Refrigeration and Air Conditioning
History and Fundamentals

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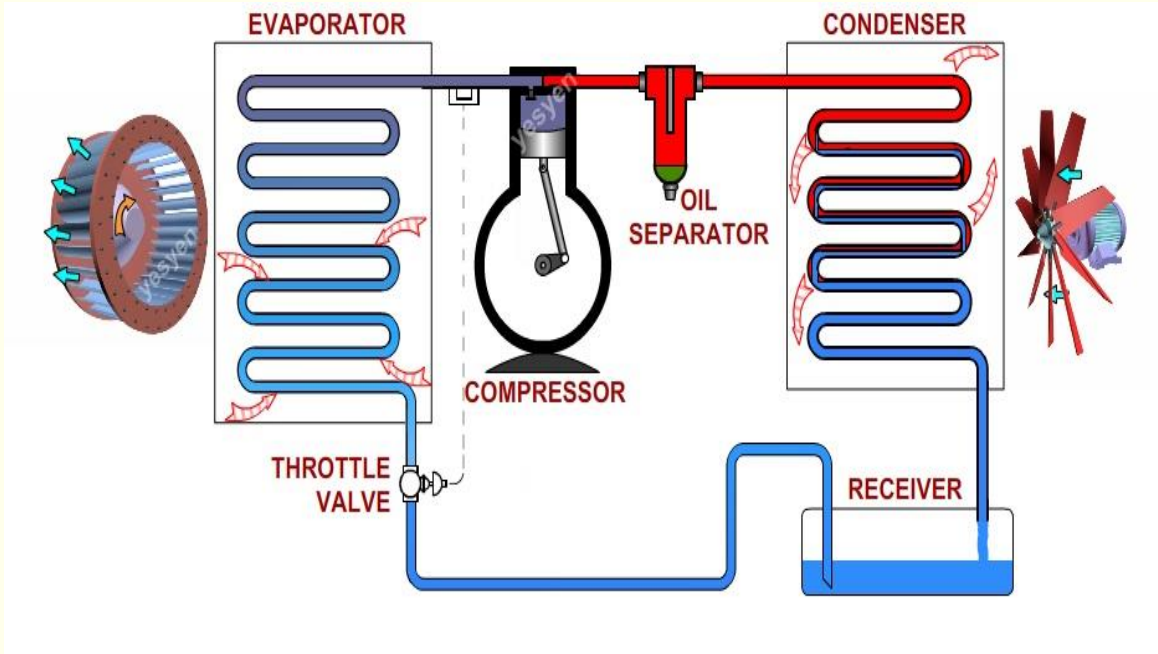
Refrigeration - Definition

- Process of Cooling of fluids to temperatures lower than those available in the surroundings at a particular time and place.

- Refrigeration is not cooling !!!
  - Cooling of Coffee
  - Cooling of water by adding ice (?)



Unit of Refrigeration capacity

- The rate of heat transfer that required to make 1 short ton (907 kg) of pure ice per day from water at 0 ℃.

- Latent heat of fusion of ice = $334\ kJ/kg$

- Heat extracted per 24 hour $= 907\ \text{kg} * 334 \frac{kJ}{kg} = \frac{3{,}02{,}938}{24\ hr}\ kJ = \frac{12{,}622.416}{3600} \frac{kJ}{sec} = 3.506 \frac{kJ}{s} = 3.506\ kW$

- 1 ton of Refrigeration = 3.506 kJ/s =3.506 kW = 4.701 HP

Appliance	Power Rating	Hours per Day	Common Power Use in a Day	Percentage of Power for the Day
Split System Air Con	1200W	6	6 kWh	18.0%
Pool Pump	1100W	8	8.8 kWh	26.5%
Electric Hot Water	3600W	1.5	5.4 kWh	16.2%
Electric Cooktop	2400W/element	1	4.8 kWh	14.4%
Fridge	150W	12	1.8 kWh	5.4%
Toaster	900W	0.2	0.18 kWh	0.5%
Microwave	1200W	0.2	0.24 kWh	0.7%
Kettle	2400W	0.2	0.48 kWh	1.4%
TV	200W	5	1.0 kWh	3.0%
Sound System	60W	4	0.24 kWh	0.7%
Phone Chargers	15W x 2	5	0.15 kWh	0.5%
Laptop	100W	2	0.2 kWh	0.6%
Combined Lighting	130W (LED)	5	0.65 kWh	2.0%
Bathroom Fan	60W	0.5	0.03 kWh	0.1%
Washing Machine	2400W	4 hrs / week	1.37 kWh	4.1%
Standby Appliances	120W	16	1.92 kWh	5.8%
TOTAL			**33.3 kWh per Day**	

Applications of Refrigeration

- Food Processing and Preservation
- Chemical and Process Industries
- Comfort and Industrial Air Conditioning
- Miscellaneous

History of Refrigeration

- Natural Refrigeration - (Prehistoric times to 19th century)
- Use of natural ice, Cooling at night, Evaporative Cooling, Use of salt solutions
- Artificial Refrigeration - 19th century onwards

Natural Refrigeration -Limitations

- Local conditions dependency
- Uncertainty due to weather
- Difficult to produce large amount of Refrigeration
- Not available to everybody

Artificial Refrigeration - history

- 1755 – Scottish Professor William Cullen produces a small quantity of Ice by evaporating ether under vacuum.

- **Principle** :

- Absorption of large quantity of heat when a liquid boils at low temperature under the action of vacuum.

Vapour Compression Refrigeration System

- 1805 – Oliver Evans (American) described a closed cycle for producing refrigeration in a continuous manner

- 1835 – Jakob Perkins patented and built the system described by Oliver Evans using Ethyl Ether as the refrigerant in London.

Domestic Refrigerator

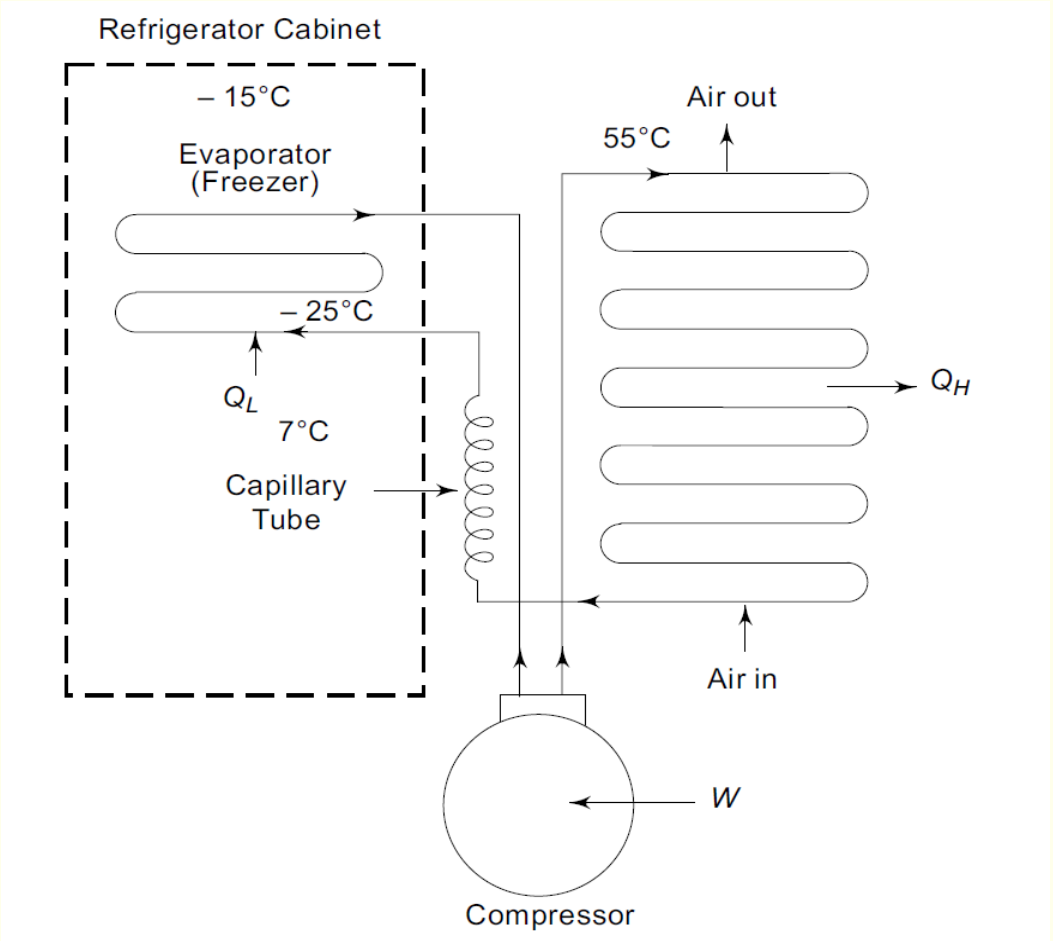
- Natural Ice based domestic Ice box is invented in 1803 and used for more than a century.

- GE introduced the first mechanical domestic refrigerator in 1911 in USA followed by Frigidaire in 1915 and Kelvinator in 1918.

- Growth of Compressor systems can be attributed to the simultaneous development of Motors and compressors, better shaft seals, automatic controls and CFCs in 1930.

Domestic Refrigerator

- Evaporator is stored in the Chiller. produces -15°C while the refrigerant evaporates at -25°C.
- Natural Convection. Cold air goes down and the hot air goes up.
- Temperature in the refrigerator is maintained at 7°C.



Vapor Absorption Refrigeration system – History

- 1810 - John Leslies demonstrates the principle using water and H2SO4.
- 1860 – Ferdinand Carre invents aqua ammonia system in France
- 1878 – Windhausen develops water-H_2SO_4 system. H_2SO_4 is later replaced by LiBr
- 1922 – Swedish students Platen and Munter develops pump less absorption system
- 1926 – Albert Einstein and Leo Szilard patents a pumpless system

Other Landmark Events

- 1874 – Raoul Pictet designs the first SO_2 based system in Geneva
- 1877 – Carl Von Linde of Germany builds the first ammonia based system
- 1885 – Fraunz Windhaussen builds the first CO_2 based system in Germany .
- 1920 – Copeland and Edwards build iso-butane based domestic Refrigerator.

Other Pioneers

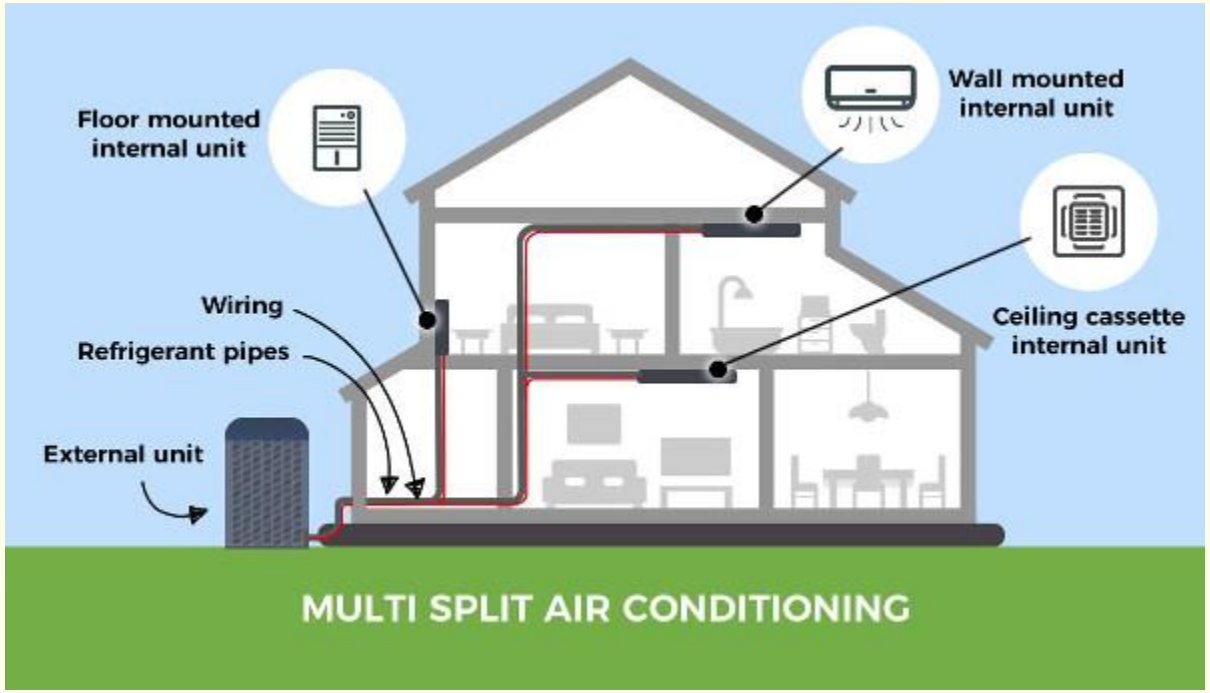
- Alexander Twining (US Engineer) received British patent in 1850 for a vapor compression system that uses Ether, Ammonia and Carbon dioxide.

- James Harrison obtains patent in 1856 for constructing Compression system using Ether, Alcohols or Ammonia.

- Charles Tellier of France patents a Dimethyl Ether based system in 1854.

Air Conditioning

- Treatment of Air so as to simultaneously control its temperature and moisture content, quality and circulation as required by occupants or products in the space.

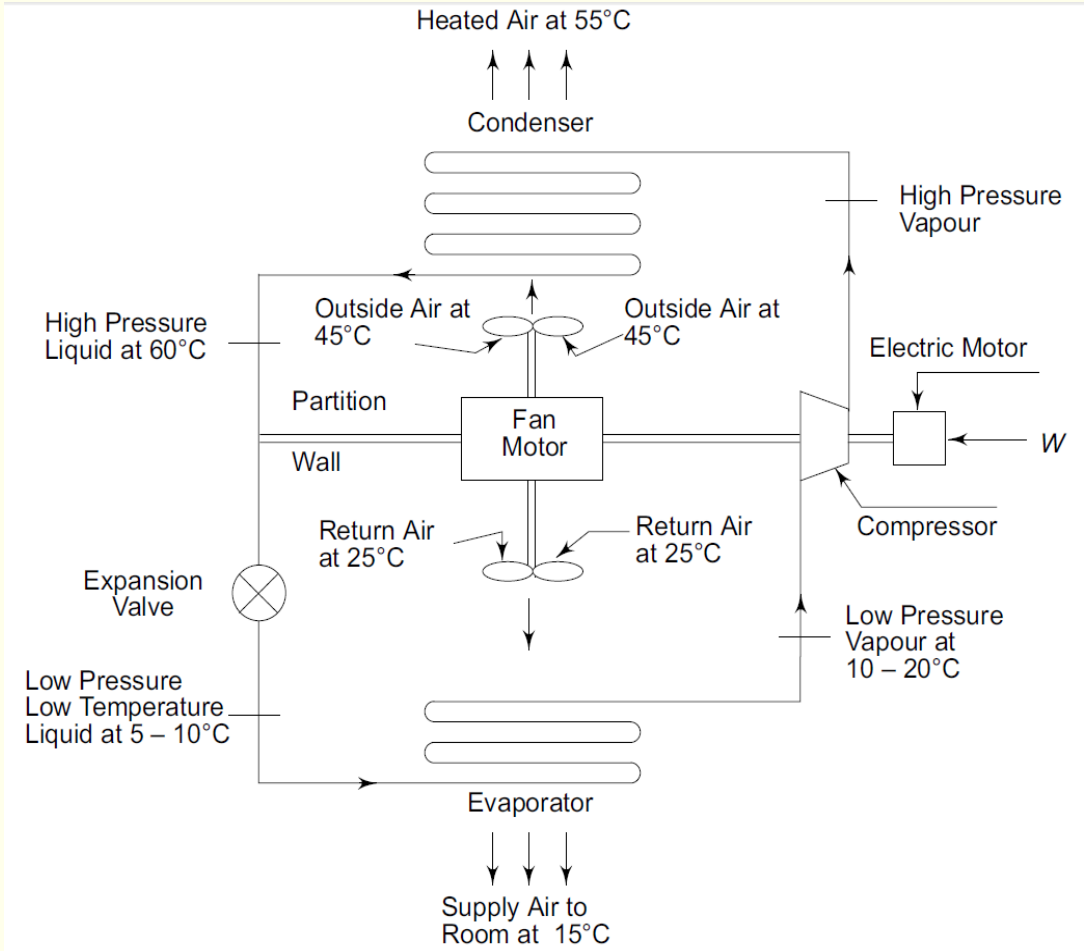


Air Conditioning System – Development

- 1891 – Eastman Kodak installs 1st system in NY for storage of photographic films
- 1894 – 1st domestic system installed in Hamburg
- 1904 – Wills Carrier designs a central system using air washers
- 1922 – Carrier develops Centrifugal compressors

Air Conditioner

- Compressor, condenser, expansion device, Evaporator
- Air Condenser or Water Condenser
- Ambient Air is used for condensation



Growth of Compression system

- The rapid growth is attributed to the simultaneous development of:

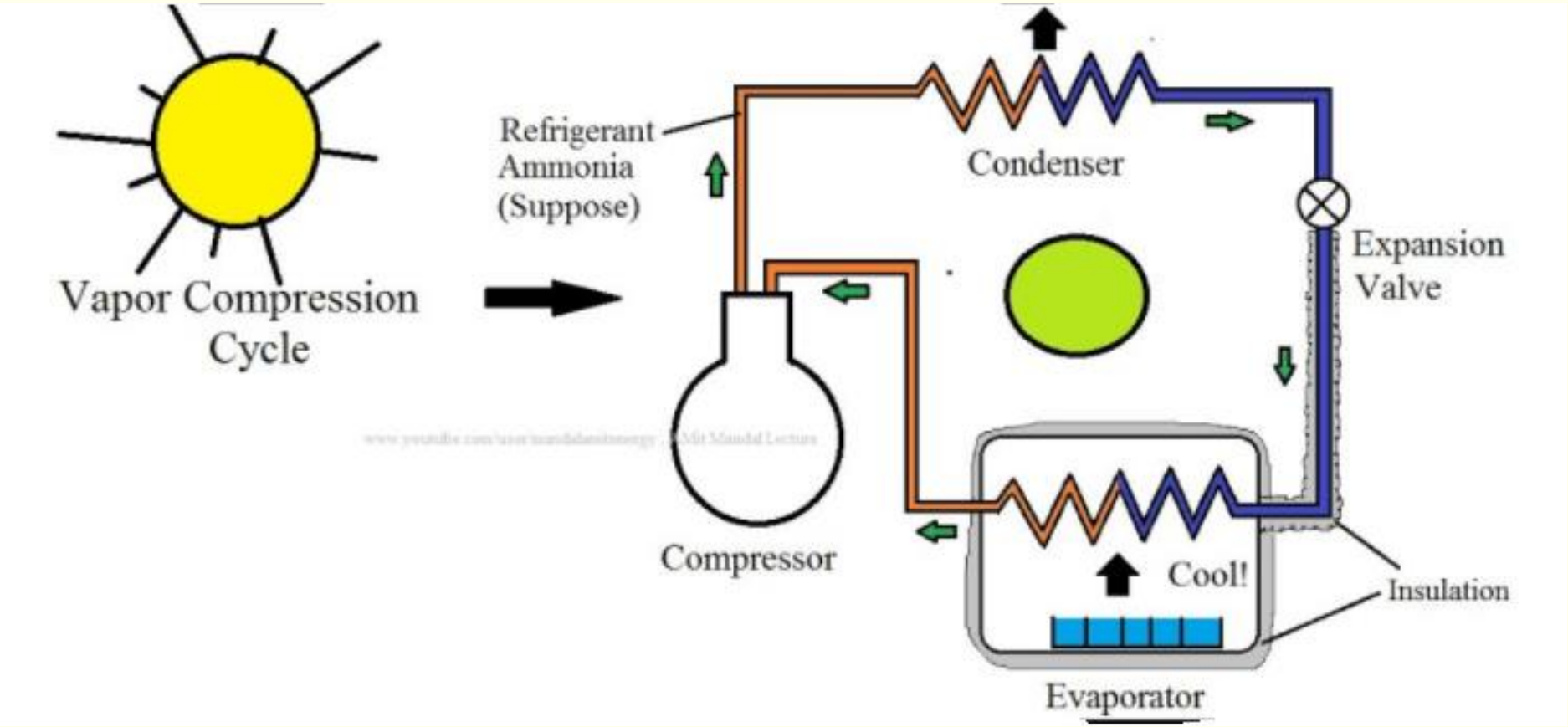
  –electric motors and compressors

  –better shaft seals

  –automatic controls, and

  –**Introduction of CFCS in 1930s!**

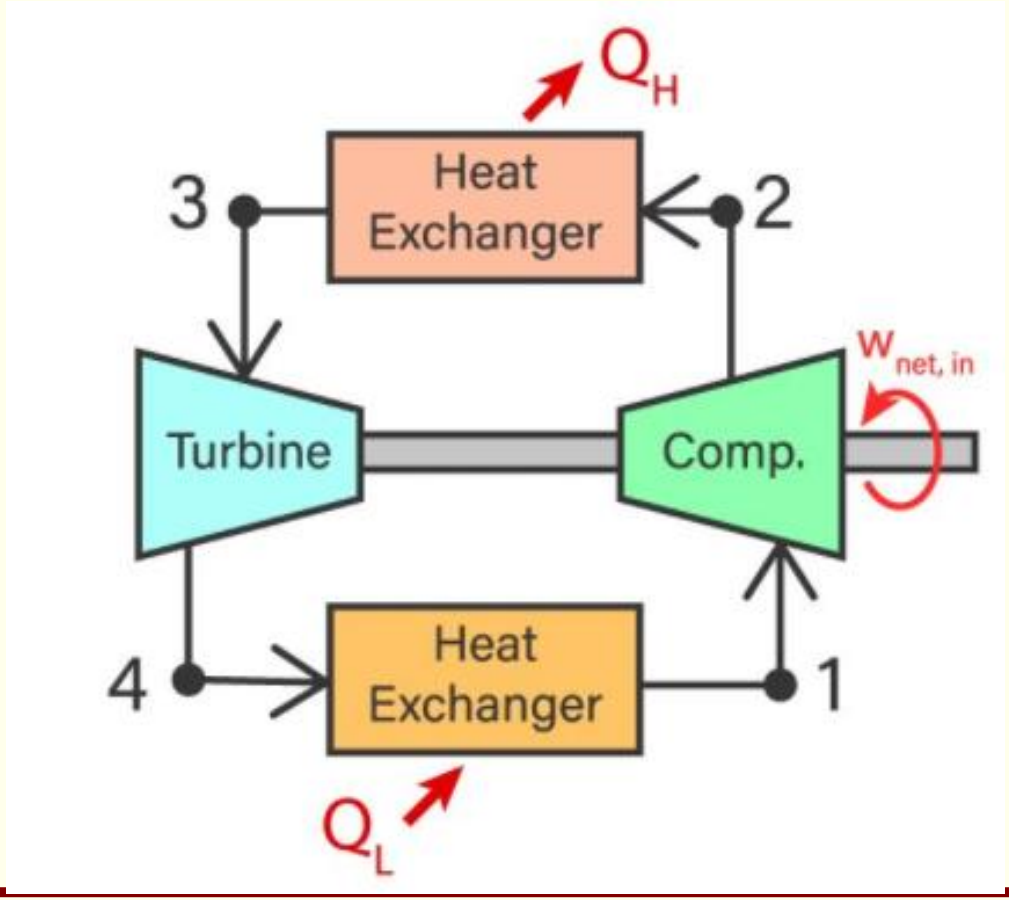
Solar energy based refrigeration systems



Solar energy based refrigeration systems

- Development of solar based absorption refrigeration systems begins in 1950s
- Professor G.O.G. L.f of America is one of the pioneers in this area
- USSR develops a 250 kg ice/day system using parabolic solar collectors
- 1st solar air conditioning system installed in Australia in 1966

Gas cycle refrigeration systems

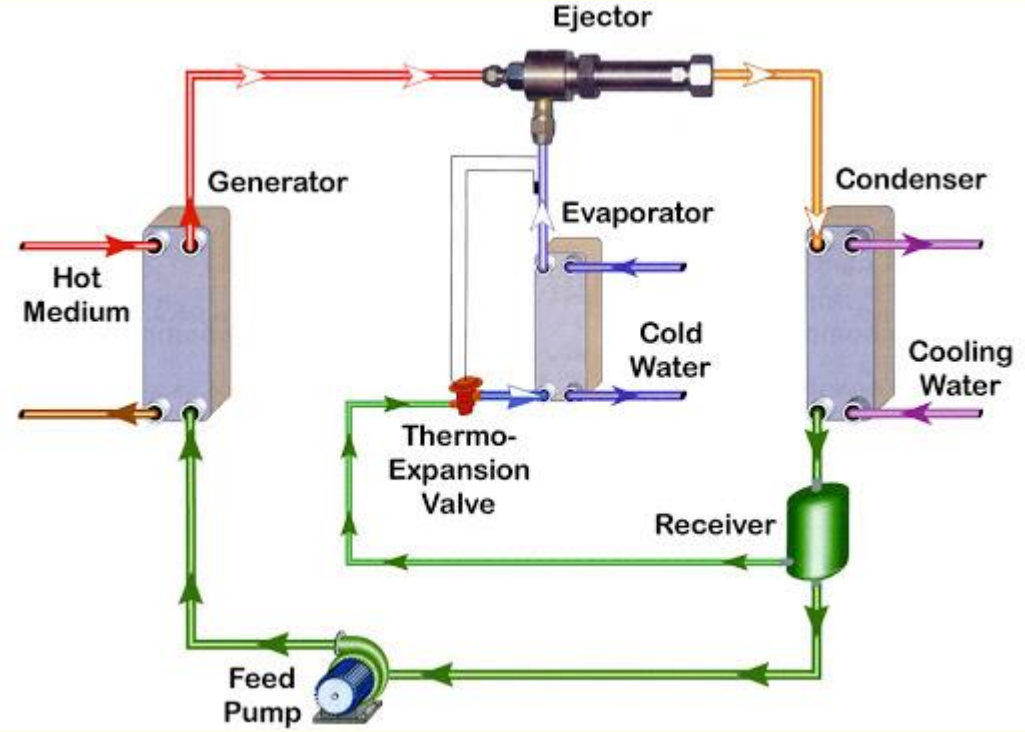


Gas cycle refrigeration systems

- Dr. John Gorrie develops the 1st air cycle refrigeration system in Florida in 1844
- Steam engine driven air cycle system developed by Alexander Kirk in 1862
- Bell and Coleman carry out several design improvements
- Paul Gifford perfects the open type machine in 1875
- Widely used for aircraft air conditioning

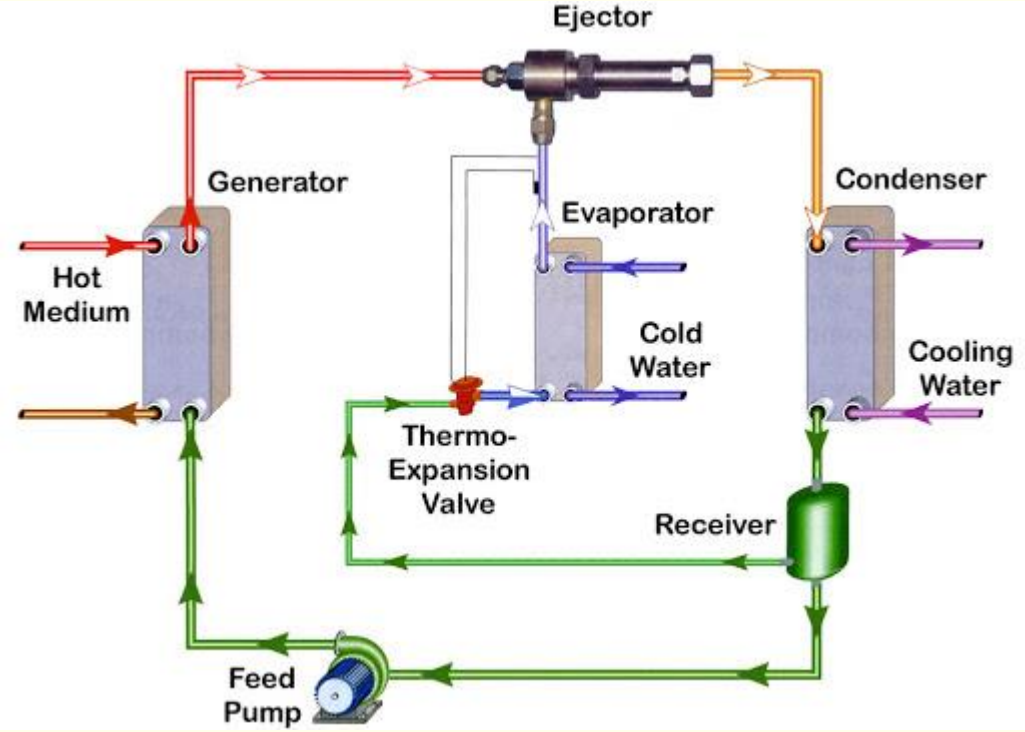
Vapour jet refrigeration systems

- French Engineer Maurice Leblanc develops steam jet refrigeration system in 1907
- Westinghouse commercializes the system in 1909 in Paris



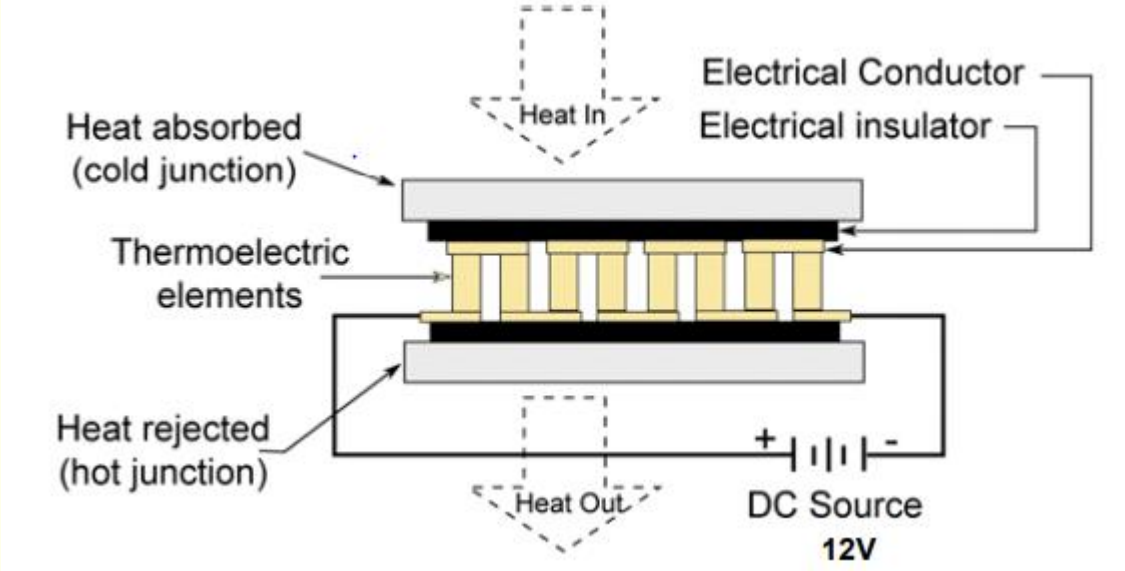
Vapour jet refrigeration systems

- From 1910 onwards these systems are used in breweries, warships etc.
- Russian engineer Badylkes develops closed cycle vapour jet systems in 1955



Thermoelectric Refrigeration systems

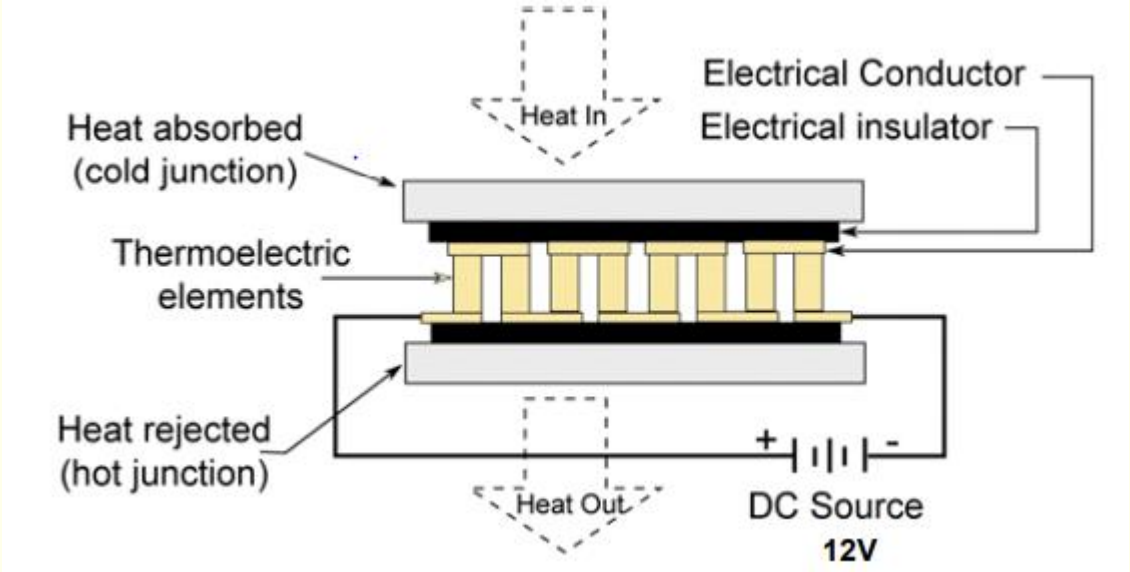
- 1821: Seebeck effect reported in Germany
- 1834: Peltier effect reported in France
- 1838: Lenz freezes a drop of water using Peltier effect with bisumth and antimony
- Russian scientist loffe pioneers semi conductor based thermoelectric systems



Thermoelectric Refrigeration systems

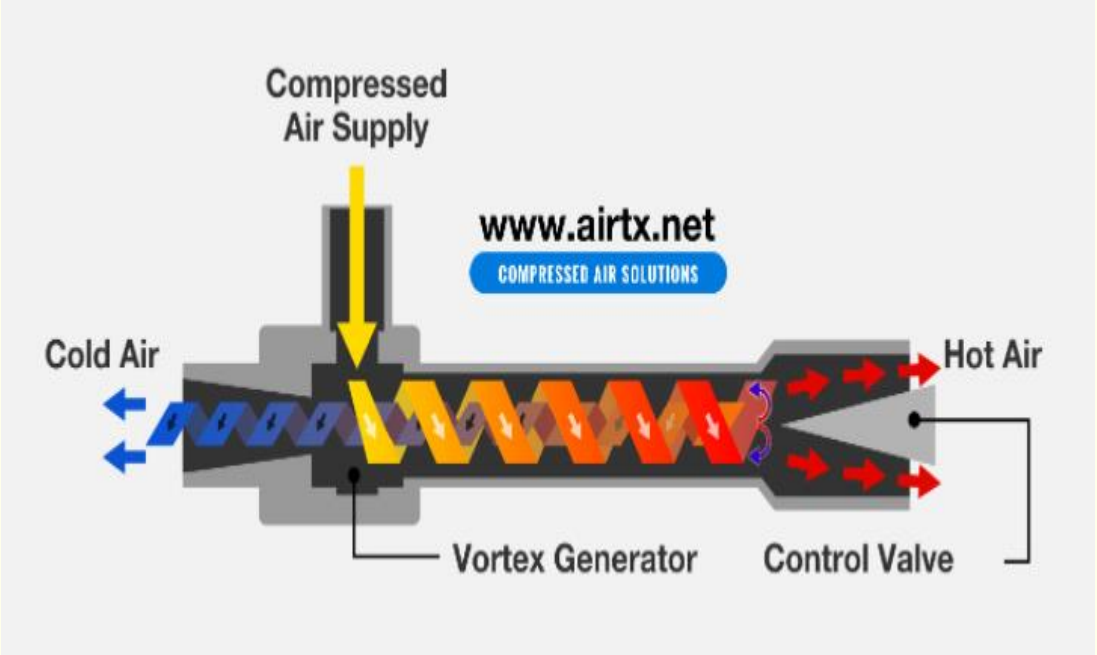
- Russia develops thermoelectric domestic refrigerators in 1949

- Large capacity systems are developed in USA since 1960



Vortex Tube Systems

- French engineer Georges Ranque discovers the Vortex (Ranque) effect in1931
- In 1945, German physicist Rudolph Hilsch explains the science behind Vortex tube
- Since then mainly used in special applications such as spot cooling of electronic and machine parts, cooling jackets etc



Applications

- Applications of refrigeration in:
  a) Food processing and preservation
  b) Chemical and process industries
  c) Special Applications

- Applications of air conditioning, namely:
  a) Industrial
  b) Comfort

Relation between refrigeration and air conditioning

- Refrigeration and air conditioning are generally treated in a single subject due to the fact that one of the most important applications of refrigeration is in cooling and dehumidification as required for summer air conditioning.

- In the form of a heat pump, a refrigeration system can also be used for winter heating

Major important area applications

- Food processing, preservation and distribution
- Chemical and process industries
- Special Applications
- Comfort air conditioning

Food processing, preservation & distribution

- Food preservation is one of the classical and most important applications of refrigeration.
- It is well known that food products can be preserved for a longer time, if stored at low temperatures
- Both live products as well as dead products can be preserved for longer times using refrigeration

Food processing, preservation & distribution

- Live products (e.q. fruits, vegetables)
- These products get spoiled due to:
  1. Bacterial activity, and
  2. Enzymatic processing

- Dead products such as fish, meat get spoiled due to bacterial activity

- The growth of bacteria and the rate of enzymatic processes are reduced at low temperature.

Effect of temperature on storage life

Food Product	Average useful storage life		
	0 °C	22 °C	38 °C
Meat	6-10	1	<1
Fish	2-7	1	<1
Poultry	5-18	1	<1
Dry meat & fish	>1000	>350 & <1000	>100 & <350
Fruits	2-180	1-20	1-7
Dry Fruits	>1000	>350 & <1000	>100 & <350
Leafy veg	3-20	1-7	1-3
Root crops	90-300	7-50	2-20
Dry seeds	>1000	>350 & <1000	>100 & <350

Cold chain

- For effective preservation of food products a cold chain is required

- A typical cold chain for fresh products consists of the following steps:
  a) Refrigeration for post-harvest treatment
  b) Refrigerated transport
  c) Refrigeration during food processing
  d) Cold storage for storing food
  e) Refrigeration at retail supermarkets etc.

Benefits of cold chain

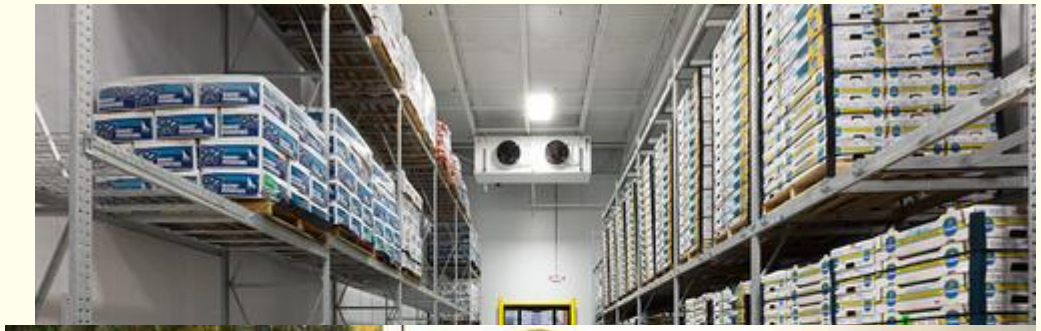
- Reduced food spoilage
- Excess crop of fruits and vegetables can be stored for use during peak demands and during off-season
- Food products can be made available in places where they are not grown
- Distress selling by farmers during on season can be prevented

Benefits of cold chain

- Conditions required for storage of food products vary from product to product.

- The storage life depends on:
  a) The type of the product stored
  b) Temperature
  c) Humidity
  d) Air velocity inside the cold storage, and
  e) Initial quality of the food products

Cold storage



Storage of other food products

- Food products such as meat, fish, poultry can be stored for longer periods in frozen conditions (= -25°C)

- Dairy products such as milk, butter, ice cream require refrigeration at various temperatures during processing and also during storage

- Beverages such as fruit juices, cold drinks, wine, beer etc. also require refrigeration during processing and storage

Applications of refrigeration in chemical & process industries

- For separation and liquefaction of gases in petrochemical industries and refineries
- For removal of heat of reaction in various chemical industries
- For dehumidification of process air in pharmaceutical industries etc
- For recovery of solvents, storage of low boiling point liquids etc.

Special applications of refrigeration

Manufacturing: Cold treatment of metals in the manufacture of precision parts, cutting tools to improve:

a) Dimensional accuracy
b) Hardness, wear resistance and tool life

Medical:

a) For storage of blood plasma, tissues etc.
b) For manufacture and storage of drugs
c) In surgery for local anesthesia

Special applications of refrigeration

- In construction for a) setting of concrete and b) for freezing wet soil to facilitate excavation
- Desalination of water by freezing
- Manufacture of ice, ice cubes, flakes etc.
- Preparation of ice skating rings
- For storage of vaccines, medicines in remote and rural areas

Solar Powered Cold Storages

Refrigerated Trucks

Applications of air conditioning

- Air conditioning is required for:

a) Providing thermal comfort to humans and other living beings - Comfort air conditioning

b) Providing conditions required for various products and processes in industries - Industrial air conditioning

Comfort air conditioning

- The objective of comfort air conditioning is to provide Thermal Comfort to the occupants
- Thermal comfort may be defined as "the state of mind that expresses satisfaction with its surroundings”
- Thermal comfort requires that the core temperature of a human body be maintained at about 37°C

Comfort air conditioning

- Similar to a HEAT ENGINE, a human body converts the chemical energy contained in food into heat and work
- To maintain temperature at required level, the body has to reject heat continuously
- The condition of the surroundings affects temperature of the body
- The basic objective of a comfort air conditioning system is to provide suitable conditions in the surroundings

Comfort conditions

- To provide comfort, the conditions in the occupied space should be kept at:
  a) Operative temperature: 20 to 26°C
  b) Humidity: Dew point temperature of 2-17°C
  c) Average air velocity: 0.15 to 0.25 m/s

- The exact values may vary slightly based on factors such as activity level, clothing etc.

- Depending on outside conditions (hot or cold) a cooling or heating system may be required to maintain inside conditions

Classification of comfort air conditioning systems

- Air conditioning systems for residences

  a) Commercial air conditioning systems

  b) Air conditioning systems for hospitals

  c) Mobile air conditioning systems etc.

- The required capacity, type of the cooling system, design aspects etc. vary significantly depending upon the final application

Industrial air conditioning

- The main purpose is to provide favorable surrounding conditions so that the required processes can be carried out and required products can be produced.
- The industrial air conditioning systems must also provide at least a partial measure of comfort to the people working in the industries
- Requirements vary from industry to industry

Industrial air conditioning

- Textile industries
- Printing presses
- Manufacturing of precision parts
- Semi-conductor industries
- Pharmaceuticals
- Photographic materials
- Computer rooms
- Mines, power plants etc.

Indoor Air Quality (IAQ)

- An air conditioning system must also provide a clean and healthy environment for the occupants

- Sick building syndrome is very common in poorly designed air conditioned buildings due to inadequate ventilation and use of improper materials

Air conditioning and energy

- Air conditioning systems must be energy efficient as they consume huge amount of energy

- Energy efficiency depends on:

a) Proper design of air conditioned building
b) Selection of suitable refrigeration systems
c) Selection of suitable indoor conditions
d) Selection of suitable controls
e) Use of thermal energy storage etc.

Conclusions

- The scope of refrigeration is very wide and applications are very diverse
- Literally thousands of scientists and engineers have contributed towards its development
- Current issues of concern are related to the development of eco-friendly and energy efficient systems that meet the requirements of the end user