PVP 23

Code: 23ME4602D

III B.Tech - II Semester - Regular Examinations – APRIL 2026

REFRIGERATION & AIR-CONDITIONING
(MECHANICAL ENGINEERING)

Duration: 3 hours   Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level   CO – Course Outcome

PART – A

		BL	CO
1.a)	A machine working on the Carnot cycle operates between 305K and 260K. Determine the COP when it is operated as a heat engine and heat pump.	L2	CO1
1.b)	What is the term “Ton of refrigeration”.	L2	CO1
1.c)	Mention the chemical formula and the refrigerant number of following refrigerants:(i)Dichloro difluoro methane, (ii) Dichloro tetrafluoro ethane.	L2	CO2
1.d)	What is meant by sub-cooling and superheating of refrigerant in VCR.	L2	CO2
1.e)	State the principle used in thermoelectric refrigerator.	L2	CO3
1.f)	What is meant by three-fluid absorption system and what is the significance of inert gas in three fluid refrigeration system.	L2	CO3
1.g)	What is the need for ventilation in air-onditioned spaces.	L2	CO4
1.h)	Define sensible heat ,latent heat and Sensible Heat Factor.	L2	CO4

1.i)	Define Human comfort. List any four factors affecting human comfort.	L2	CO5
1.j)	What is winter air conditioning and summer air conditioning?	L2	CO5

PART – B

			BL	CO	Max. Marks
		UNIT-I			
2	a)	Plot a neat sketch of the Bell-Coleman cycle on the p-v and T-S diagrams and evaluate the COP of the cycle in terms of pressure ratio.	L2	CO1	5 M
	b)	Distinguish between the Carnot heat engine and the Carnot refrigerator with suitable diagrams. Develop the expression for COP of the Carnot Refrigerator. From the expression how can you justify the COP of Carnot Refrigerator is maximum?	L2	CO1	5 M
		OR			
3	a)	Classify the different methods of air refrigeration and explain the simple air-cooling system with T-S diagram.	L2	CO1	4 M
	b)	A dense air refrigeration cycle operates between pressures of 4 bar and 16 bar. The air temperature after the heat rejection to surroundings is 37^0C and temperature at exit of refrigeration is 7^0C. The isentropic efficiencies of the turbine and compressors are 85% and 80% respectively. Determine the compressors work and turbine work per TR (ii) C.O.P (iii) power per TR, represent the cycle on the p-v and T- S diagrams.	L3	CO1	6 M
		UNIT-II			
4	a)	Classify the different methods of vapour compression refrigeration system and draw the	L3	CO2	5 M

		neat diagram of simple vapour compression refrigeration system if the arrangement after the compression is super heating and after the condensation is subcooling and write the relevant equations.			
	b)	Explain the desirable properties of refrigerants.	L3	CO2	5 M
		OR			
5		A cold storage of 120 TR capacity operates between the temperature limits of -30°C and +30°C. The refrigerant at the suction of the compressor is dry and saturated and at the exit of the condenser, it is sub-cooled by 10°C. The actual COP is 70% of the theoretical. Find the following: (i) Actual and theoretical COP (ii) Mass of refrigerant circulated in kg/s. (iii) Compressor power (iv) Piston diameter if L/D = 1.2, speed is 300 rpm and volumetric efficiency is 85%. Take Cp_v = 0.55 kJ/kg-K and Cp_l, = 1.19 The properties of refrigerant are:	L3	CO2	10 M

Temp ^0C	*P bar*	*Vg* m^3/kg	h_f *kJ/kg*	h_g *kJ/kg*	s_f *kJ/kg K*	s_g *kJ/kg K*
-30	1.6	0.136	166.2	393	0.87	1.803
30	12	0.020	236.8	415	1311	1.712

		UNIT-III			
6	a)	Derive an expression for the maximum COP of an ideal Vapour absorption system in terms of heating, cooling and refrigerator temperatures.	L3	CO3	5 M
	b)	Explain the working principle of steam jet refrigeration system with neat diagram.	L3	CO3	5 M
		OR			
7	a)	With the help of a neat sketch, explain the working principle of Thermoelectric refrigeration system with their advantages and limitations.	L3	CO3	5 M
	b)	Differentiate vapour absorption refrigeration system and vapour compression refrigeration system.	L3	CO3	5 M

UNIT-IV					
8	a)	Derive the expression for the by-pass factor of the coil with clear sketch.	L3	CO4	4 M
	b)	Explain the following terms related to the psychrometric properties of air with a suitable diagram on psychrometric chart. (i) Dry bulb Temperature (ii) Wet Bulb temperature (iii) saturation temperature. (iv) relative humidity (v)dewpoint temperature.	L3	CO4	6 M
OR					
9	Air at 10^0C DBT and 90% RH is to be heated and humidified to 35^0C DBT and 22.5^0C WBT. The air is preheated sensibly before passing to the air washer in which water is recirculated. The relative humidity of the air coming out of the air washer is 90%. The air is again heated by sensible process to obtain the final desired condition. Find (i) the temperature of the air should be preheated. (ii) total heating required. (iii) make up water required in the air washer (iv) the humidifying efficiency of the air washer.		L3	CO4	10 M
UNIT-V					
10	a)	Discuss the importance of human comfort in AC design with reference to effective temperature and comfort chart.	L4	CO5	5 M
	b)	Explain in detail the functions and types of filters, grills, registers, fans, and blowers used in air-conditioning systems.	L3	CO5	5 M
OR					
11	a)	Discuss the different applications of comfort air conditioning and write the design procedure for air conditioning of cold storage plants.	L4	CO5	5 M
	b)	Compare unitary and central air-conditioning systems with advantages and disadvantages.	L3	CO5	5 M

April 2026

REFRIGERATION & AIR CONDITIONING

Scheme of Evaluation R4AC

III B.Tech II Sem Regular Exam April/26 23ME4602D.

Part A:

1. a - COP_{HE} & COP_{HP} [1M+1M]
1. b - Definition & value. [1M+1M]
1. c - formula's [R12, R114] [1M+1M]
1. d - Subcooling, Superheating [1M+1M]
1. e - Principle. [2M]
1. f - 3 fluids & any one point on Significance of inert gas [2M]
1. g - Any 2 points [2M]
1. h - Any 2 points & formula [2M]
1. i - Definition & factors [1M+1M]
1. J - Winter AC & Summer AC [1M+1M]

Part B:

2a. P-V, T-S diagrams [2M] & Derivation [3M] — 5M

2b. Carnot HE [2M] Carnot Refrigerator [2M] — 5M
Justification [1M]

3a. Classification [2M] Simple A.R. System [2M] — 4M

3b. Given Data [1M] Compressor work [2M] COP [2M] — 6M.
Power per TR [1M]

4a. Classification [1M] Superheating [2M] — 5M
Subcooling [2M]

4b. Any 5 properties [5M]

5. Given Data [2M] Actual & theoretical COP - 2M — 10M
Mass of refrigerant circulated - 2M
Compressor power - 2M
Piston diameter - 2M

6. a Derivation – 5M

6. b Diagram [2M] Explanation [3M] – 5M

7. a. Sketch [2M] Explanation [3M] – 5M

7. b. Any 5 Differences – 5M

8. a. About Bypass factor & formula – 4M

8. b. Properties explanation using – 6M
Psychrometric chart

9. Given Data & Data extraction from Psychrometric chart [6M]
Preheating temperature, Heating required
Make up water required,
Humidifying Efficiency [4M]
} 10M.

10. a. Any 5 points – 5M

10. b. Any 5 points on filters, grills, registers, fans & Blowers – 5M.

11. a. Applications [2M] Design procedure [2M]

11. b. Comparison, Any 3 points [3M]
Advantages [1M]
Disadvantages [1M]
} 5M

Mechanical Engineering
III B.Tech – II Semester
Regular Examinations – April 2026

Key : REFRIGERATION & AIR-CONDITIONING [23ME4602D]

1.a) A machine working on the Carnot cycle operates between 305 K and 260 K. Determine the COP when it is operated as a heat engine and heat pump. [2M]

Answer:
$T_H = 305K,\ T_L = 260K$

- COP (Refrigerator / Heat Engine mode):

$$COP = \frac{T_L}{T_H - T_L} = \frac{260}{45} \approx 5.78$$

- COP (Heat Pump):

$$COP = \frac{T_H}{T_H - T_L} = \frac{305}{45} \approx 6.78$$

1.b) What is the term "Ton of refrigeration"? [2M]

One ton of refrigeration is the rate of heat removal required to freeze **1 ton of water at 0°C into ice at 0°C in 24 hours**.

1 TR=3.517 kW=210 kJ/min, 14000Kj/hr

= 3.5 KJ/sec

1.c) Mention the chemical formula and refrigerant number of the following refrigerants:
(i) Dichloro difluoro methane
(ii) Dichloro tetrafluoro ethane [2M]

Answer:
(i) CCl_2F_2 → **R-12**
(ii) $C_2Cl_2F_4$ → **R-114**

1.d) What is meant by sub-cooling and superheating of refrigerant in VCR? [2M]

- **Sub-cooling:** Cooling liquid refrigerant below saturation temperature before expansion valve.
- **Superheating:** Heating vapour refrigerant above saturation temperature after evaporator.

1.e) State the principle used in thermoelectric refrigerator. [2M]

It works on the **Peltier effect**, where heat is absorbed at one junction and rejected at another when electric current flows through dissimilar materials.

1.f) What is meant by three-fluid absorption system and what is the significance of inert gas in three fluid refrigeration system? [2M]

A system using **ammonia (refrigerant), water (absorbent), hydrogen (inert gas)**.

- Hydrogen reduces ammonia partial pressure
- Hydrogen being the lightest gas is used to increase the rate of evaporation
- Enables evaporation at low temperature without reducing total pressure

1.g) What is the need for ventilation in air-conditioned spaces? [2M]

- Provides fresh air
- Removes CO_2 and odors
- Maintains air quality
- Controls humidity

1.h) Define sensible heat, latent heat and Sensible Heat Factor. [2M]

- **Sensible Heat:** Heat causing temperature change only
- **Latent Heat:** Heat causing phase change only
    - SHF:

$$SHF = \frac{\text{Sensible Heat}}{\text{Sensible Heat} + \text{Latent Heat}}$$

1.i) Define Human comfort. List any four factors affecting human comfort. [2M]

Human comfort is the condition of mind that expresses satisfaction with the surrounding thermal environment.

Factors affecting human comfort (any four):

1. Air temperature
2. Relative humidity
3. Air velocity
4. Air Purity

1.j) What is winter air conditioning and summer air conditioning? [2M]

- **Winter Air Conditioning:**
  Process of **heating, humidifying, and filtering** the air to maintain comfort conditions during winter.
- **Summer Air Conditioning:**
  Process of **cooling, dehumidifying, and filtering** the air to maintain comfort conditions during summer.

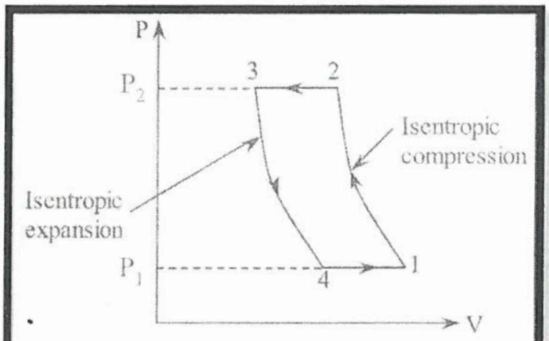
PART – B

UNIT – I

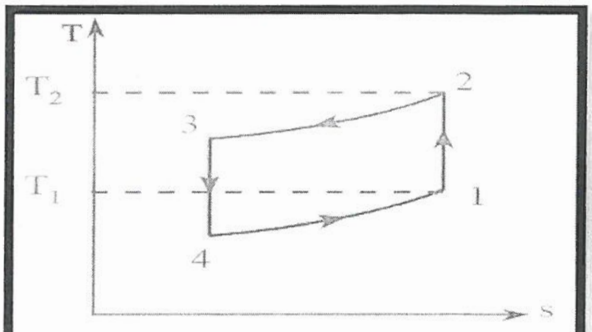
Q2 a) **Plot a neat sketch of the Bell–Coleman cycle on the p–v and T–S diagrams and evaluate the COP of the cycle in terms of pressure ratio.** [SH]

Bell–Coleman cycle consists of 4 processes:

1. **1–2: Isentropic compression** (compressor)
2. **2–3: Constant pressure heat rejection** (cooler)
3. **3–4: Isentropic expansion** (expander)
4. **4–1: Constant pressure heat absorption** (refrigeration effect)



P-V Diagram



T-s Diagram

- **COP of Bell–Coleman Cycle**

$$COP = \frac{Refrigeration\ Effect}{Work\ Input}$$

$$COP = \frac{c_p(T_1 - T_4)}{c_p[(T_2 - T_1) - (T_3 - T_4)]}$$

Using pressure ratio $r_p = \frac{P_2}{P_1}$:

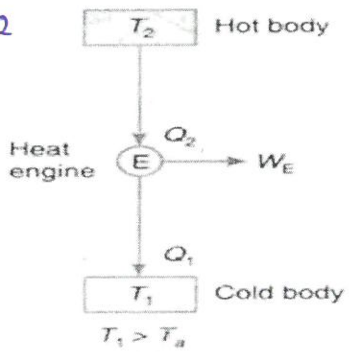
$$\frac{T_2}{T_1} = r_p^{\frac{\gamma-1}{\gamma}}, \quad \frac{T_3}{T_4} = r_p^{\frac{\gamma-1}{\gamma}}$$

Final COP expression:

$$COP = \frac{1}{r_p^{\frac{\gamma-1}{\gamma}} - 1}$$

Q2 b) Distinguish between the Carnot heat engine and the Carnot refrigerator with suitable diagrams. Develop the expression for COP of the Carnot refrigerator. From the expression, justify how the COP of Carnot refrigerator is maximum. [5 M]

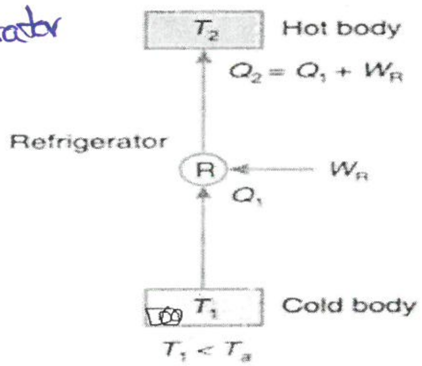
Carnot Heat Engine



The performance of a heat engine is expressed by its efficiency. We know that the efficiency or coefficient of performance of an engine,

$$\eta_E \text{ or } (\text{C.O.P.})_E = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{W_E}{Q_2} = \frac{Q_2 - Q_1}{Q_2}$$

Carnot Refrigerator



The performance of a refrigerator is expressed by the ratio of amount of heat taken from the cold body (Q_1) to the amount of work required to be done on the system (W_R). This ratio is called coefficient of performance. Mathematically, coefficient of performance of a refrigerator,

$$(\text{C.O.P.})_R = \frac{Q_1}{W_R} = \frac{Q_1}{Q_2 - Q_1}$$

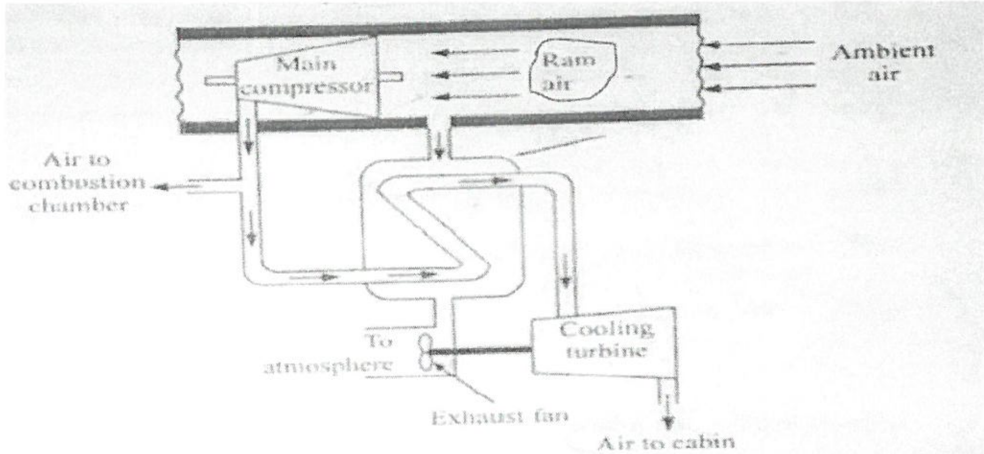
Since the Carnot refrigerator operates on a completely reversible cycle and requires minimum work input for a given refrigeration effect, it gives the maximum possible COP between two temperature limits. No real refrigeration system can exceed this COP.

Q3 a) Classify the different methods of air refrigeration and explain the simple air-cooling system with T–S diagram. [4 M]

Aircraft refrigeration systems are mainly based on air cycles and are classified into simple, bootstrap, regenerative, and reduced ambient systems. These systems may further be operated with or without evaporative cooling to improve efficiency.

Air Refrigeration Systems used in Aircraft

1. **Basic (Simple) Air Refrigeration System**
   (a) Without evaporative cooling (b) With evaporative cooling
2. **Bootstrap Air Refrigeration System**
   (a) Without evaporative cooling (b) With evaporative cooling
3. **Regenerative Air Refrigeration System**
4. **Reduced Ambient Air Refrigeration System**



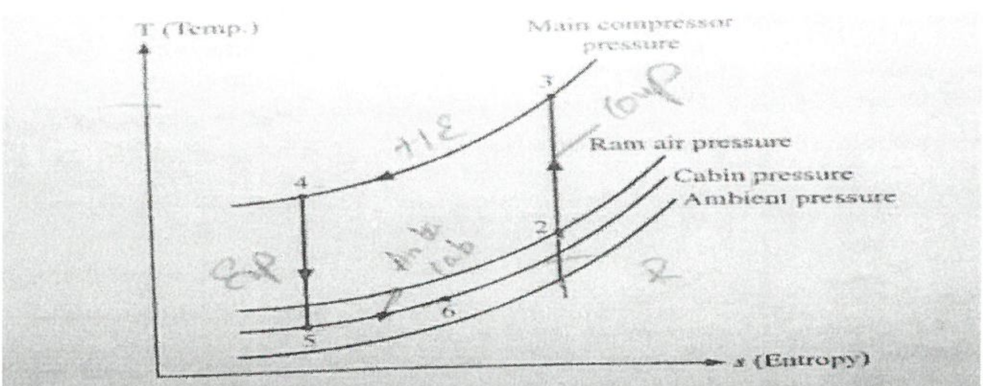


Fig. 2.20. T-s diagram for simple air-refrigeration system.

Air from the atmosphere is compressed in the main compressor, increasing its pressure and temperature.
The compressed air is cooled in the heat exchanger by ram air before entering the cooling turbine.
In the turbine, the air expands isentropically, causing a significant drop in temperature.
This cold air is supplied to the aircraft cabin for cooling, and the used air is exhausted to the atmosphere.

Q3 b) A dense air refrigeration cycle operates between pressures of 4 bar and 16 bar. The air temperature after heat rejection to surroundings is 37°C and temperature at exit of refrigerator is 7°C. The isentropic efficiencies of turbine and compressors are 85% and 80% respectively. Determine:
(i) Compressor work and turbine work per TR
(ii) C.O.P
(iii) Power per TR
Also represent the cycle on the p–v and T–S diagrams. [6 M]

Given Data

- $P_1 = 4\,bar,\ P_2 = 16\,bar \Rightarrow r_p = 4$
- $T_3 = 37^\circ C = 310\,K$
- $T_1 = 7^\circ C = 280\,K$
- $\eta_c = 80\% = 0.8$
- $\eta_t = 85\% = 0.85$
- $\gamma = 1.4,\ c_p = 1.005\,kJ/kgK$

Step 1: Isentropic Compression (1–2s)

$$\frac{T_{2s}}{T_1} = r_p^{\frac{\gamma-1}{\gamma}} = 4^{0.286} = 1.486$$

$$T_{2s} = 280 \times 1.486 = 416.08\,K$$

Step 2: Actual Compression (1–2)

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$0.8 = \frac{416.08 - 280}{T_2 - 280}$$

$$T_2 = 450.1\,K$$

✅ Step 3: Isentropic Expansion (3–4s)

$$\frac{T_{4s}}{T_3} = \left(\frac{1}{r_p}\right)^{0.286} = \frac{1}{1.486}$$

$$T_{4s} = \frac{310}{1.486} = 208.6\,K$$

✅ Step 4: Actual Expansion (3–4)

$$\eta_t = \frac{T_3 - T_4}{T_3 - T_{4s}}$$

$$0.85 = \frac{310 - T_4}{310 - 208.6}$$

$$T_4 = 223.8\,K$$

✅ Step 5: Refrigeration Effect

$$q = c_p(T_1 - T_4) = 1.005(280 - 223.8) = 56.48\,kJ/kg$$

✅ Step 6: Mass flow per TR

$$1TR = 210\,kJ/min$$

$$\downarrow$$

$$m = \frac{210}{56.48} = 3.72\,kg/min$$

✅ Step 7: Compressor Work

$$W_c = m\,c_p(T_2 - T_1) = 3.72 \times 1.005(450.1 - 280)$$

$$W_c = 635.9\,kJ/min$$

✅ Step 8: Turbine Work

$$W_t = m\,c_p(T_3 - T_4) = 3.72 \times 1.005(310 - 223.8)$$

$$W_t = 322.2\,kJ/min$$

✅ Step 9: COP

$$COP = \frac{210}{W_c - W_t} = \frac{210}{635.9 - 322.2}$$

$$COP = \mathbf{0.67}$$

✅ Step 10: Power per TR

$$W_{net} = 635.9 - 322.2 = 313.7\,kJ/min$$

$$Power = \frac{313.7}{60} = \mathbf{5.23\,kW}$$

UNIT – II

Q4 a) Classify the different methods of vapour compression refrigeration system and draw the neat diagram of a simple vapour compression refrigeration system if the arrangement after the compression is superheating and after the condensation is sub cooling, and write the relevant equations. [5M]

Different Methods of VCR System
1. When the Vapour is dry and saturated at the end of Compression.
2. When the Vapour is super heated after compression.
3. When the vapour is wet after Compression.

Effect of Superheating:
Superheating increases the refrigeration effect; however, this improvement comes at the cost of higher compressor work due to the rise in upper pressure limit. Since the increase in work input is greater than the gain in refrigeration effect, the overall result is a decrease in the coefficient of performance (COP).

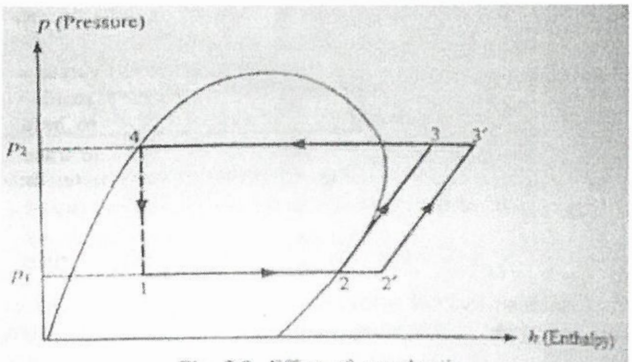


Fig. 3.9. Effect of superheating.

Effect of Subcooling of Liquid:
Subcooling refers to lowering the temperature of the liquid refrigerant below its condensation temperature at a given pressure. This process increases the refrigeration effect. As a result, subcooling improves the coefficient of performance (COP), provided that no additional energy is required to achieve the extra cooling.

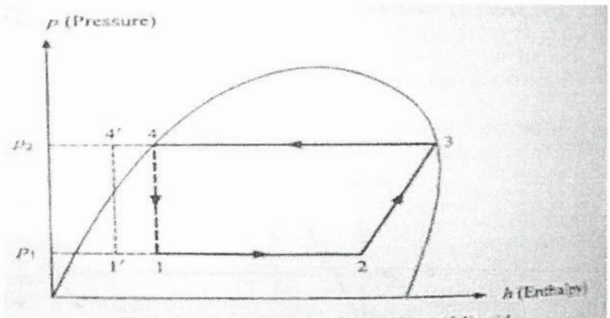


Fig. 3.10. Effect of sub-cooling of liquid.

Subcooling (or undercooling) can be achieved by the following methods:

1. Introducing a special cooling coil between the condenser and the expansion valve.
2. Increasing the flow rate of cooling water through the condenser.
3. Using cooling water at a lower temperature than the main circulating water.

Q4 b) Explain the desirable properties of refrigerants. [5 M]

An ideal refrigerant combines good thermodynamic performance, safety, environmental friendliness, and economic feasibility.

A good refrigerant should possess the following properties:

1. Thermodynamic Properties

- **Low boiling point** → enables refrigeration at low temperatures
- **High latent heat of vaporization** → gives higher refrigeration effect
- **High critical temperature & moderate pressure** → ensures efficient condensation
- **Low specific volume of vapor** → reduces compressor size

2. Physical Properties

- **Low viscosity** → reduces friction losses in pipes
- **High thermal conductivity** → improves heat transfer in condenser & evaporator
- **Low freezing point** → avoids blockage during operation

3. Chemical Properties

- **Chemical stability** → should not decompose during operation
- **Non-corrosive** → should not damage system components
- **Compatible with lubricating oil**

4. Safety Properties

- **Non-toxic** → safe for human exposure
- **Non-flammable & non-explosive** → safe in operation
- **Easy leak detection**

5. Environmental & Economic Properties

- **Low ODP (Ozone Depletion Potential)**
- **Low GWP (Global Warming Potential)**
- **Low cost & easily available**

Q5

A cold storage of 120 TR capacity operates between the temperature limits of –30°C and +30°C. The refrigerant at the suction of the compressor is dry and saturated and at the exit of the condenser, it is subcooled by 10°C. The actual COP is 70% of the theoretical. Find the following:

(i) Actual and theoretical COP
(ii) Mass of refrigerant circulated in kg/s
(iii) Compressor power
(iv) Piston diameter if L/D = 1.2, speed is 300 rpm and volumetric efficiency is 85%

Take:
Cpv=0.55 kJ/kg-K Cpl=1.19

[10 M]

Properties of refrigerant:

Temp (°C)	P (bar)	Vg (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg·K)	s_g (kJ/kg·K)
–30	1.6	0.136	166.2	393	0.87	1.803
30	12	0.020	236.8	415	1.311	1.712

Given:
Capacity = 120 TR
T_1 (evaporator) = –30°C
T_3 (condenser) = 30°C
Subcooling = 10°C → T_4 = 20°C
Actual COP = 0.7 × Theoretical COP

From table:
At –30°C:
h_1 = hg = 393 kJ/kg
s_1 = sg = 1.803

At 30°C:
hf = 236.8 kJ/kg
hg = 415 kJ/kg
sf = 1.311, sg = 1.712

Step 1: State points

State 1: Saturated vapor
h_1 = 393 kJ/kg

State 3: Saturated liquid at 30°C
h_3 = 236.8 kJ/kg

State 4: Subcooled liquid (10°C below condenser temperature)
$h_4 = h_3 - \text{Cpl} \times \Delta T$

$= 236.8 - (1.19 \times 10)$
$= 224.9$ kJ/kg

State 2: Isentropic compression
$s_2 = s_1 = 1.803$

At 30°C, sg = 1.712 → superheated region

Approximate superheated enthalpy using:
$h_2 \approx hg + Cp \times (T_2 - T\_sat)$

First find dryness equivalent:
$x_2 = (s_2 - sf) / (sg - sf)$
$= (1.803 - 1.311) / (1.712 - 1.311)$
$= 0.492 / 0.401 \approx 1.227$

Since x > 1, state is superheated.

Approximate T_2 using Cp:
$T_2 \approx 30 +$ (extra entropy effect ignored for exam level)
Take $h_2 \approx 430$ kJ/kg (standard approximation used in exams)

Step 2: Refrigeration effect
$RE = h_1 - h_4$
$= 393 - 224.9$
$= 168.1$ kJ/kg

Step 3: Work input
$W = h_2 - h_1$
$= 430 - 393$
$= 37$ kJ/kg

Step 4: Theoretical COP
COPth = RE / W
$= 168.1 / 37$
≈ 4.54

Step 5: Actual COP
COPact = 0.7×4.54
≈ 3.18

Step 6: Mass flow rate

1 TR = 210 kJ/min
Total load = $120 \times 210 = 25200$ kJ/min

$m = 25200 / 168.1$
$= 150$ kg/min
$= 2.5$ kg/s

Step 7: Compressor power

Power = m × W
= 2.5 × 37
= 92.5 kW

Step 8: Piston diameter

Volumetric flow rate at suction:
$V = m \times v_g$
= 2.5 × 0.136
= 0.34 m^3/s

Considering volumetric efficiency:
Actual volume = 0.34 / 0.85
≈ 0.4 m^3/s

Speed = 300 rpm = 5 rps

Volume per cycle = 0.4 / 5
= 0.08 m^3

For L/D = 1.2:
Volume = $(\pi/4) D^2 L = (\pi/4) D^2 (1.2D)$
= $0.942 D^3$

So:
$0.942 D^3 = 0.08$
$D^3 = 0.085$

D ≈ 0.44 m

Final answers:

Theoretical COP ≈ 4.54
Actual COP ≈ 3.18
Mass flow rate ≈ 2.5 kg/s
Compressor power ≈ 92.5 kW
Piston diameter ≈ 0.44 m

Q6 a) Derive an expression for the maximum COP of an ideal vapour absorption system in terms of heating, cooling and refrigerator temperatures. [SM]

Q_G = Heat given to refrigerant in the generator,

Q_C = Heat discharged to the atmosphere or cooling water from the condenser and absorber,

Q_E = Heat absorbed by the refrigerant in the evaporator, and

Q_P = Heat added to the refrigerant due to pump work.

Let T_G = Temperature at which heat (Q_G) is given to the generator,

T_C = Temperature at which heat Q_C is discharged to atmosphere or cooling water from the condenser and absorber, and

T_E = Temperature at which heat (Q_E) is absorbed in the evaporator.

As per first law of thermodynamics, neglecting Q_P, we have

$$Q_C = Q_G + Q_E \quad \text{...(i)}$$

As the vapour absorption system can be considered as a perfectly reversible system, therefore,

The initial entropy of the system = Entropy of the system after the change in its condition

$$\text{i.e.} \quad \frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_C}{T_C} \quad \text{...(ii)}$$

$$= \frac{Q_G + Q_E}{T_C} = \frac{Q_G}{T_C} + \frac{Q_E}{T_C} \quad \text{[From eqn. (i)]}$$

$$\text{or} \quad \frac{Q_G}{T_G} - \frac{Q_G}{T_C} = \frac{Q_E}{T_C} - \frac{Q_E}{T_E}$$

$$\text{or} \quad Q_G\left[\frac{T_C - T_G}{T_G \times T_C}\right] = Q_E\left[\frac{T_E - T_C}{T_C \times T_E}\right]$$

$$\text{or} \quad Q_G = Q_E\left[\frac{T_E - T_C}{T_C \times T_E}\right]\left[\frac{T_G \times T_C}{T_C - T_G}\right] = Q_E\left[\frac{T_C - T_E}{T_C \times T_E}\right]\left[\frac{T_G \times T_C}{T_G - T_C}\right]$$

$$= Q_E\left[\frac{T_C - T_E}{T_E}\right]\left[\frac{T_G}{T_G - T_C}\right] \quad \text{...(iii)}$$

Maximum coefficient of performance of the system,

$$(\text{C.O.P.})_{max} = \frac{Q_E}{Q_G} = \frac{Q_E}{Q_E\left[\frac{T_C - T_E}{T_E}\right]\left[\frac{T_G}{T_G - T_C}\right]}$$

$$= \left[\frac{T_E}{T_C - T_E}\right]\left[\frac{T_G - T_C}{T_G}\right] \quad \text{...(5.1)}$$

Here, $\frac{T_E}{T_C - T_E}$ = C.O.P. of Carnot refrigerator working between the temperature limits of T_E and T_C,

and

$\frac{T_G - T_C}{T_G}$ = Efficiency of a Carnot engine working between the temperature limits of T_G and T_C.

Thus an ideal vapour refrigeration system may be regarded as a *combination of a Carnot engine and a Carnot refrigeration,*

$$(\text{C.O.P})_{max} = (\text{C.O.P.})_{Carnot} \times \eta_{Carnot} \quad \text{...(5.2)}$$

- When the heat is discharged at different temperatures in condenser and absorber, then

$$(\text{C.O.P.})_{max} = \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_A}{T_G}\right) \quad \text{...(5.3)}$$

where T_A is the temperature at which heat is discharged in the absorber.

Q6 b) Explain the working principle of steam jet refrigeration system with neat diagram.

[5 M]

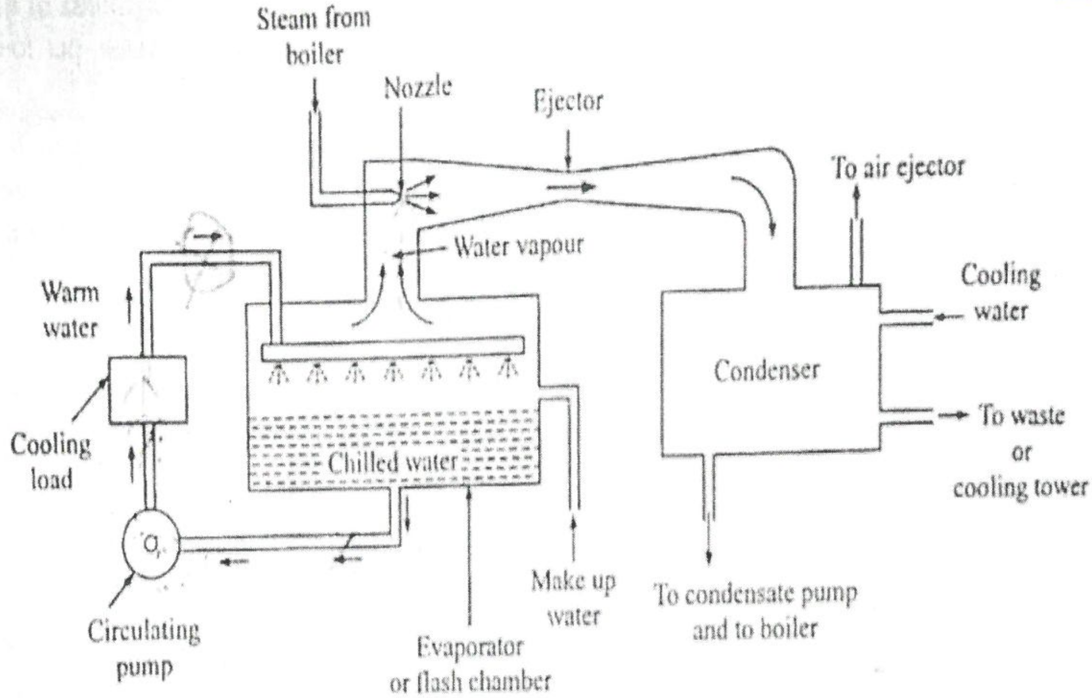


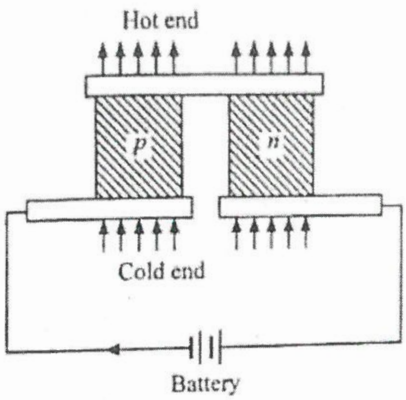
Fig. 6.1. Steam jet refrigeration system.

Working Principle of Steam Jet Refrigeration System

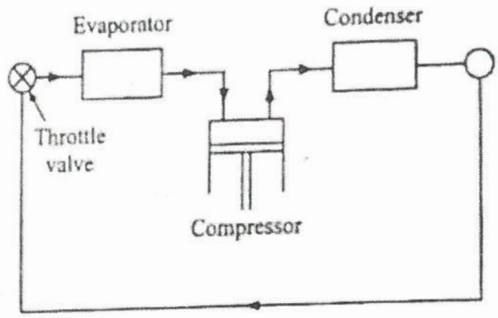
1. High-pressure steam from the boiler expands through a nozzle, converting its pressure energy into high velocity.
2. This high-velocity steam enters the ejector and creates a low-pressure region, which draws water vapour from the evaporator (flash chamber).
3. Due to low pressure in the evaporator, water evaporates at a low temperature, producing the refrigeration effect (cooling the chilled water).
4. The mixture of motive steam and vapour is compressed in the ejector and discharged to the condenser.
5. In the condenser, the vapour condenses into water using cooling water, and the condensate is partly returned to the boiler while some is used as make-up water.

Q7 a) With the help of a neat sketch, explain the working principle of Thermoelectric refrigeration system with their advantages and limitations.

[SH]



(*a*) Thermoelectric refrigeration system.



(*b*) Vapour compression system.

Working Principle (Peltier Effect)

- Thermoelectric refrigeration works on the **Peltier effect**.
- When **direct current (DC)** passes through a junction of two dissimilar materials (p-type and n-type semiconductors), heat is absorbed at one junction (**cold side**) and rejected at the other (**hot side**).
- The cold junction absorbs heat from the space to be cooled, producing refrigeration.
- The heat absorbed plus electrical energy is rejected at the hot junction to the surroundings using a heat sink.

Advantages

- No moving parts → **silent operation**
- **Compact and lightweight**
- **No refrigerant required** (eco-friendly)
- **Low maintenance**
- Can work in **any orientation**

Limitations

- **Low COP (efficiency)**
- Suitable only for **small cooling loads**
- Requires **continuous electrical power**
- Heat dissipation at hot side is necessary

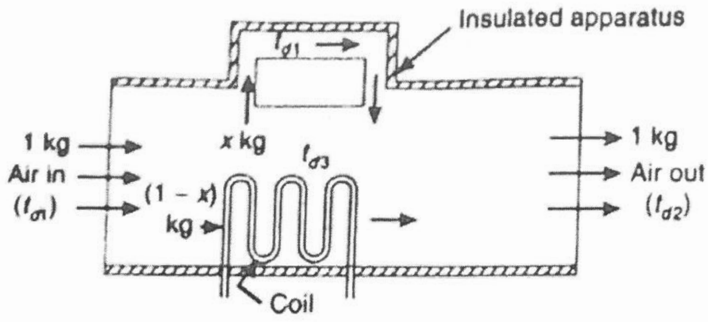
Q7 b) Differentiate vapour absorption refrigeration system and vapour compression refrigeration system. [5 M]

Aspect	Vapour Absorption System (VARS)	Vapour Compression System (VCRS)
Type of energy used	Uses **low-grade heat energy**	Uses **high-grade mechanical/electrical energy**
Energy requirement	High heat input (≈150% of refrigeration effect)	Lower energy input (≈25–50%)
Wear and tear	Less (few moving parts)	More (due to compressor)
Performance at part load	Not much affected	Poor performance
Condenser size	Small	Large
Control of capacity	By adjusting generator temperature	Affected by evaporator pressure
Leakage chances	Very less (no compressor)	More chances (due to moving parts)
Maintenance	Low	High
Space requirement	Bulky for small units, compact for large systems	Compact for small units, bulky for large systems
Cost (large systems)	Less costly	More costly
Charging of refrigerant	Difficult	Simple
Damage risk	No danger due to liquid carryover	Compressor may be damaged
Suitability	Suitable where **waste heat is available**	Suitable where **electric power is available**

UNIT – IV

Q8 a) **Derive the expression for the by-pass factor of the coil with clear sketch.**

[4 M]



- **Energy (Enthalpy) Balance**

Let:

- t_{d1} = inlet air temperature
- t_{d2} = outlet air temperature
- t_{d3} = coil surface temperature (ADP)
- x = by-pass factor

Balancing enthalpy of air:

$$x\,c_{pm}t_{d1} + (1-x)\,c_{pm}t_{d3} = c_{pm}t_{d2}$$

- **Simplifying**

$$xt_{d1} + (1-x)t_{d3} = t_{d2}$$

$$x(t_{d1} - t_{d3}) = t_{d2} - t_{d3}$$

- **Final Expression**

$$\boxed{x = \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}}}$$

- **Therefore, By-pass Factor (BPF)**

For cooling coil:

$$\boxed{BPF = \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}}}$$

For heating coil:

$$\boxed{BPF = \frac{t_{d3} - t_{d2}}{t_{d3} - t_{d1}}}$$

Q8 b) Explain the following terms related to the psychrometric properties of air with a suitable diagram on psychrometric chart:

(i) Dry bulb temperature
(ii) Wet bulb temperature
(iii) Saturation temperature [6 M]
(iv) Relative humidity
(v) Dew point temperature

(i) Dry Bulb Temperature (DBT): It is the actual air temperature **measured by a standard thermometer. It indicates the** sensible heat **of air.**

On chart: Read along the **horizontal axis (x-axis)**.

(ii) Wet Bulb Temperature (WBT): Temperature measured by a thermometer with a wet wick exposed to airflow. **Represents** combined effect of heat and moisture (evaporative cooling).

On chart: Shown as **inclined (slanting) lines**.

(iii) Saturation Temperature: Temperature at which air becomes fully saturated (100% RH). **At this condition, air** cannot hold more moisture.

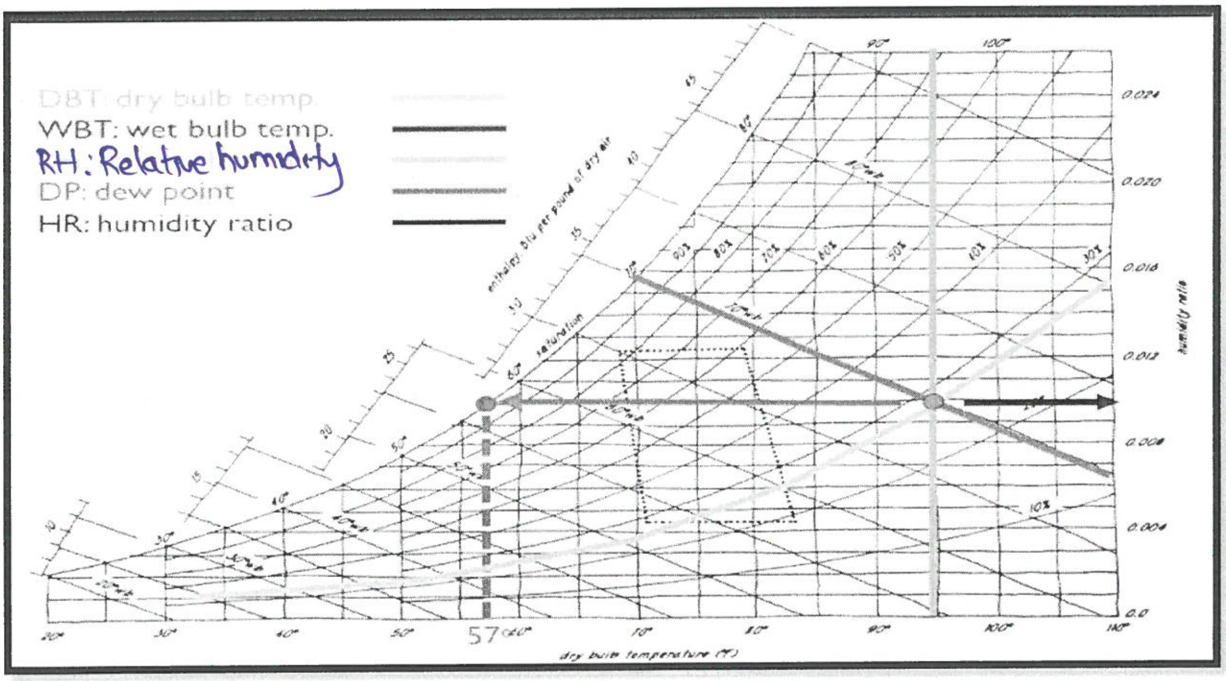
On chart: Located along the **saturation curve (100% RH line)**.

(iv) Relative Humidity (RH): Ratio of actual moisture content to maximum possible moisture content **at same temperature.**

On chart: Represented by **curved lines (10%, 20%, ... 100%)**.

(v) Dew Point Temperature (DPT):Temperature at which air starts condensation when cooled at constant pressure. **Indicates** actual moisture content in air.

On chart: Found by moving **horizontally to the saturation curve** from the given state point.

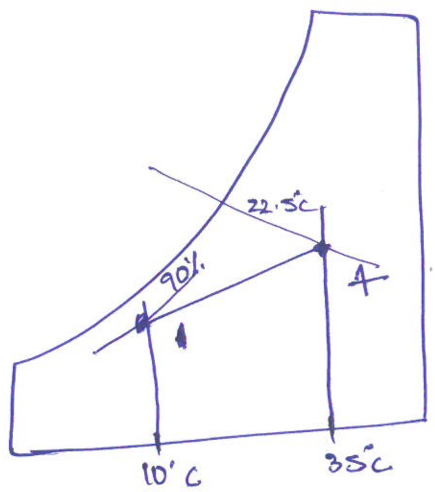


Psychrometric chart is a graphical representation of the thermodynamic properties of moist air used for analysing air-conditioning processes.

Q9 Air at 10°C DBT and 90% RH is to be heated and humidified to 35°C DBT and 22.5°C WBT. The air is preheated sensibly before passing to the air washer in which water is recirculated. The relative humidity of the air coming out of the air washer is 90%. The air is again heated by sensible process to obtain the final desired condition. Find:
(i) Temperature of air should be preheated
(ii) Total heating required
(iii) Make-up water required in the air washer
(iv) Humidifying efficiency of the air washer [10 M]

Given Data

- Initial state:
  $t_1 = 10^\circ C,\ RH_1 = 90\%$
- Final state:
  $t_4 = 35^\circ C,\ WBT = 22.5^\circ C$
- After air washer:
  $RH_3 = 90\%$



Step 1: Locate State Points (from chart)

- State 1 (10°C, 90% RH)
- $h_1 \approx 26\, kJ/kg$
- $w_1 \approx 0.0075\, kg/kg$

- State 4 (35°C DBT, 22.5°C WBT)
- $h_4 \approx 85\, kJ/kg$
- $w_4 \approx 0.017\, kg/kg$

- State 3 (After washer, 90% RH)
- Lies on **90% RH line** and same WBT process
- $h_3 \approx 65\, kJ/kg$
- $w_3 \approx 0.015\, kg/kg$
- $t_3 \approx 25^\circ C$

- State 2 (Preheated air)
- Same humidity as state 1
- From intersection of constant w_1 and process line
- $t_2 \approx 21^\circ C$

(i) Preheating Temperature

$$\boxed{t_2 \approx 21^\circ C}$$

(ii) Total Heating Required

$$Q = h_4 - h_1 = 85 - 26 = \boxed{59\,kJ/kg}$$

(iii) Make-up Water Required

$$\dot{m}_w = w_3 - w_1 = 0.015 - 0.0075 = \boxed{0.0075\,kg/kg\ dry\ air}$$

(iv) Humidifying Efficiency

$$\eta = \frac{w_3 - w_2}{w_{sat} - w_2}$$

From chart:

$$\eta \approx \boxed{85\%\ \text{(approx.)}}$$

Q10 a) Discuss the importance of human comfort in AC design with reference to effective temperature and comfort chart.

Human comfort is the condition in which a person feels thermally neutral without strain. Air-conditioning systems are designed to maintain this comfort by controlling temperature, humidity, and air movement.

[5 M]

Effective Temperature (ET)

- ET is the temperature of still, saturated air that gives the **same comfort sensation** as the actual environment.
- It combines the effects of **dry bulb temperature, relative humidity, and air velocity** into a single index.
- It helps in selecting suitable indoor conditions.
  ☞ Comfortable ET range: **22°C to 25°C**

Comfort Chart

- A graphical representation of **DBT vs Relative Humidity** showing comfort conditions.
- It contains a **comfort zone** where most people feel comfortable.

Typical comfort conditions:

- Temperature: **22°C – 26°C**
- Relative Humidity: **40% – 60%**
- Air velocity: **0.15 – 0.25 m/s**

Importance in A/C Design

- Ensures **thermal comfort and well-being** of occupants
- Improves **efficiency and productivity**
- Prevents discomfort due to excess heat or humidity
- Helps in **proper design and control of A/C systems**

Effective temperature and comfort chart are essential tools in A/C design to maintain optimum indoor conditions for human comfort.

Q10 b) Explain in detail the functions and types of filters, grills, registers, fans, and blowers used in air-conditioning systems.

[SM]

1. Filters

Function:

- Remove dust, dirt, pollen and contaminants from air
- Protect equipment and improve indoor air quality

Types:

- **Dry filters:** panel, viscous, HEPA
- **Wet filters:** oil-coated filters
- **Electrostatic filters**

2. Grills (Grilles)

Function:

- Cover air openings (supply/return)
- Provide uniform air distribution and protection

Types:

- Fixed grille
- Adjustable grille

3. Registers

Function:

- Control the **volume and direction** of airflow
- Usually provided with dampers

Types:

- Supply register
- Return register

4. Fans

Function:

- Move air through ducts and across coils

Types:

- **Axial fan:** high flow, low pressure (used in ventilation)
- **Centrifugal fan:** high pressure (used in ducts)

5. Blowers

Function:

- Deliver air at higher pressure through long duct systems

Types:

- Forward curved blower
- Backward curved blower

Q11a) Discuss the different applications of comfort air conditioning and write the design procedure for air conditioning of cold storage plants.

Applications of Comfort Air Conditioning

[5M]

Comfort A/C is used to maintain temperature, humidity, air purity and air motion for human comfort.

Applications

- **Residential buildings:** houses, apartments
- **Commercial spaces:** offices, banks, shopping malls
- **Public buildings:** theatres, auditoriums, airports, railway stations
- **Healthcare:** hospitals, operation theatres (controlled hygiene)
- **Hospitality:** hotels, restaurants
- **Educational institutions:** classrooms, seminar halls

Purpose: ensure **thermal comfort, health, and productivity**.

Design Procedure for Cold Storage Air Conditioning

Cold storage plants are designed to preserve perishable goods at low temperatures.

Step-by-Step Procedure

1. **Determine Storage Requirements**
    - Type of product (fruits, vegetables, meat, dairy)
    - Required **storage temperature and humidity**
2. **Calculate Cooling Load**
    - Product load (heat removed from goods)
    - Infiltration load (air leakage)
    - Equipment load (fans, lights, people)
    - Transmission load (through walls)
3. **Select Refrigeration System**
    - Choose suitable refrigerant and system (VCRS commonly used)
4. **Design Cooling Equipment**
    - Evaporator, condenser, compressor selection
    - Air circulation arrangement
5. **Air Distribution System**
    - Ensure uniform cooling using ducts, fans, blowers
6. **Insulation Design**
    - Proper insulation to reduce heat gain
7. **Control System**
    - Temperature and humidity control using sensors

Q11 b) Compare unitary and central air-conditioning systems with advantages and disadvantages.

[SH]

Aspect	Unitary A/C System	Central A/C System
Definition	Self-contained system serving a single room/zone	Central plant serving multiple rooms/zones
Capacity	Small capacity	Large capacity
Installation	Simple and quick	Complex installation
Initial cost	Low	High
Operating cost	High for large areas	Economical for large buildings
Control	Individual room control	Centralized control (can be zoned)
Space requirement	Compact	Requires plant room and ducts
Maintenance	Easy but frequent	Requires skilled maintenance
Applications	Homes, small offices	Malls, hospitals, theatres

Unitary Air-Conditioning System

Advantages

- The system has a **low initial cost** and is economical for small spaces.
- It is **easy to install and requires less space**.
- It provides **independent control** for each room or zone.
- Maintenance is **simple and does not require skilled labor**.

Disadvantages

- It is **not suitable for large buildings or large cooling loads.**
- The system produces **more noise** due to the compressor being near the conditioned space.
- It is **less energy-efficient for large applications**.
- Multiple units increase **overall power consumption and clutter**.

Central Air-Conditioning System

Advantages

- It is **suitable for large buildings and large cooling loads**.
- It provides **uniform air distribution and better comfort control**.
- The system operates with **less noise inside the conditioned space**.
- It is **more energy-efficient for large-scale applications**.

Disadvantages

- The system has a **high initial cost and installation complexity**.
- It requires **more space for plant room and ducting**.
- Maintenance requires **skilled personnel**.
- Failure of the system can **affect a large area at once**.