Refrigeration & Air-Conditioning Systems

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ME 101 : Introduction to Mechanical Engineering
`http://zahurul.buet.ac.bd/ME101/`

Applications of Refrigeration System

1. Domestic refrigeration
2. Commercial & Industrial refrigeration
   - Food storage & processing
   - Ice rinks
   - Low temperature liquid storage/transportation
   - De-waxing of oil
   - Separation and condensation of gases
   - Solidification and separation of solid
   - Low temperature testing
   - Removal of heat of reaction etc.
3. Marine & transportation refrigeration
4. Comfort air-conditioning
5. Industrial air-conditioning

Food Preservation by Refrigeration

- Preservation of perishables by refrigeration involves the use of low temperature as a means of eliminating or retarding the activity of spoilage agents.
- For storage, the product is chilled and stored at some temperature above its freezing point. Frozen storage requires freezing of the product and storage at some temperature between -12° to -23°C.
- Factors affecting the quality of frozen product:
  - Nature and composition of product to be frozen
  - Care in selecting, handling & preparing the product for freezing
  - Freezing method
  - Storage condition

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.
- Functions of industrial air-conditioning include:
  - control of moisture of hygroscopic materials.
  - govern the chemical/bio-chemical reaction rates.
  - limit the variation of size of precision manufacturing items because of thermal expansion and contraction.
  - provide clean, filtered air for production of quality products.
  - ensure space temperature/humidity/air-motion for production requirement.

Refrigeration Capacity/Performance Parameters

- **1 ton refrigeration (1 RT or TR)**: heat absorbed by 1 (short) ton (2000 lb) of ice uniformly melting at 0°C in 24 hours. One RT refrigeration system that can freeze 1 ton (2000 lb) of liquid water at 0°C into ice at 0°C in 24 hr.

  $1\ RT = 3.516\ kW = 12000\ BTU/hr$

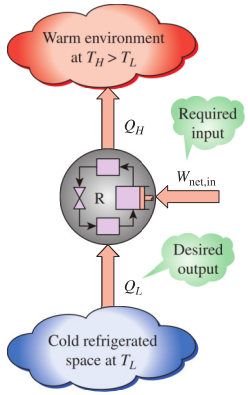
- **Coefficient of Performance**:

$$COP = \frac{Refrigeration\ Effect}{Net\ Work\ Required}$$

- kW/ton $\Rightarrow$ power required per ton of refrigeration

$$kW/ton = \frac{3.516}{COP}$$

COP: Refrigeration & Air-Conditioning System



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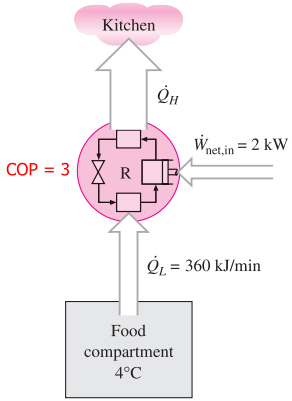

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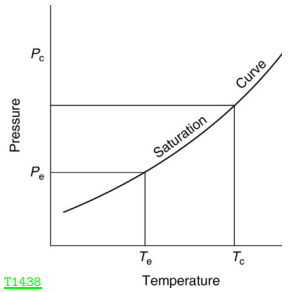
Coefficient of Performance, $COP_R = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_L}{W_{net,in}}$

Basic Refrigeration System using 2-Phase Refrigerant



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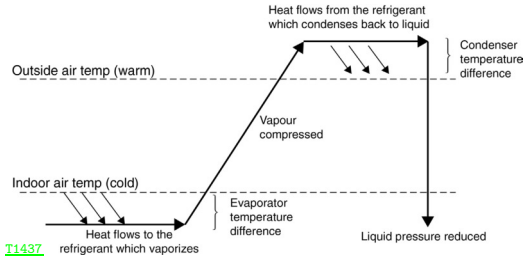

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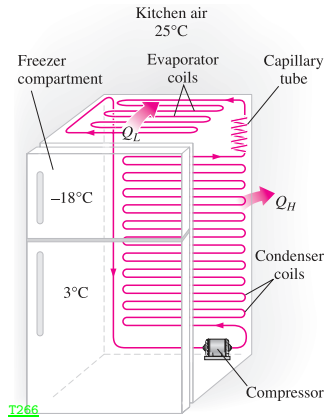
Basic Vapour Compression Refrigeration System



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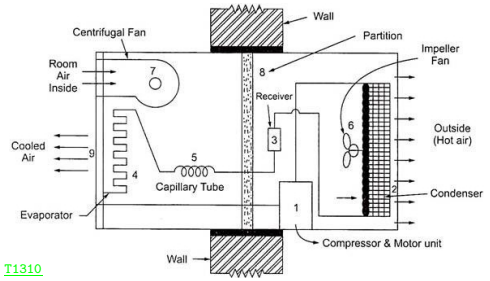

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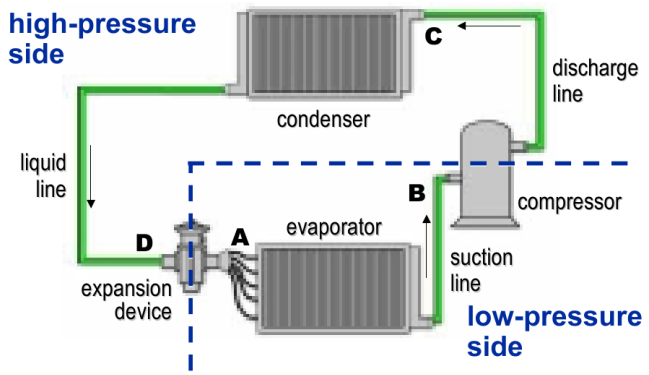

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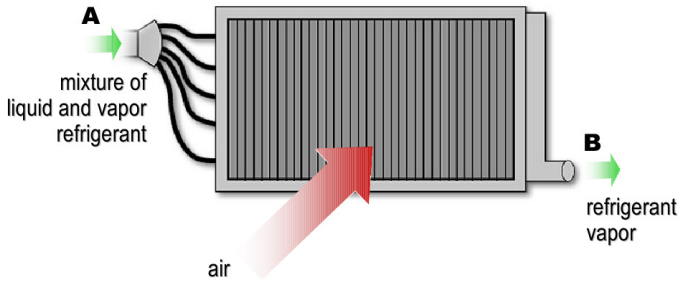
Evaporator



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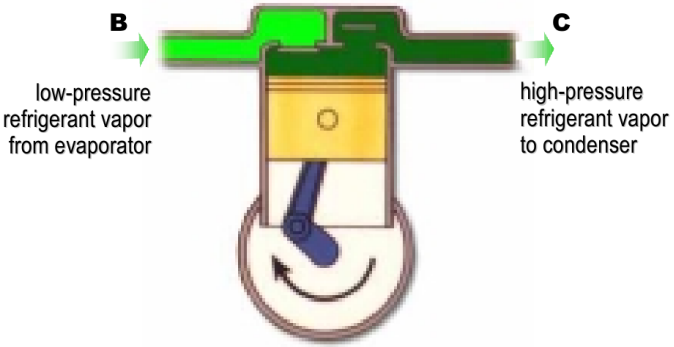
Compressor



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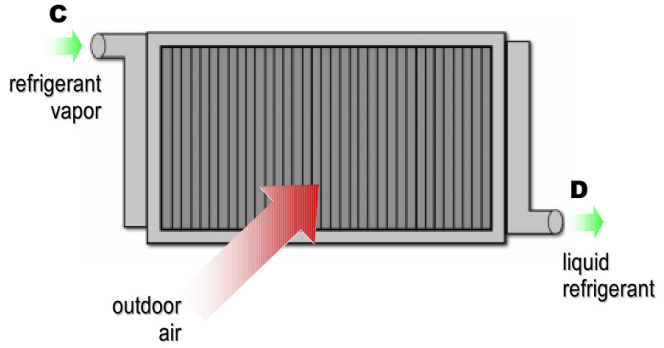
Condenser



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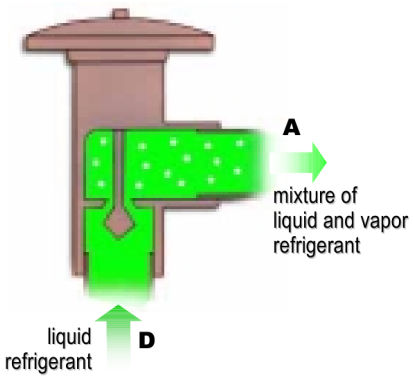
Expansion Device



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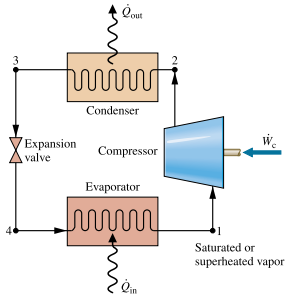
Basic Vapour-Compression Refrigeration Cycle



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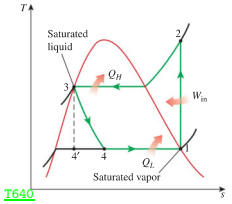

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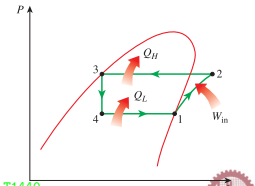

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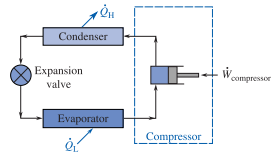
1 → 2: Isentropic compression, $P_{evap} \rightarrow P_{cond}$

2 → 3: Isobaric heat rejection, Q_H

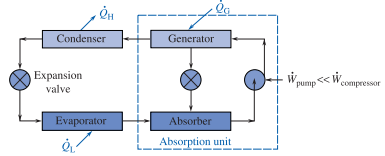
3 → 4: Isenthalpic expansion, $P_{cond} \rightarrow P_{evap}$

4 → 1: Isobaric heat extraction, Q_L

Vapour Absorption Refrigeration System



(a) Standard vapor-compression refrigeration.



(b) Absorption vapor-compression refrigeration.

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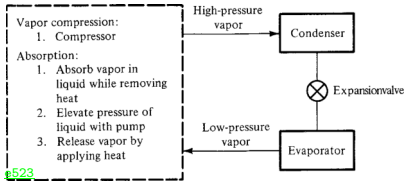

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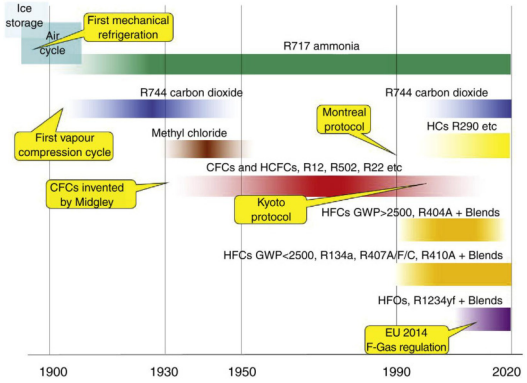
- Pump consumes significantly less electricity than compressor.
- A large amount of heat is required in the generator to release the dissolved vapour to result in low COP.
- Low grade heat (waste heat,solar energy etc.) can be used in the generator, and the system can be economic.

Refrigerants

Refrigerants are well known as the fluids providing a cooling effect during the phase change from liquid to vapour. These are used in refrigeration, air conditioning, and heat pump systems, as well as process systems.



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Some Desirable Properties of Refrigerants

- High latent heat of vaporisation ⇒ less refrigerant flow required
- High suction gas density ⇒ small and compact equipment
- Low compression ratio ⇒ low power consumption and higher volumetric efficiency of compressors.
- Positive but not excessive pressures at evaporating and condensing conditions.
- Low condensing pressure ⇒ lighter compressors, piping etc.
- High thermal conductivity ⇒ good heat transfer, reduced size of heat transfer equipment.
- Chemically stable, compatible with construction materials and miscible with lubricants.
- Non-corrosive, non-toxic, non-flammable and environmentally friendly.

Classifications of Refrigerants

A refrigerant may be a single chemical compound or a mixture (blend) of multiple compounds.

- **Azeotropic Mixtures**: these are blends of multiple refrigerants that evaporate & condense as a single substance & do not change their volumetric composition or saturation temperature when they evaporate or condense at a constant pressure.
- **Zeotropic Mixtures**: these are blends of multiple refrigerants that evaporate & condense as a single substance & do change their volumetric composition or saturation temperature when they evaporate or condense at a constant pressure.
- **Blends**: mixtures of two or more chemical compounds are blends.

Prefixes & Atoms in Refrigerants

Name	Prefix	Atoms Contained
Chlorofluorocarbon	CFC	Cl, F, C
Hydrochlorofluorocarbon	HCFC	H, Cl, F, C
Hydrobromofluorocarbon	HBFC	H, Br, F, C
Hydrofluorocarbon	HFC	H, F, C
Hydrocarbon	HC	H, C
Perfluorocarbon	PFC	F, C
Halon	Halon	Br, Cl (in some), F, H (in some), C

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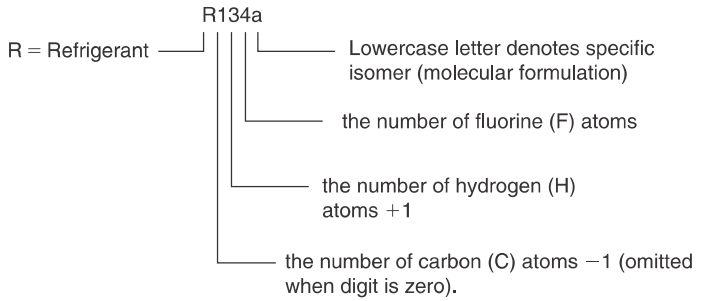
Numbering of Refrigerants: Halocarbon/Hydrocarbon



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- $CHCl_2CF_3 \rightarrow 3F + 1H + 2C \rightarrow R123$
- $CCl_3F \rightarrow 1F + 0H + 1C \rightarrow R11$
- $CHClF_2 \rightarrow 2F + 1H + 1C \rightarrow R22$
- $CH_4 \rightarrow 0F + 4H + 1C \rightarrow R50$
- $C_3H_8 \rightarrow 0F + 8H + 3C \rightarrow R290$

Safety Requirements/Environmental Issues of Refrigerants

- According to ANSI/ASHRAE 34-1997, safety groups are classified as follows:
  - A1 : lower toxicity & no flame propagation
  - A2 : lower toxicity & lower flammability
  - A3 : lower toxicity & higher flammability
  - B1 : higher toxicity & no flame propagation
  - B2 : higher toxicity & lower flammability
  - B3 : higher toxicity & higher flammability
- **Ozone Depletion Potential (ODP)**: of a refrigerant represents its effect on atmospheric ozone, and the reference point usually adopted is ODP = 1.0 fro CFC R11.
- **Global Warming Potential (GWP)**: of a gas may be defined as the index comparing the climate impact on its emission to that of emitting the same amount of carbon dioxide. R134a has a GWP equivalent to 1300 kg CO_2.

Refrigerant	Composition	Application	GWP (CO_2 = 1)	Safety class	Boiling point °C
HCFC					
R.22	$CHClF_2$	HT, MT	1810	A1	−41
HFCs chlorine free					
R.134a	CF_3CH_2F	HT, MT	1430	A1	−26
R.125	CF_3CHF_2	Blends	3500	A1	−48
R.143a	CF_3CHF_3	Blends	4470	A2	−48
R.32	CH_2F_2	HT	675	A2L	−52
R.404A	R.143a/125/134a	LT	3922	A1	−47
R.407C	R.32/125/134a	HT	1774	A1	−44
R.410A	R.32/125	HT	2088	A1	−51
Other R.32 Blends	R.32 + HFCs	LT	1770–2280	A1	−46 to −48
Other R.125 Blends	R.125 + HFCs	HT, MT, LT	1830–3300	A1	−43 to −48
HFOs					
R.1234yf	$CH_2 = CFCF_3$,	MAC, HT	4	A2L	−29
R.1234ze[E]	CHF = CHCF3	HT	6	A2L	−19
HFO/HFC Blends	R.1234yf/134a, R.1234ze[E]/R.134a	Various	600–1500	A1	−20 to −50

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Refrigerant	Composition	Application	GWP (CO_2 = 1)	Safety class	Boiling point °C
HCs halogen free					
R.290	C_3H_8 Propane	HT, MT	3	A3	−42
R.1270	C_3H_6 Propylene	LT	3	A3	−48
R.600a	C_4H_{10} IsoButane	MT	3	A3	−12
R.290 Blends	R.290 + HCs	HT, LT, MT	3	A3	−30 to −48
Other halogen free					
R.717	NH_3 Ammonia	LT (MT, HT)	0	B2	−33
R.744	CO_2 Carbon Dioxide	HT, MT, LT	1	A1	−57*

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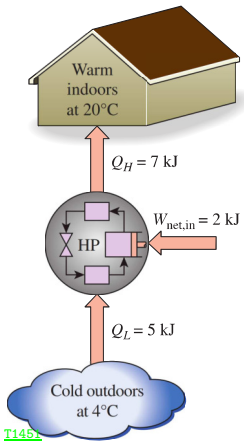
Heat Pump



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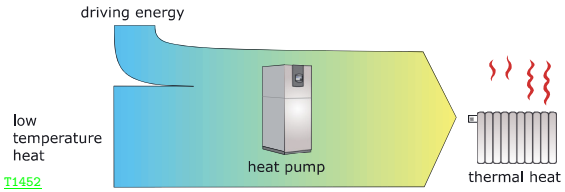

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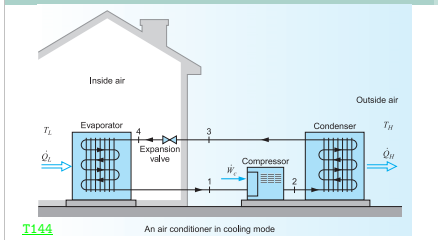
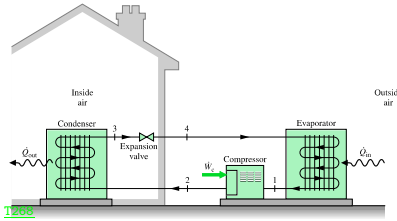
- $COP_R = \frac{Q_L}{W_{net,in}} = \frac{5}{2} = 2.5$
- $COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{7}{2} = 3.5$
- 7 kW electrical heating needs **7 kW** electricity.
- **2 kW** electricity is needed using heat pump.



T144 An air conditioner in cooling mode



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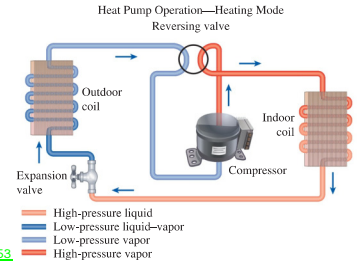
Cooling mode *Heating mode*



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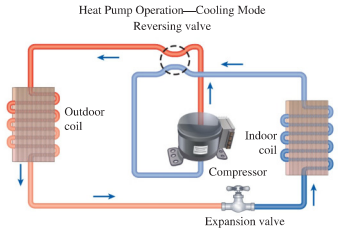
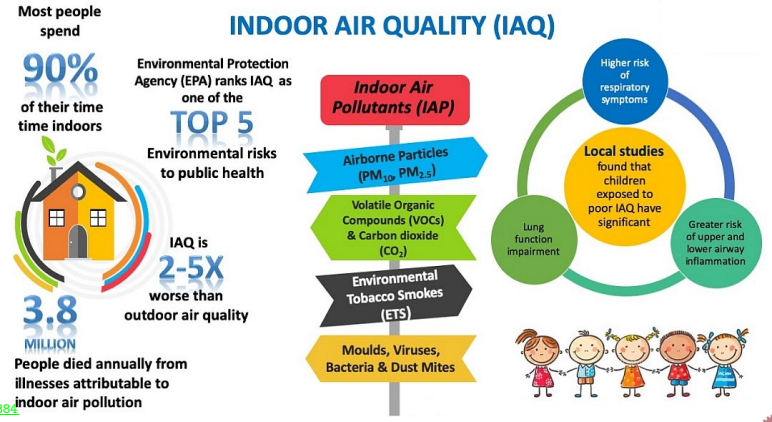


INDOOR AIR QUALITY



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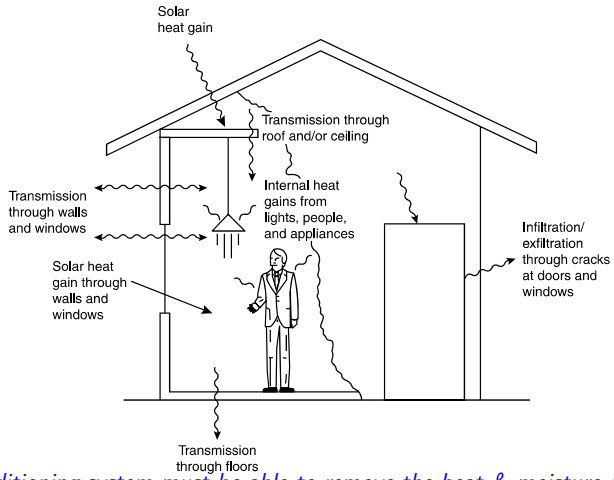
Heat Transfer to/from Building Space



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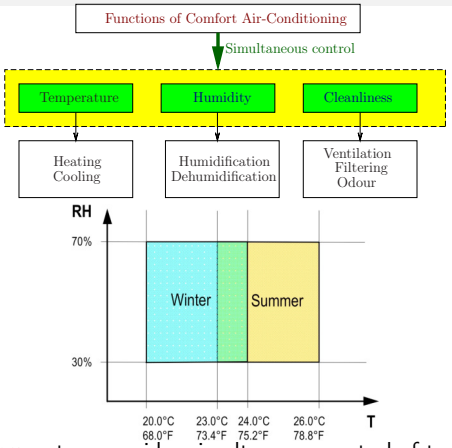
Air-conditioning system must be able to remove the heat & moisture gain/loss.

Comfort Air-Conditioning



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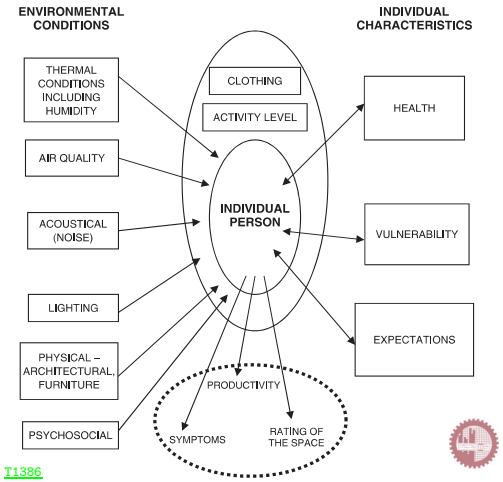
♣ **Air conditioning** system provides simultaneous control of temperature, humidity and cleanliness for thermal comfort. **Air-cooler** only cools air with reduction in moisture content of air.

Factors Influencing Thermal Comfort

1. Activity level
2. Clothing
3. Expectation
4. Air temperature
5. Radiant temperature
6. Humidity
7. Air speed



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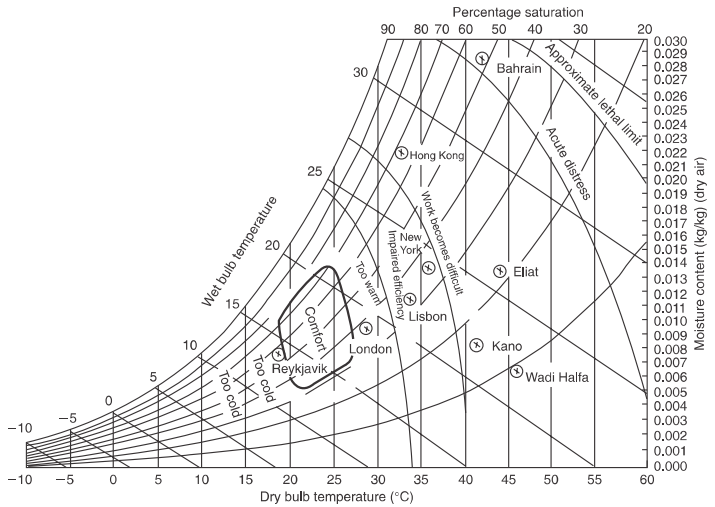
Typical Climate Conditions



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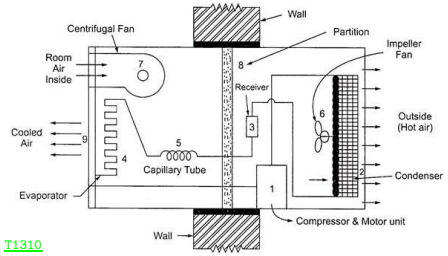
Window AC



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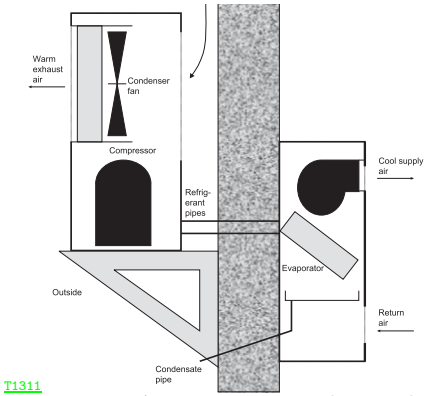
- Small (capacity <3 TR), compact and cheap.
- Noise and vibration are transmitted into room.
- Requires suitable wall for installation.

Split Type AC



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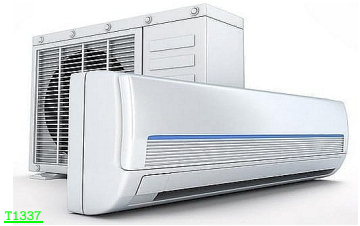

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Compressor/condenser part of the refrigeration system separate from the evaporator coil and connected by the refrigerant lines to the air system, which includes the evaporator.

Features	Window AC	Split-system
Number of units	One	Two
Pricing	Usually less expensive than similar split-systems	More expensive than similar window ACs
Installation	Comparatively easy*	Requires costly professional installation
Cooling capacity (residential)	Limited to 2.0 tons (24,000 BTU/hour)	Up to 5.0 tons (60,000 BTU/hour)
Efficiency	Generally less efficient	Generally more efficient
Noise	Quite noisy	Produces little noise
Maintenance	Relatively easy	Requires professional repair and cleaning services
Flexibility	Limited installation options	There are certain limitations, but generally more flexibility in installation. Split ACs can be installed even in rooms without a window. Multiple indoor unit installation is possible
Design	Unified design	Various design options

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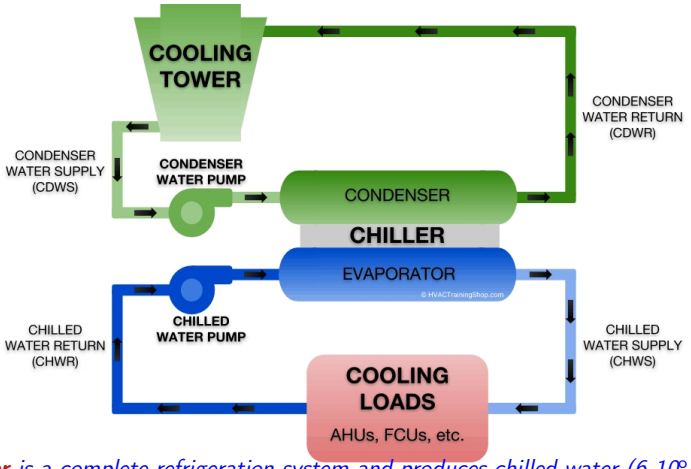
Central Air-conditioning System



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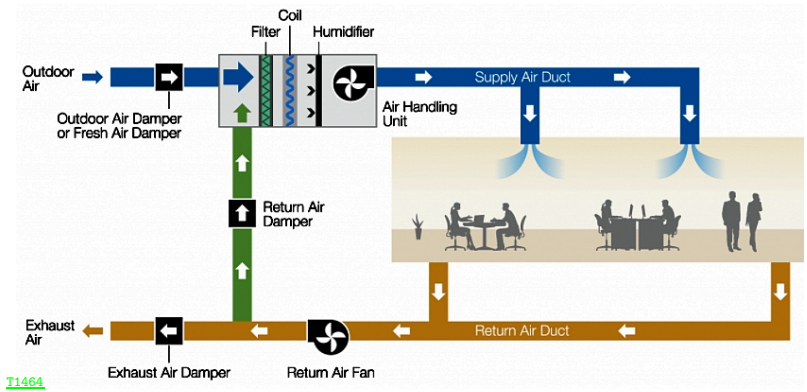
Chiller *is a complete refrigeration system and produces chilled water (6-10°C) for FCU and AHU.*



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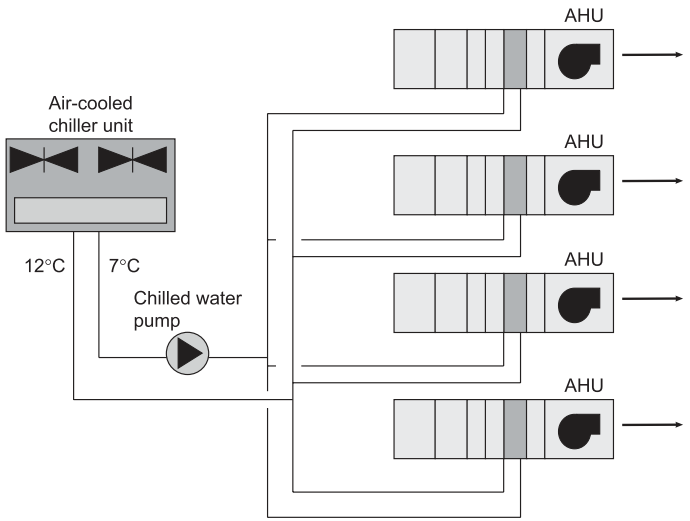

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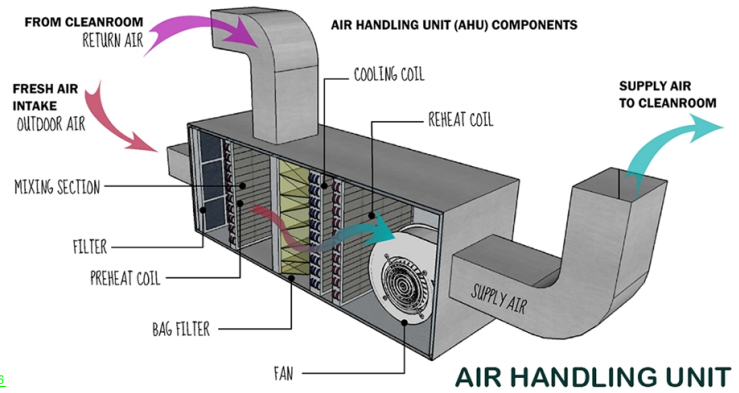
Air Handling Unit (AHU)



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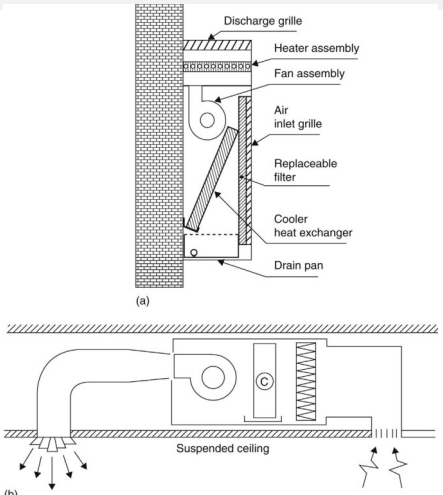
AHU prepares clean air at a required temperature and humidity.

Fan Coil Unit (FCU)



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FCU receives air from room and cools it using chilled water cooled cooling coils.