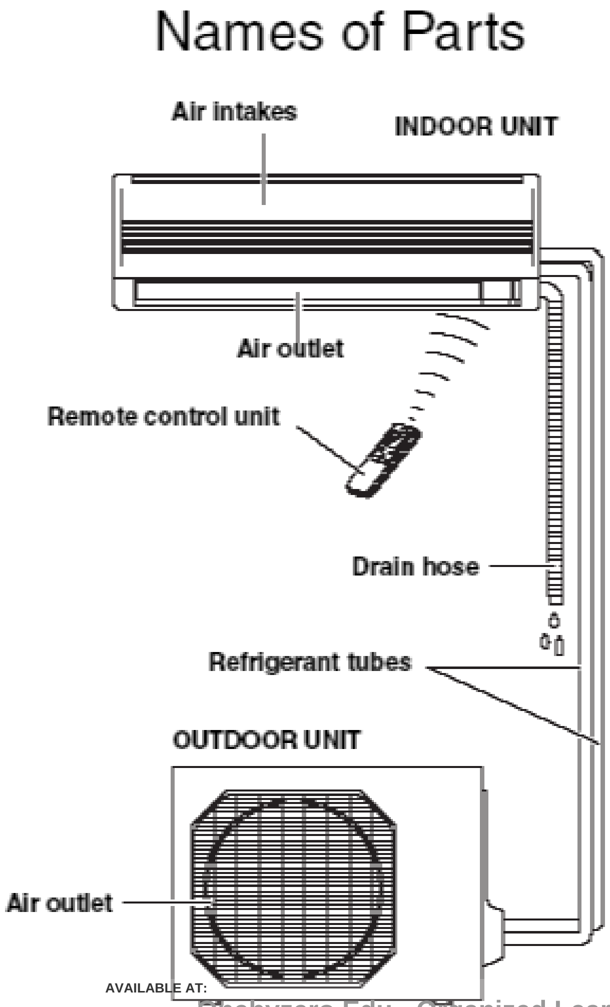




Air Conditioning Systems

Split Package Units

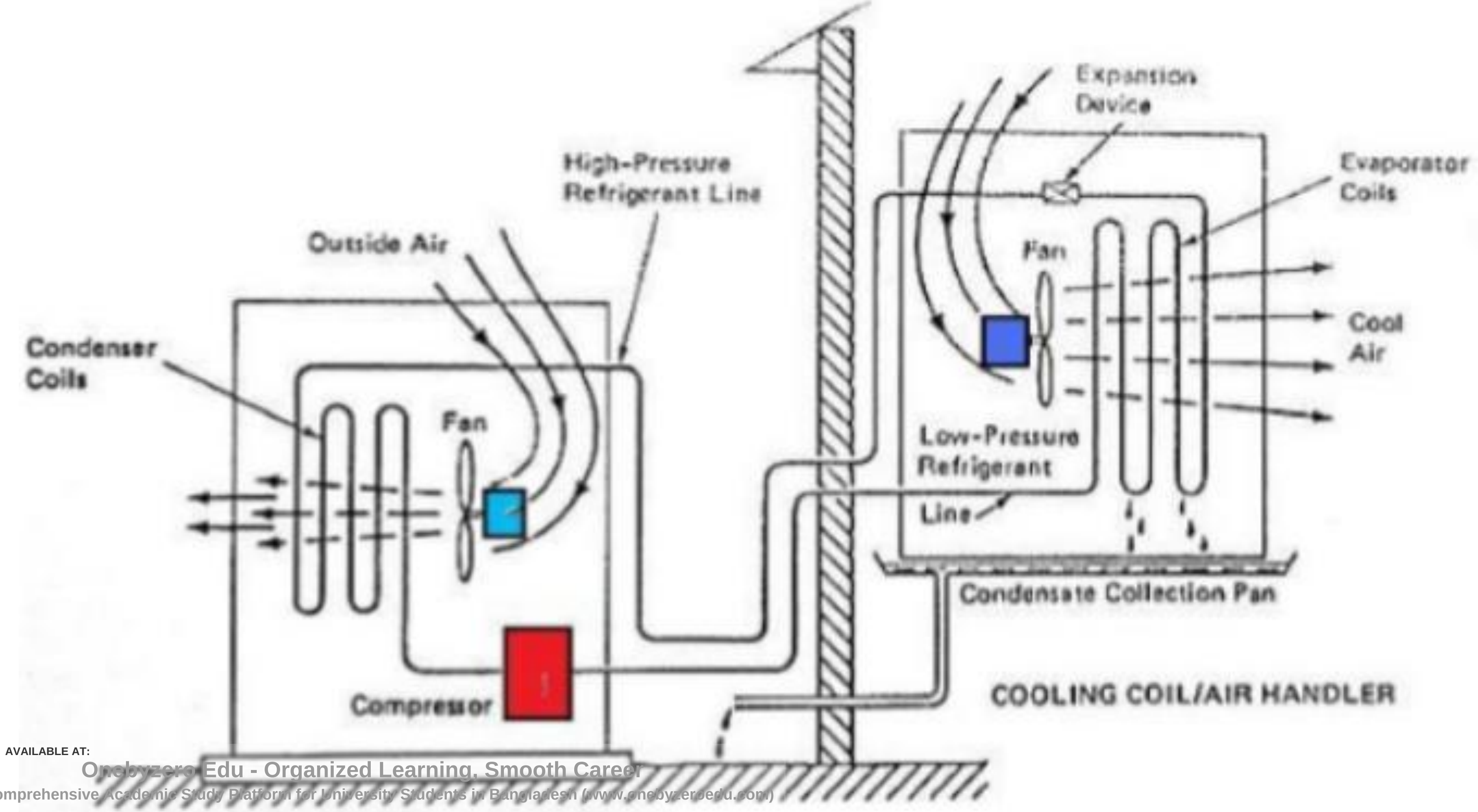
Split System



Air Conditioning Systems

Split Package Units

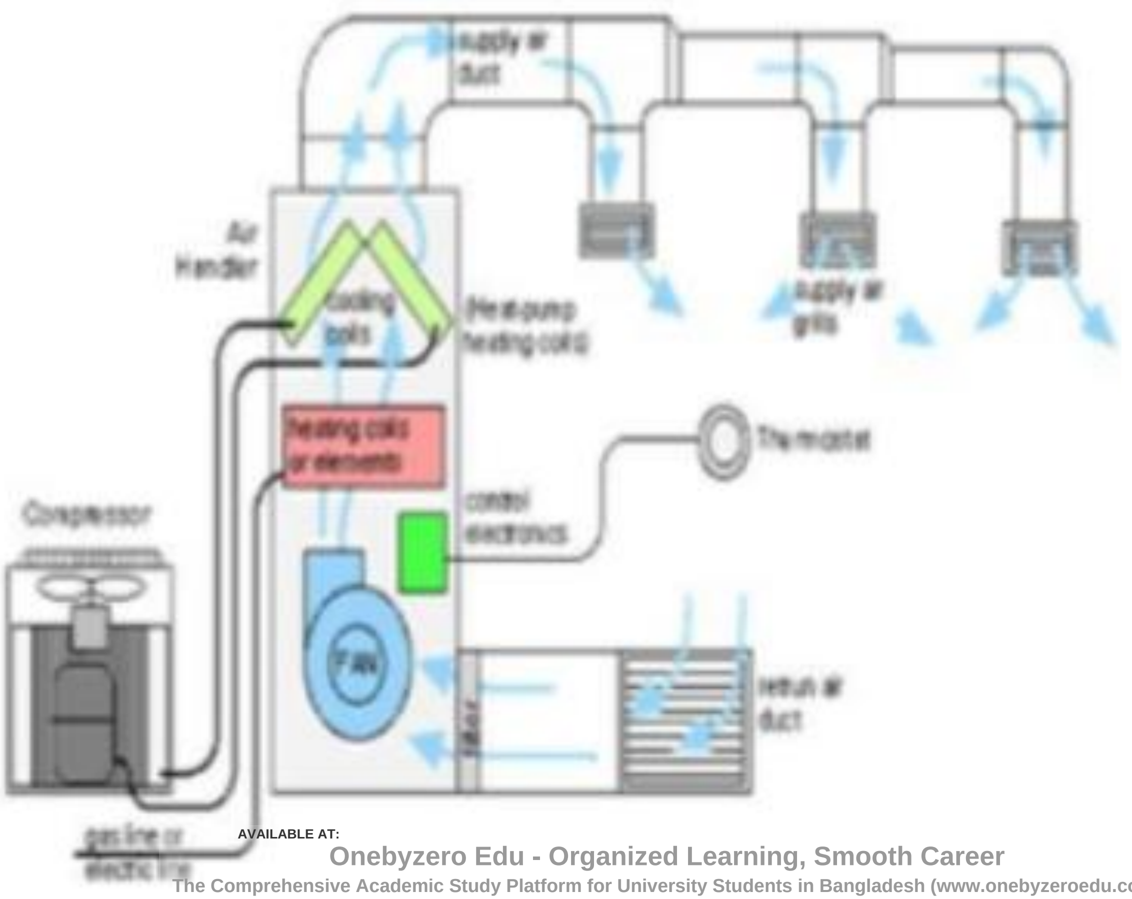
Split System



Air Conditioning Systems

Split Package Units

Ducted Split Type A/C



Air Conditioning Systems

Split Package Units

Multi Split Type A/C

Air Conditioning Systems

Split Package Units

Chiller Type or Central A/C