

UNIT-4

Air Conditioning

Air Conditioning – Psychrometric Properties, Processes and Psychrometric Chart

Psychrometry

Psychrometry is the study of the thermodynamic properties of moist air and the processes involving moist air.

Moist Air = Dry Air + Water Vapour

Psychrometric Properties

1. Dry Bulb Temperature (DBT)

- Temperature measured by an ordinary thermometer.
- Denoted by **T_{db}**.

2. Wet Bulb Temperature (WBT)

- Temperature measured by a thermometer with a wet wick around its bulb.
- Denoted by **T_{wb}**.

3. Dew Point Temperature (DPT)

- Temperature at which water vapour starts condensing from air.

4. Relative Humidity (RH)

$$RH = \frac{\text{Actual Vapour Pressure}}{\text{Saturation Vapour Pressure}} \times 100$$
$$RH = \frac{\text{Actual Vapour Pressure}}{\text{Saturation Vapour Pressure}} \times 100$$

- Indicates the amount of moisture present in air.

5. Specific Humidity (Humidity Ratio)

- Mass of water vapour per kg of dry air.

6. Degree of Saturation

- Ratio of actual humidity ratio to saturated humidity ratio.

7. Enthalpy of Moist Air

- Total heat content of moist air.
- Unit: kJ/kg of dry air.

8. Specific Volume

- Volume occupied by 1 kg of dry air and associated water vapour.

Psychrometric Processes

1. Sensible Heating

- Temperature increases.
- Humidity ratio remains constant.

V State 1 —————→ State 2

2. Sensible Cooling

- Temperature decreases.
- Humidity ratio remains constant.

State 1 ←———— State 2

3. Humidification

- Moisture is added to air.
- Humidity ratio increases.

4. Dehumidification

- Moisture is removed from air.

- Humidity ratio decreases.

5. Cooling and Dehumidification

- Temperature decreases.
- Moisture decreases simultaneously.

6. Heating and Humidification

- Temperature and humidity increase simultaneously.

7. Adiabatic Humidification

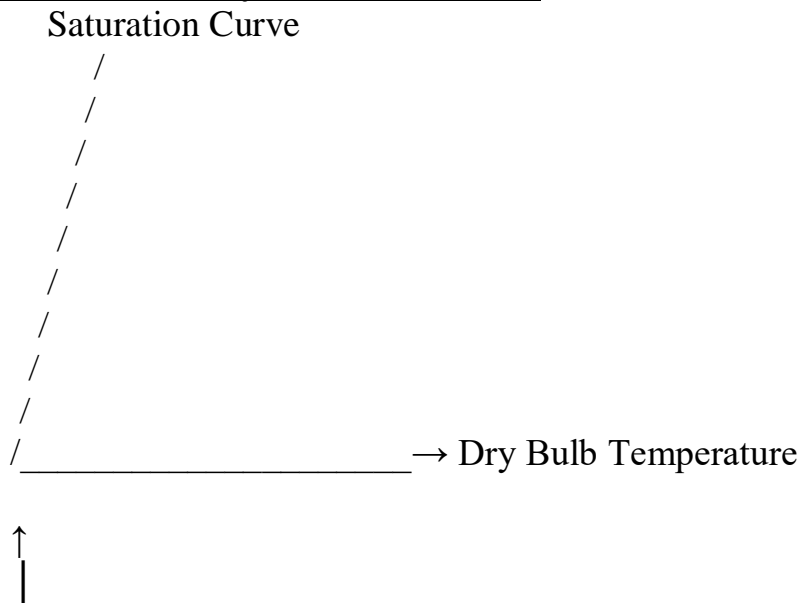
- Moisture added without heat transfer.
- Enthalpy remains nearly constant.

Psychrometric Chart

Definition

A **Psychrometric Chart** is a graphical representation of the properties of moist air.

Construction of Psychrometric Chart



Specific Humidity

Axes

- Horizontal Axis → Dry Bulb Temperature (DBT)
- Vertical Axis → Humidity Ratio (Specific Humidity)

Applications of Psychrometric Chart

- Air-conditioning design.
- Cooling load calculations.
- HVAC system analysis.
- Industrial drying processes.
- Ventilation system design.
- Refrigeration engineering.

Requirements of Comfort Air Conditioning

Definition

Comfort air conditioning is the process of controlling temperature, humidity, air motion, and air purity to provide comfortable conditions for human occupants.

Requirements of Comfort Air Conditioning

1. Temperature Control

- Comfortable temperature: **22°C to 27°C**
- Maintains thermal comfort.

2. Humidity Control

- Relative humidity: **40% to 60%**
- Prevents excessive dryness or dampness.

3. Air Motion

- Air velocity: **0.15 to 0.25 m/s**
- Provides proper ventilation and comfort.

4. Air Purity

- Removal of dust, smoke, bacteria, and odors.

5. Noise Control

- Quiet operation for occupant comfort.

Thermodynamics of Human Body

The human body continuously produces heat through metabolism.

Sources of Heat Loss

1. **Conduction**
 - Heat transfer through direct contact.
2. **Convection**
 - Heat transfer to surrounding air.
3. **Radiation**
 - Heat transfer to surrounding surfaces.
4. **Evaporation**
 - Heat loss through sweating.

Heat Balance Equation

Heat Produced = Heat Lost

When heat production equals heat loss, the body feels comfortable.

Effective Temperature (ET)

Definition

Effective Temperature (ET) is the temperature of saturated air that gives the same feeling of comfort as the actual air condition.

It combines the effects of:

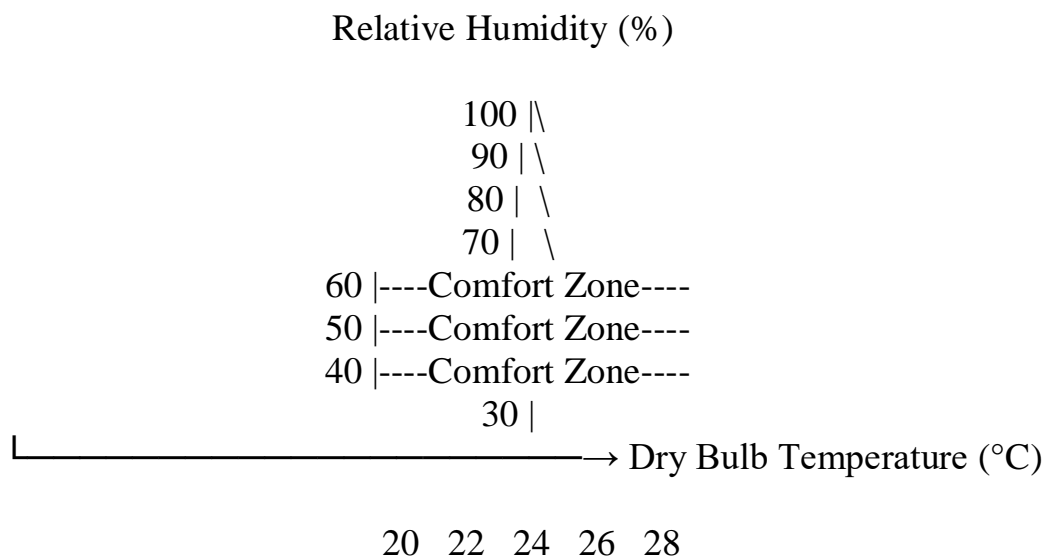
- Dry bulb temperature
- Relative humidity
- Air velocity

Comfort Range

- Effective Temperature \approx **21°C to 24°C**

Comfort Chart

A comfort chart shows the region where most people feel comfortable.



Comfort Zone

- Temperature: **22°C–27°C**
- Relative Humidity: **40%–60%**

Parameters Influencing Effective Temperature

1. Dry Bulb Temperature (DBT)

- Higher DBT increases effective temperature.

2. Relative Humidity (RH)

- Higher humidity makes the air feel warmer.

3. Air Velocity

- Increased air movement improves cooling and reduces effective temperature.

4. Mean Radiant Temperature

- Heat radiation from surrounding walls and objects affects comfort.

5. Clothing

- Heavy clothing increases warmth.
- Light clothing increases comfort in summer.

6. Metabolic Rate

- Physical activity increases body heat production.

7. Age and Health

- Comfort levels vary among individuals.

Factor	Effectors Affecting Human Comfort	Effect
Temperature		Directly affects comfort
Humidity		Controls sweating and evaporation
Air Velocity		Influences cooling effect
Air Purity		Affects health and comfort
Stress Level		Affects mental comfort

Factor	ctors Affecting Human Comfort	Effect
othing	ters heat transfer	
ctivity Level	anges metabolic heat generation	

Heating Load Calculations

Definition

Heating load is the amount of heat energy required to maintain a desired indoor temperature when the outdoor temperature is lower than the indoor temperature.

Formula

$$Q = UA(T_i - T_o) \quad Q = UA(T_i - T_o) \quad Q = UA(T_i - T_o)$$

Where:

- **Q** = Heating load (W)
- **U** = Overall heat transfer coefficient (W/m²·K)
- **A** = Area of wall/roof/window (m²)
- **T_i** = Indoor temperature (°C)
- **T_o** = Outdoor temperature (°C)

Components of Heating Load

1. Transmission Heat Loss

Heat lost through:

- Walls
- Roofs
- Floors
- Doors
- Windows

Formula:

$$Q_t = UA(T_i - T_o) \quad Q_t = UA(T_i - T_o) \quad Q_t = UA(T_i - T_o)$$

2. Ventilation Heat Loss

Heat loss due to fresh air entering the room.

Formula:

$$Q_v = m C_p (T_i - T_o) \quad Q_v = m C_p (T_i - T_o)$$

Where:

- **m** = Mass flow rate of air (kg/s)
- **C_p** = Specific heat of air (1.005 kJ/kg·K)

3. Infiltration Heat Loss

Heat loss through cracks and openings around doors and windows.

Formula:

$$Q_i = \rho V C_p (T_i - T_o) \quad Q_i = \rho V C_p (T_i - T_o)$$

Where:

- **ρ** = Density of air (1.2 kg/m³)
- **V** = Air volume flow rate (m³/s)

Total Heating Load

$$Q_{total} = Q_t + Q_v + Q_i \quad Q_{total} = Q_t + Q_v + Q_i$$

Example 1: Wall Heat Loss

Given:

- Wall Area = 25 m²

- $U = 1.5 \text{ W/m}^2\text{K}$
- Indoor Temperature = 22°C
- Outdoor Temperature = 5°C

Solution:

$$Q = UA(T_i - T_o) = 1.5 \times 25 \times (22 - 5) = 637.5 \text{ W}$$

Answer:

Heating load through wall = 637.5 W

Example 2: Ventilation Heat Loss

Given:

- Air flow rate = 0.4 kg/s
- $C_p = 1.005 \text{ kJ/kg}\cdot\text{K}$
- Indoor temperature = 20°C
- Outdoor temperature = 5°C

Solution:

$$Q = mC_p(T_i - T_o) = 0.4 \times 1.005 \times (20 - 5) = 6.03 \text{ kW}$$

Answer:

Ventilation heating load = 6.03 kW

Example 3: Total Heating Load

Given:

- Transmission loss = 4 kW
- Ventilation loss = 2 kW
- Infiltration loss = 1 kW

Solution:

$$Q_{total}=4+2+1Q_{total}=4+2+1Q_{total}=7 \text{ kW}Q_{total}=7 \text{ kW}$$

Answer:

Total Heating Load = 7 kW

Factors Affecting Heating Load

1. Outdoor temperature
2. Indoor design temperature
3. Building insulation
4. Number of windows and doors
5. Air infiltration rate
6. Ventilation requirement
7. Building orientation
8. Wind velocity

Applications

- Residential buildings
- Hospitals
- Schools
- Offices
- Industrial buildings
- Cold regions heating systems

Summer/Winter Heating Load Calculation

A **heating load calculation** determines the amount of heat that must be supplied to a building to maintain the desired indoor temperature during cold weather. The heating load is mainly affected by:

1. Heat losses through the building structure
2. Heat losses due to infiltration
3. Effects of solar radiation
4. Effects of internal heat sources

1. Heat Losses Through Structure

Heat is lost from the building through walls, roofs, floors, windows, and doors by conduction.

The heat loss through a building component is calculated as:

$$Q = UA(T_i - T_o)$$

Where:

- Q = Heat loss (W)
- U = Overall heat transfer coefficient ($\text{W}/\text{m}^2 \cdot \text{K}$)
- A = Area of the surface (m^2)
- T_i = Indoor design temperature ($^\circ\text{C}$)
- T_o = Outdoor design temperature ($^\circ\text{C}$)

Total Structural Heat Loss

The total heat loss through the structure is:

$$Q_s = \sum UA(T_i - T_o)$$

Higher insulation reduces the U-value and therefore decreases heating requirements.

2. Heat Losses Due to Infiltration

Infiltration is the uncontrolled leakage of outside air into a building through cracks around doors, windows, and other openings.

The heat loss due to infiltration is:

$$Q_i = \rho c_p V (T_i - T_o)$$

Where:

- ρ = Density of air (kg/m^3)
- c_p = Specific heat of air ($\text{kJ}/\text{kg} \cdot \text{K}$)

- V = Volume flow rate of infiltrated air (m^3/s)
- $T_i - T_o$ = Temperature difference

In HVAC practice, it is often written as:

$$Q_i = 1.2 V (T_i - T_o)$$

where V is in m^3/s and Q_i is in watts.

Factors Affecting Infiltration

- Wind speed
- Building height
- Door opening frequency
- Quality of construction
- Pressure differences

3. Effects of Solar Radiation on Heating Load

Solar radiation entering through windows provides **free heat gain**.

Winter Season

- Solar heat gain reduces the heating load.
- South-facing windows (in the Northern Hemisphere) receive significant solar energy.
- Heating equipment size can be reduced because part of the heating requirement is supplied by the sun.

Solar heat gain:

$$Q_{\text{solar}} = A_g \times \text{SHGF} \times \text{SC}$$

Where:

- A_g = Glass area
- SHGF = Solar Heat Gain Factor
- SC = Shading Coefficient

Summer Season

- Solar radiation increases indoor temperature.
- It increases the cooling load rather than the heating load.

Thus:

- **Winter:** Solar radiation decreases heating load.
- **Summer:** Solar radiation increases cooling load.

4. Effects of Internal Heat Sources on Heating Load

Internal heat sources generate heat inside the building and reduce the heating requirement.

Common Internal Heat Sources

1. Occupants
2. Lighting systems
3. Electrical equipment
4. Computers and appliances
5. Industrial processes

Total internal heat gain:

$$Q_{\text{internal}} = Q_{\text{people}} + Q_{\text{lights}} + Q_{\text{equipment}}$$

Impact

- During winter, internal gains reduce the required heating capacity.
- In commercial buildings, internal gains can significantly offset heating needs.
- During summer, these gains increase cooling loads.

Total Winter Heating Load

The net heating load is:

$$Q_H = Q_{\text{structure}} + Q_{\text{infiltration}} - Q_{\text{solar}} - Q_{\text{internal}}$$

Where:

- $Q_{\text{structure}}$ = Heat loss through walls, roof, floor, windows, etc.
- $Q_{\text{infiltration}}$ = Heat loss due to air leakage
- Q_{solar} = Solar heat gain
- Q_{internal} = Internal heat gains

Problem: Winter Heating Load Calculation
Question

A building has the following characteristics:

- Wall area = 120 m², U=0.5 U = 0.5 W/m²·K
- Roof area = 80 m², U=0.3 U = 0.3 W/m²·K
- Window area = 20 m², U=2.5 U = 2.5 W/m²·K
- Indoor temperature = 22°C
- Outdoor temperature = 2°C

- Infiltration air flow rate = 0.15 m³/s
- Solar heat gain = 1500 W
- Internal heat gain from occupants and equipment = 2000 W

Calculate the net winter heating load.

Solution
Step 1: Calculate Structural Heat Loss

Temperature difference:

$$\Delta T = 22 - 2 = 20^\circ\text{C}$$

Heat loss through walls

$$Q_{\text{walls}} = U A \Delta T$$

$$Q_{\text{walls}} = 0.5 \times 120 \times 20$$

$$=0.5 \times 120 \times 20 Q_{\text{walls}} = 1200 \quad WQ_{\text{walls}} = 1200; WQ_{\text{walls}} = 1200W$$

Heat loss through roof

$$Q_{\text{roof}} = 0.3 \times 80 \times 20 Q_{\text{roof}} = 0.3 \times 80 \times 20 Q_{\text{roof}} = 480 \\ WQ_{\text{roof}} = 480; WQ_{\text{roof}} = 480W$$

Heat loss through windows

$$Q_{\text{windows}} = 2.5 \times 20 \times 20 Q_{\text{windows}} = 2.5 \times 20 \times 20 Q_{\text{windows}} \\ = 2.5 \times 20 \times 20 Q_{\text{windows}} = 1000 \quad WQ_{\text{windows}} = 1000; WQ_{\text{windows}} = 1000W$$

Total structural heat loss

$$Q_{\text{structure}} = 1200 + 480 + 1000 Q_{\text{structure}} = 1200 + 480 + 1000 Q_{\text{structure}} \\ = 1200 + 480 + 1000 Q_{\text{structure}} = 2680 \quad WQ_{\text{structure}} = 2680; WQ_{\text{structure}} = 2680W$$

Step 2: Calculate Infiltration Heat Loss

Using:

$$Q_{\text{infiltration}} = 1.2 V \Delta T \times 1000 Q_{\text{infiltration}} = 1.2 V \Delta T \times 1000 Q_{\text{infiltration}} \\ = 1.2 V \Delta T \times 1000 Q_{\text{infiltration}} = 1.2 \times 0.15 \times 20 \times 1000 Q_{\text{infiltration}} = 1.2 \times 0.15 \\ \times 20 \times 1000 Q_{\text{infiltration}} = 1.2 \times 0.15 \times 20 \times 1000 Q_{\text{infiltration}} = 3600 \\ WQ_{\text{infiltration}} = 3600; WQ_{\text{infiltration}} = 3600W$$

Step 3: Calculate Total Heat Loss

$$Q_{\text{loss}} = Q_{\text{structure}} + Q_{\text{infiltration}} Q_{\text{loss}} = Q_{\text{structure}} + Q_{\text{infiltration}} Q_{\text{loss}} \\ = Q_{\text{structure}} + Q_{\text{infiltration}} Q_{\text{loss}} = 2680 + 3600 Q_{\text{loss}} = 2680 + 3600 Q_{\text{loss}} \\ = 2680 + 3600 Q_{\text{loss}} = 6280 \quad WQ_{\text{loss}} = 6280; WQ_{\text{loss}} = 6280W$$

Step 4: Subtract Heat Gains

Solar gain:

$$Q_{\text{solar}} = 1500 \quad WQ_{\text{solar}} = 1500; WQ_{\text{solar}} = 1500W$$

Internal gain:

$$Q_{\text{internal}} = 2000 \quad WQ_{\text{internal}} = 2000; WQ_{\text{internal}} = 2000W$$

Total gains:

$$Q_{\text{gain}} = 1500 + 2000 Q_{\text{gain}} = 1500 + 2000 Q_{\text{gain}} = 1500 + 2000 Q_{\text{gain}} = 3500$$

$$W_{Q_{\text{gain}}}=3500\text{ W}; W_{Q_{\text{gain}}}=3500\text{ W}$$

Step 5: Calculate Net Heating Load

$$Q_H = Q_{\text{loss}} - Q_{\text{gain}} \\ Q_H = 6280 - 3500 \\ Q_H = 2780 \text{ W}$$

Answer

$$Q_H = 2780 \text{ W} = 2.78 \text{ kW}$$

The building requires a heating system capacity of **2.78 kW**.

Air Cleaners, Humidifiers, and Dehumidifiers

These are important air-conditioning and indoor air-quality devices used to improve comfort and health in buildings.

1. Air Cleaners

Definition

Air cleaners are devices used to remove dust, smoke, pollen, bacteria, and other airborne contaminants from the air.

Purpose

- Improve indoor air quality.
- Protect occupants from allergies and respiratory problems.
- Keep HVAC equipment clean.

Types of Air Cleaners

(a) Mechanical Filters

- Use fibrous materials to trap particles.
- Examples: HEPA filters, panel filters.

(b) Electrostatic Precipitators

- Charge dust particles electrically.
- Charged particles are attracted to collecting plates.

(c) Activated Carbon Filters

- Remove odors, gases, and volatile organic compounds (VOCs).

(d) UV Air Purifiers

- Use ultraviolet light to destroy microorganisms.

Applications

- Hospitals
- Offices
- Homes
- Clean rooms
- Laboratories

2. Humidifiers

Definition

Humidifiers are devices that increase the moisture content (humidity) of air.

Need for Humidification

During winter or in dry climates, indoor air becomes very dry, causing:

- Dry skin
- Eye irritation
- Respiratory discomfort
- Static electricity

Types of Humidifiers

(a) Spray Humidifier

- Water is sprayed into the air stream as fine droplets.

(b) Pan Humidifier

- Air passes over a water surface and absorbs moisture.

(c) Steam Humidifier

- Steam is injected directly into the air.
- Provides precise humidity control.

(d) Ultrasonic Humidifier

- Uses ultrasonic vibrations to create a fine mist.

Advantages

- Improves comfort.
- Prevents drying of materials such as wood and paper.
- Reduces static electricity.

3. Dehumidifiers

Definition

Dehumidifiers are devices used to remove excess moisture from the air.

Need for Dehumidification

uHigh humidity can cause:

- Discomfort
- Mold growth
- Corrosion
- Damage to stored products

Types of Dehumidifiers

(a) Refrigeration Dehumidifier

- Air passes over a cold coil.
- Moisture condenses and is removed.
- Most common type.

(b) Desiccant Dehumidifier

- Uses moisture-absorbing materials such as silica gel.
- Suitable for very low humidity requirements.

Working Principle of Refrigeration Dehumidifier

1. Moist air enters the unit.
2. Air passes over a cooling coil.
3. Water vapor condenses.
4. Dry air is reheated and supplied to the room.

Applications

- Food storage
- Pharmaceutical industries
- Museums
- Data centers
- Residential buildings