MODULE –I

Climatology (21ARC43) – Faculty of Architecture, Sharnbasva University

Course Structure:

- Lectures/Week: 2
- Studio/Week: 1
- Credits: 3
- Total Teaching Hours: 42
- Marks Distribution:
  - CEE: 50
  - SEE: 50
  - Exam Duration: 3 hours

Objectives:

1. Understand elements of climate, classification, and thermal comfort.
2. Analyze overheated/underheated periods, sun path diagrams, and building thermal performance.
3. Learn thermal heat gain/loss and insulation techniques.
4. Study shading devices and natural ventilation.
5. Explore natural daylighting and climate-considerate design.

Modules & Topics:

Module I – Introduction to Climate (8 Hours)

1. Climate-Built Form Interaction
   - Examples of climate's influence on architecture.
   - Elements, measurement, and representation of climate data.
   - Tropical climate classification and characteristics.
2. Major Climatic Zones in India
   - Impact of landscape on site/microclimate.
3. Thermal Comfort Indices
   - Factors: Effective temperature, corrected effective temperature, bioclimatic chart, tropical summer index.
   - Measuring methods: Kata-thermometer, globe thermometer.

Module II – Thermal Comfort (10 Hours)

4. Overheated & Underheated Periods
   - Air temperature analysis in different climatic zones.
   - Solar heating & passive cooling optimization.
5. Sun-Path Diagram
   - Solar geometry & chart-based design considerations.
6. Thermal Performance of Building Elements
   - Effect of thermo-physical properties of materials.

Module I – Introduction to Climate (8 Hours)
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Module I – Introduction to Climate (8 Hours)

1. Climate-Built Form Interaction

- Climate influences architectural design, including:
  - Building orientation (positioning for optimal sunlight and wind flow).
  - Material selection (heat-absorbing or insulating materials).
  - Ventilation strategies (cross-ventilation, stack effect).
  - Shading devices (overhangs, louvers, trees).
  - Passive heating & cooling techniques (thermal mass, earth cooling, courtyards).

Climate and Its Influence on Architectural Design

The **climate** of a location plays a pivotal role in shaping architectural responses to ensure comfort, energy efficiency, and sustainability. Architecture that is responsive to climate minimizes mechanical energy needs by leveraging natural environmental conditions.

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1. Building Orientation

Objective:

To optimize solar gain, daylighting, and natural ventilation by strategically positioning the building on the site.

Design Strategies:

- **Cold Climates**: Orient large windows towards the **south** (in the northern hemisphere) to maximize passive solar heating.
- **Hot Climates**: Minimize east and west-facing windows to reduce heat gain from low-angle morning and evening sun.
- **Wind Consideration**: Align openings with prevailing wind directions to enhance cross-ventilation.

Example:

In India, buildings in hot-dry regions like Rajasthan are often oriented east-west with small openings on the east and west to reduce solar exposure.

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2. Material Selection

Objective:

To regulate heat transfer and maintain indoor thermal comfort by using appropriate construction materials.

Climate-Based Selection:

- **Hot Climates**: Use **light-colored, reflective materials** with low thermal mass (e.g., lime plaster, terracotta tiles).
- **Cold Climates**: Use **high thermal mass materials** like stone, brick, or concrete to store daytime heat.
- **Humid Climates**: Use **breathable, moisture-resistant materials** (e.g., bamboo, treated wood).

Example:

Mud bricks, used traditionally in warm regions, offer both thermal insulation and high heat storage capacity.

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3. Ventilation Strategies

Objective:

To enhance indoor air quality and comfort by maximizing airflow.

Techniques:

- **Cross-Ventilation**: Align windows or openings on opposite walls to allow air to pass through rooms.
- **Stack Effect**: Use vertical spaces (like atriums or vents) to exhaust hot air upward and draw cool air from below.
- **Ventilated Roofs**: Employ double-roof systems to prevent heat transfer from the roof to living spaces.

Example:

Kerala homes often feature high ceilings and central courtyards that facilitate vertical airflow.

4. Shading Devices

Objective:

To control solar gain and prevent overheating, particularly in summer.

Types of Shading:

- **Horizontal Overhangs**: Effective on south-facing windows to block high-angle summer sun.
- **Vertical Louvers**: Useful for east and west facades to block low-angle sun.
- **Natural Shading**: Use of **deciduous trees**, pergolas, or creepers that provide seasonal shading.

Example:

Jaali (perforated screens) in Mughal architecture allow filtered light and airflow while reducing solar radiation.

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5. Passive Heating and Cooling Techniques

Objective:

To regulate indoor temperature without mechanical systems by using the building's form, materials, and interaction with the environment.

Strategies:

- **Thermal Mass**: Use materials that absorb heat during the day and release it at night.
- **Earth Cooling Tubes**: Circulate air through buried pipes to use the earth's stable temperature for cooling.
- **Courtyards**: Enhance air movement and act as heat sinks; common in hot-arid and warm-humid climates.
- **Night Flushing**: Expel warm indoor air at night using natural ventilation.

Example:

Traditional Haveli architecture in North India uses internal courtyards and thick walls for passive climate control.

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2. Elements, Measurement, and Representation of Climate Data

Elements of Climate:

- Temperature: Air temperature, diurnal variations.
- Humidity: Moisture content in the air.
- Wind: Speed, direction, seasonal variations.
- Solar Radiation: Intensity, duration, angle.
- Precipitation: Rainfall, snowfall, and its effects.

Measurement Tools:

- Thermometers – Measure temperature.
- Hygrometers – Measure humidity.
- Anemometers – Measure wind speed.
- Solarimeters – Measure solar radiation.
- Rain Gauges – Measure precipitation levels.

Representation of Climate Data:

- Climate graphs (temperature vs. rainfall).
- Sun-path diagrams (sun movement through the year).
- Wind rose diagrams (dominant wind directions).

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3. Tropical Climate Classification & Characteristics

- Tropical Wet (Rainforest) – High humidity, frequent rainfall, dense vegetation.
- Tropical Monsoon – Seasonal rainfall variation, hot summers.
- Tropical Wet & Dry (Savanna) – Distinct wet & dry seasons, moderate rainfall.
- Hot & Dry Climate (Desert) – High temperature fluctuations, minimal rainfall.

Common Architectural Responses in Tropical Climates:

- High ceilings & ventilated roofs for heat dissipation.
- Large overhangs & shaded areas for solar protection.
- Light-colored materials to reflect heat.
- Courtyards & open spaces for airflow.

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4. Major Climatic Zones in India

1. Hot & Dry (Rajasthan, Gujarat, parts of MP & Maharashtra)
    - Thick walls, small windows, courtyards for passive cooling.
2. Warm & Humid (Coastal regions – Kerala, Tamil Nadu, West Bengal)
    - Large openings, verandas, sloped roofs for rain protection.
3. Composite (Delhi, Lucknow, Central India)
    - Combination of strategies based on seasonal variations.
4. Cold (Himalayan regions – Ladakh, Sikkim, Himachal Pradesh)
    - Small windows, insulated walls, solar passive heating.
5. Moderate (Bangalore, Pune, parts of Maharashtra)
    - Balanced design with cross-ventilation & moderate insulation.

Effect of Landscape on Microclimate:

- Vegetation: Reduces heat gain, improves humidity.
- Water Bodies: Regulate temperature, increase humidity.
- Topography: Hills and valleys influence wind patterns.
- Urban Heat Island Effect: Concrete & asphalt increase temperatures.

Effect of Landscape on Microclimate

Definition of Microclimate:

A **microclimate** is a localized atmospheric zone where the climate differs from the surrounding area. In architectural and urban design, modifying the microclimate through landscape elements can significantly improve environmental quality, reduce energy consumption, and enhance comfort.

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1. Vegetation

Impact:

- **Temperature Reduction**: Trees and shrubs provide shade, reducing **surface and air temperatures** by 2°C to 8°C.
- **Evapotranspiration**: Plants release water vapor, enhancing **humidity** and aiding in evaporative cooling.
- **Air Quality Improvement**: Green cover filters dust and pollutants.

Applications:

- **Green roofs** and **vertical gardens** in urban areas
- **Tree-lined streets** to provide shade and reduce glare
- **Planting buffer zones** around buildings to cool prevailing winds

Example:

Dense tree canopies in campus landscapes (e.g., IIM Bangalore) provide shaded walkways and reduce heat stress.

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2. Water Bodies

Impact:

- **Thermal Regulation**: Large water surfaces absorb heat during the day and release it slowly at night, **moderating temperature extremes**.
- **Humidity Enhancement**: Evaporation from lakes, ponds, and fountains increases **ambient humidity**, especially beneficial in hot-dry climates.
- **Psychological Comfort**: Water features also provide **acoustic masking** and visual cooling.

Applications:

- Reflecting pools and artificial lakes in urban planning
- Courtyard fountains in traditional architecture (e.g., Persian, Mughal)

Example:

The **Lotus Temple complex** in Delhi uses surrounding water bodies to passively cool the site.

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3. Topography

Impact:

- **Wind Modification**: Hills, valleys, and slopes influence **wind direction, speed, and pressure zones**.
- **Temperature Zoning**: Low-lying areas may trap cold air, while hilltops may be windier and cooler.
- **Solar Exposure**: South-facing slopes (in the northern hemisphere) receive more sunlight, influencing design decisions.

Applications:

- Placement of buildings for maximum ventilation or solar gain based on slope orientation
- Earth berms used to shield buildings from cold winds

Example:

The traditional settlement pattern in **Leh, Ladakh** is adapted to south-facing slopes for optimal solar access during winters.

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4. Urban Heat Island (UHI) Effect

Definition:

The **Urban Heat Island effect** refers to the increased temperature in urban areas compared to surrounding rural areas, primarily due to human activity and the built environment.

Contributors:

- Extensive use of **concrete, asphalt, and dark surfaces**
- **Reduced vegetation** and green cover
- High-density building layout with poor airflow

Mitigation through Landscaping:

- **Green infrastructure** (parks, green roofs)
- **Permeable pavements** and light-colored surfaces
- **Street trees and urban forests** to break up expanses of heat-absorbing surfaces

Example:

Cities like **Ahmedabad and Hyderabad** have initiated UHI mitigation through urban greening projects and water-sensitive urban design.

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5. Thermal Comfort Indices

Thermal comfort is a crucial aspect of indoor environmental quality, and understanding the thermal balance of the human body is essential for designing comfortable spaces.

Thermal Balance of the Human Body

The human body maintains its internal temperature through a balance of heat gain and heat loss. The thermal balance equation is:

$$M = W + Q + C + R + E$$

Where:

- M = Metabolic rate (heat production)
- W = Work done (mechanical energy)
- Q = Heat gain (radiation, convection, conduction)
- C = Convection (heat loss through air movement)
- R = Radiation (heat loss through radiation)
- E = Evaporation (heat loss through sweating)

Thermal Comfort Indices

Several indices are used to evaluate thermal comfort:

1. Effective Temperature (ET): A measure of the combined effects of temperature, humidity, and air movement.

2. Corrected Effective Temperature (CET): An adjustment of ET to account for the effects of radiation.

3. Bioclimatic Chart: A graphical representation of the relationship between temperature, humidity, and thermal comfort.

4. Tropical Summer Index (TSI): Developed by CBRI Roorkee, this index assesses thermal comfort in tropical climates.

Thermal Comfort

1. Importance

Thermal comfort is a vital component of indoor environmental quality. It affects health, productivity, and overall well-being, and is essential in designing energy-efficient and comfortable spaces.

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3. Thermal Comfort Indices

- **Effective Temperature (ET)**: Combines temperature, humidity, and air movement to reflect perceived comfort.
- **Corrected Effective Temperature (CET)**: Enhances ET by including radiation effects.
- **Bioclimatic Chart**: Visual tool showing comfort zones based on temperature and humidity.
- **Tropical Summer Index (TSI)**: Developed for tropical climates by CBRI Roorkee; assesses comfort with region-specific parameters.

Thermal Comfort Indices: Detailed Explanation

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1. Effective Temperature (ET)

Definition:

Effective Temperature is a composite index that reflects how the human body perceives thermal comfort, based on **air temperature**, **humidity**, and **air movement**.

Key Parameters:

- **Air Temperature (Dry Bulb Temperature)**
- **Relative Humidity**
- **Air Velocity**

Purpose:

To quantify comfort levels in a single value, allowing designers to evaluate the combined impact of thermal variables on occupants.

Example:

A room with 26°C dry bulb temperature, 60% humidity, and a gentle breeze might have the same *effective temperature* as a cooler room with no airflow and higher humidity.

Application:

Used in HVAC design and thermal comfort studies to assess indoor environments without considering radiant heat.

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2. Corrected Effective Temperature (CET)

Definition:

The **Corrected Effective Temperature** is an enhanced version of ET that includes the effect of **mean radiant temperature (MRT)** — i.e., heat exchange through radiation between the body and surrounding surfaces.

Why CET Matters:

In spaces exposed to sunlight, heated walls, or large windows, **radiant heat** significantly affects thermal comfort. CET accounts for this additional factor, making it a more accurate index than ET.

Additional Parameters Considered:

- **Mean Radiant Temperature (MRT)**
- **Clothing insulation**
- **Activity levels**

Use in Practice:

Architects use CET when designing spaces with **large glazed surfaces** or **direct sun exposure** (e.g., atriums, lobbies, greenhouses).

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3. Bioclimatic Chart

Definition:

A **Bioclimatic Chart** is a **graphical tool** that helps determine the most suitable passive strategies (e.g., natural ventilation, shading, insulation) based on **outdoor air temperature** and **relative humidity**.

Components:

- X-axis: Dry Bulb Temperature
- Y-axis: Relative Humidity
- Comfort zone marked in the central area
- Zones suggesting passive design strategies (e.g., evaporative cooling, heating, humidification)

Purpose:

- To **visually analyze climate data** for a given location.
- To guide design decisions in **climate-responsive architecture**.

Example:

Victor Olgyay's bioclimatic chart is a widely referenced model that indicates whether a given outdoor condition requires heating, cooling, or ventilation.

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4. Tropical Summer Index (TSI)

Definition:

The **Tropical Summer Index** is a region-specific comfort index developed by the **Central Building Research Institute (CBRI), Roorkee**, to assess thermal comfort in **hot and humid tropical climates**.

Parameters Considered:

- Dry Bulb Temperature
- Relative Humidity
- Air Movement (Wind Speed)
- Clothing insulation and metabolic rate (simplified for typical Indian context)

Unique Feature:

TSI is calibrated for **Indian climatic conditions**, making it more suitable than international indices like PMV (Predicted Mean Vote) for local use in **residences, schools, and offices**.

Comfort Classification:

TSI values are categorized to indicate levels of discomfort:

- **<25**: Comfortable
- **25–30**: Slight discomfort
- **>30**: Severe discomfort

Application:

Used in **building code development**, design of **thermal insulation**, and optimization of **natural ventilation** in tropical India.

Measuring Indoor Air Movement

1. Kata-thermometer: A device used to measure air movement and temperature.

Measuring Indoor Radiation

1. Globe Thermometer: A device used to measure radiation temperature.

These tools and indices help designers, architects, and engineers create comfortable indoor environments that promote occupant health, productivity, and well-being.

Thermal Comfort

1. Thermal Balance: The human body maintains its internal temperature through a balance of heat gain and heat loss.

2. Thermal Comfort Indices:

    - Effective Temperature (ET)

    - Corrected Effective Temperature (CET)

    - Bioclimatic Chart

    - Tropical Summer Index (TSI)

3. Measuring Indoor Air Movement:

    - Kata-thermometer

4. Measuring Indoor Radiation:

    - Globe Thermometer

Key Factors Affecting Thermal Comfort

1. Temperature

2. Humidity

3. Air Movement

4. Radiation

Importance of Thermal Comfort

1. Occupant Health

2. Productivity

3. Well-being

Design Considerations

1. Building Orientation

2. Insulation

3. Shading Devices

4. Ventilation “?:

- Kata-Thermometer – Measures cooling power of air movement.
- Globe Thermometer – Measures radiant temperature & heat exchange.

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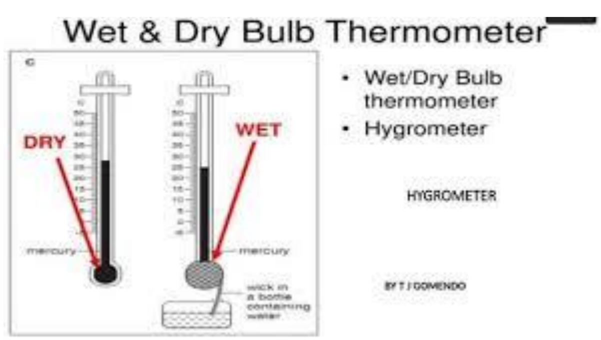
1. Kata-Thermometer

A Kata-Thermometer is a specialized device used to measure the cooling power of air movement. It helps determine how effectively air circulation can remove heat from the human body or objects in a space.



How It Works:

- The thermometer consists of a glass bulb filled with alcohol or mercury.

- It is heated to a fixed high temperature (usually around 38-40°C).
- Once heated, it is placed in the air and allowed to cool naturally.
- The time taken for the temperature to drop to a lower fixed value (e.g., 35°C) is recorded.
- A faster cooling time indicates stronger air movement and better ventilation.

Why It's Useful:

- Helps in assessing indoor ventilation effectiveness.
- Determines if a space has enough air movement for thermal comfort.
- Used in architectural design to optimize cross-ventilation.

Example Application:

- In hot & humid climates, strong air movement is needed to remove body heat. A Kata-Thermometer can help determine if a building's natural ventilation is sufficient.

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2. Globe Thermometer

A Globe Thermometer is used to measure radiant temperature and heat exchange in an environment. Unlike normal thermometers, which measure air temperature, the Globe Thermometer accounts for the heat emitted by surrounding surfaces, making it useful in analyzing thermal comfort.

Structure & Working:

- Consists of a hollow black globe (usually 150mm in diameter) with a thermometer inside.
- The black surface absorbs radiation from surrounding objects (walls, ceiling, furniture, etc.).
- Measures the Mean Radiant Temperature (MRT), which includes air temperature + radiant heat from surfaces.

Why It's Important:

- Helps assess the impact of heat radiation from walls, roofs, and windows on thermal comfort.
- Used in bioclimatic design to minimize excessive heat gain/loss in buildings.
- Essential in urban planning to evaluate the impact of heat islands (areas with high heat radiation due to asphalt, concrete, etc.).

Example Application:

- In hot climates, buildings with dark-colored surfaces may radiate excessive heat. A Globe Thermometer helps measure and design for better heat control by using reflective materials or shading elements.

Comparison Table: Kata-Thermometer vs. Globe Thermometer

Parameter	Kata-Thermometer	Globe Thermometer
Measures	Cooling power of air movement	Radiant temperature & heat exchange
How It Works	Records cooling time of a heated thermometer	Measures temperature inside a black globe
Key Factor	Air movement (ventilation)	Radiant heat from surrounding surfaces
Use in Architecture	Evaluates ventilation efficiency	Assesses heat gain/loss from surroundings
Example	Checking airflow in naturally ventilated buildings	Measuring heat from walls, windows, or streets

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Conclusion:

Both thermometers are crucial for climate-responsive architecture.

- Kata-Thermometer helps design well-ventilated spaces.
- Globe Thermometer helps minimize radiant heat discomfort in buildings and urban areas.

Module II – Thermal Comfort (10 Hours) 4. Overheated & Underheated Periods o Air temperature analysis in different climatic zones. o Solar heating & passive cooling optimization. 5. Sun-Path Diagram o Solar geometry & chart-based design considerations. 6. Thermal Performance of Building Elements o Effect of thermo-physical properties of materials. ___________________________________ _______

Module II – Thermal Comfort (10 Hours)

4. Overheated & Underheated Periods

Definition:

- Overheated period: When indoor temperatures exceed comfortable levels due to excessive solar gain.
- Underheated period: When indoor temperatures fall below comfort levels due to insufficient heat gain or excessive heat loss.

Air Temperature Analysis in Different Climatic Zones:

Each climatic zone has unique thermal comfort challenges, requiring different design strategies:

1. Hot & Dry (Rajasthan, Gujarat, parts of MP & Maharashtra)
    - Overheating is a major issue due to intense solar radiation.
    - Buildings need high thermal mass, shading devices, and evaporative cooling.
2. Warm & Humid (Coastal regions – Kerala, Tamil Nadu, West Bengal)
    - High moisture levels make heat feel worse (low evaporation).
    - Cross-ventilation, shaded outdoor spaces, and lightweight materials help cooling.
3. Composite (Delhi, Lucknow, Central India)
    - Experiences both overheating (summer) and underheating (winter).
    - Needs adaptive designs with seasonal strategies (shading in summer, insulation in winter).
4. Cold (Himalayan regions – Ladakh, Sikkim, Himachal Pradesh)
    - Underheating is a bigger issue due to prolonged cold conditions.
    - Passive solar heating, high insulation, and compact building forms are essential.
5. Moderate (Bangalore, Pune, parts of Maharashtra)
    - Balanced climate; overheating and underheating are mild.
    - Requires well-designed openings, shading, and natural ventilation.

Solar Heating & Passive Cooling Optimization:

Strategies for Solar Heating (Cold Climates)

- South-facing windows maximize solar gain in winter.
- Thermal mass walls (brick, concrete) store heat during the day and release it at night.
- Dark-colored surfaces absorb and retain heat.

Strategies for Passive Cooling (Hot Climates)

- Shading devices: Overhangs, pergolas, and louvered screens block direct sunlight.
- Light-colored materials: Reflect solar radiation instead of absorbing it.
- Courtyards & water features: Enhance evaporative cooling.

- Stack ventilation: Uses height differences to improve airflow.

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5. Sun-Path Diagram

What is a Sun-Path Diagram?

A Sun-Path Diagram is a graphical representation of the sun's movement across the sky at different times of the day and year. It helps architects design buildings to:

- Maximize natural lighting in cold climates.
- Minimize overheating in warm climates.
- Optimize solar panel angles for energy efficiency.

Solar Geometry Considerations:

- Solar Altitude (Height Angle): The angle of the sun above the horizon.
- Solar Azimuth (Horizontal Angle): The direction of the sun from true north.
- Seasonal Variation:
  - Summer: Sun is higher; shading is crucial.
  - Winter: Sun is lower; maximizing solar gain is important.

Chart-Based Design Considerations:

- Shading Devices:
  - Horizontal shades (overhangs) work well for south-facing windows.
  - Vertical shades (fins) are effective for east & west-facing windows.
- Building Orientation:
  - North-South orientation is ideal to minimize direct sunlight exposure.
  - Avoid large west-facing openings to reduce afternoon heat gain.
- Solar Panel Positioning:
  - Panels should be tilted at an angle equal to the latitude for maximum efficiency.

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6. Thermal Performance of Building Elements

What is Thermal Performance?

Thermal performance refers to how well a building material regulates heat transfer (heat gain/loss), affecting indoor comfort.

Effect of Thermo-Physical Properties of Materials:

Different materials react differently to heat. Important factors include:

1. Thermal Conductivity (k):
   - Measures how easily heat passes through a material.

- Low conductivity = Good insulation (e.g., wood, clay, straw, foam).
- High conductivity = Poor insulation (e.g., metal, glass, concrete).

2. Thermal Mass:
   - The ability of a material to absorb, store, and release heat over time.
   - High thermal mass (e.g., brick, stone, concrete) helps stabilize temperature swings.
   - Low thermal mass (e.g., timber, glass) heats up and cools down quickly.
3. Reflectivity & Absorptivity:
   - Light-colored surfaces reflect heat (ideal for hot climates).
   - Dark-colored surfaces absorb heat (ideal for cold climates).
4. U-Value (Thermal Transmittance):
   - Lower U-value = better insulation.
   - Example: Single-glazed windows (high U-value) lose more heat than double-glazed windows (low U-value).
5. Air Permeability:
   - Determines how easily air can pass through a material.
   - Good for ventilation (e.g., breathable walls in humid regions).
   - Bad in cold climates (requires airtight insulation).

Optimizing Building Elements for Thermal Comfort:

- Walls & Roofs:
  - Use high thermal mass materials for stable indoor temperatures.
  - Add insulation layers to reduce heat loss/gain.
- Windows & Glazing:
  - Use double-glazing or tinted glass to reduce heat transfer.
  - Incorporate adjustable shading devices for seasonal control.
- Floors & Ceilings:
  - Earth-coupled floors (like mud flooring) help keep interiors cool in hot regions.
  - Suspended wooden floors work well in cold climates to prevent heat loss.

Summary Table – Key Concepts & Strategies

Concept	Definition	Strategies
Overheated & Underheated Periods	Temperature variations affecting comfort	Passive heating & cooling strategies
Solar Heating	Maximizing sun exposure for warmth	South-facing windows, thermal mass
Passive Cooling	Reducing heat gain naturally	Shading, ventilation, reflective materials
Sun-Path Diagram	Chart showing sun's movement	Used for shading & building orientation
Thermal Performance	How materials regulate heat transfer	Insulation, thermal mass, reflectivity

CLIMATOLOGY

MODULE –II

Module-II Thermal comfort 4. Thermal comfort-2: Calculation of Overheated and Under heated period (based on air temperature only) for locations in Climatic zones and their optimization in terms of solar heating and Passive cooling desired. 5. Sun-path diagram: Solar geometry & design for orientation and use of solar charts in climatic design. 6. Thermal performance of building elements: Effect of thermo-physical properties of building materials and elements on indoor thermal environment. Convection, Radiation, concept of S ol-air temperature and Solar Gain factor.

Thermal Comfort – Part 2: Overheated and Underheated Periods

Definition: Thermal comfort refers to the condition of mind that expresses satisfaction with the thermal environment, primarily influenced by air temperature in this context.

Calculation Approach:

- **Overheated Period**: When daily mean temperature exceeds the upper comfort threshold (e.g., 30°C).
- **Underheated Period**: When daily mean temperature falls below the lower comfort threshold (e.g., 18°C).
- These thresholds are often derived from adaptive comfort models (e.g., ASHRAE 55 or Indian standards like NBC).

Methodology:

- Collect **daily air temperature data**.
- Compare with **thermal comfort thresholds**.
- Count the **number of days/hours** exceeding/falling below the limits.

Optimization:

- **Solar Heating**: Optimize through **south-facing windows, thermal mass**, and **greenhouse principles** in cold climates.
- **Passive Cooling**: Employ **cross-ventilation, shading devices, high albedo materials, night ventilation**, and **thermal mass** for delay in heat transmission.

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5. Sun-Path Diagram: Solar Geometry & Design

Sun Path Diagram: Understanding Solar Geometry for Building Design

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What is a Sun Path Diagram?

A Sun Path Diagram is a graphical representation of the sun's trajectory across the sky for a specific latitude. It shows the position of the sun (solar altitude and azimuth) throughout the day and across different times of the Equinoxes

Equinoxes occur when the Sun is directly above the equator, resulting in nearly equal day and night across the globe.

- **Spring (Vernal) Equinox**: March 21 *(approximately)*
- **Autumn (Fall) Equinox**: September 23 *(approximately)*

These mark the beginning of **spring** and **autumn** in many cultural calendars.

year, particularly on:

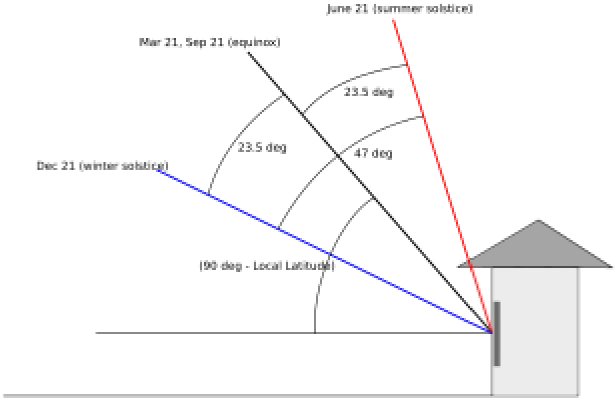
- **(Summer March 21 & September 23)**
- **Solstice (June 21)**
- **Winter Solstice (December 21) Equinoxes**

Solstices

Solstices are the points when the Sun reaches its highest or lowest position in the sky at noon, marking the longest and shortest days of the year.

- **Summer Solstice**: June 21 *(approximately)*
  - Longest day of the year in the **Northern Hemisphere**
  - Marks the start of **summer**
- **Winter Solstice**: December 21 *(approximately)*
  - Shortest day of the year in the **Northern Hemisphere**
  - Marks the beginning of **winter**

https://m.youtube.com/watch?v=HN6rVPzYfD8&pp=ygUJI3N1bmNoYXJ0



http://www.cccarchitecture.org/solar-paths-and-positions

Core Solar Geometry Terms:

- **Solar Altitude (α)**: The angle of the sun above the horizon.
- **Solar Azimuth (Az)**: The angle of the sun measured clockwise from true north.
- **Declination (δ)**: The angle between the sun's rays and the equatorial plane.
- **Hour Angle (H)**: The measure of time before/after solar noon, expressed in degrees (15° per hour).
- **Latitude (φ)**: Determines the shape and coverage of the sun path diagram for a location.

Solar Geometry – Key Concepts

- **Solar Altitude (α):**
  The vertical angle of the sun above the horizon; higher values mean the sun is higher in the sky.
- **Solar Azimuth (Az):**
  The horizontal angle of the sun, measured clockwise from true north, indicating the sun's compass direction.
- **Declination (δ):**
  The tilt angle between the solar rays and Earth's equatorial plane; varies throughout the year due to Earth's axial tilt.
- **Hour Angle (H):**
  Represents the sun's position relative to solar noon, measured in degrees (15° per hour); negative in the morning, positive in the afternoon.
- **Latitude (φ):**
  Geographic coordinate that defines how the sun path diagram is shaped for any given location; crucial for determining solar angles throughout the year.

□ 1. Understand the Basic Layout

- The diagram is usually a **polar graph** (circular) where:
    - The **center** represents the **observer's location**.
    - **Concentric circles** represent different **solar elevations** (angle of the sun above the horizon).
    - **Radial lines** (spokes) represent **azimuth angles** (compass directions, e.g., North, East).

□ 2. Azimuth Lines (Direction)

- **0° (or 360°)** is **true north**.
- **90°** is **east**, **180°** is **south**, and **270°** is **west**.
- These lines help identify where the sun rises and sets at different times of the year.

□ 3. Altitude Circles (Height of Sun)

- Circles mark the **sun's altitude** above the horizon (0° to 90°).
- The further from the center, the **higher the sun** in the sky.

□ 4. Sun Paths

- **Curved lines** show the **sun's path** across the sky on specific dates.
- Typical dates shown: **June 21** (summer solstice), **March/Sept 21** (equinoxes), and **Dec 21** (winter solstice).
    - June 21: Longest path, highest altitude.
    - Dec 21: Shortest path, lowest altitude.
    - Equinoxes: Intermediate paths.

□ 5. Time of Day

- Numbers along the curves indicate **solar time** (usually in hours).
- Trace a point on the curve to see where the sun will be at a specific **time** and **date**.

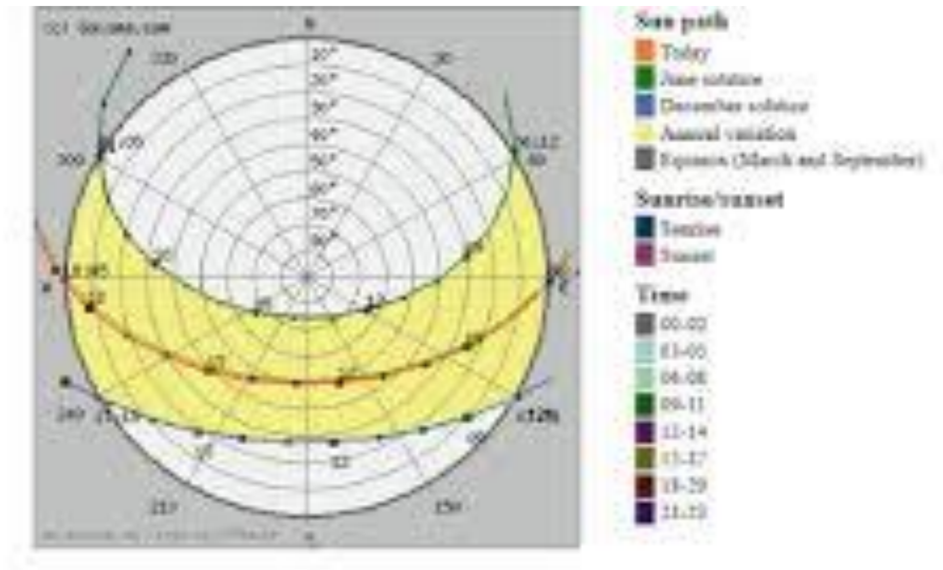
□ 6. Shading & Design Implications

- Analyze when parts of a building or site are in **sun or shadow**.
- Helps determine:
    - **Window orientation**
    - **Overhang sizing**
    - **Solar panel placement**
    - **Vegetation planning**

✅Practical Use Example

If you're designing a building in the **northern hemisphere**:

- Orient main windows to the **south** to capture winter sun.
- Use **overhangs** to block high summer sun.
- Use the diagram to avoid placing large obstructions that would block morning or afternoon light.



How It's Used in Design:

1. **Building Orientation**:
    - Maximize solar gain in winters (e.g., face buildings south in Northern Hemisphere).
    - Minimize solar heat in summers via strategic orientation.
2. **Shading Devices**:
    - Design **overhangs, louvers, pergolas** based on sun angles.
    - Prevent direct sunlight on windows during peak summer.
3. **Daylighting**:
    - Optimize **natural light** by placing skylights and clerestory windows appropriately.
4. **Solar Panel Placement**:
    - Align **photovoltaics (PV)** and **solar thermal panels** with optimal sun angles.

Types of Sun Path Diagrams:

- **Stereographic**: Most common, shows daily sun paths as curved lines.
- **Rectangular / Cartesian**: Useful in software-based simulations.
- **Solar Charts**: Include overlays like shading masks and building profiles.

Tools to Generate or Use Sun Path Diagrams:

- **Manual Methods**:
  - Use standard sun-path templates for your location's latitude.
- **Software**:
  - **SketchUp + Heliodon Tool**
  - **Climate Consultant**
  - **SunCalc**, **Ladybug Tools** (Grasshopper/Rhino)
  - **Ecotect Analysis**

Solar Geometry Concepts:

- **Solar altitude angle (α)**
- **Solar azimuth angle (A)**
- **Declination (δ), Hour angle (H), and Latitude (φ)**

Sun-Path Diagrams:

- Graphical tools showing the sun’s position at different times/days of the year.
- Used to understand **solar exposure**, **shading**, and **daylighting**.

Design Applications:

- Orientation of **buildings** for optimal solar gain or avoidance.
- Designing **overhangs and shading devices**.
- **Window placement** for thermal and visual comfort.

Solar Charts Usage:

- Derive data for **building facades** and **roof inclinations**.
- Assess **sunlight penetration** and determine optimal angles for **solar panels**.

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6. Thermal Performance of Building Elements

Key Thermo-Physical Properties:

- **Thermal Conductivity (k)**
- **Density (ρ)**
- **Specific Heat (c)**
- These affect **thermal inertia** and **lag time**.
-

Modes of Heat Transfer:

- **Conduction**: Through building envelope.
- **Convection**: Between surfaces and air.
- **Radiation**: Solar radiation and long-wave emission.

Derived Metrics:

- **Sol-Air Temperature (T_sol-air)**:

Sol-Air Temperature (T_{sol-air})

Definition: Sol-Air Temperature is an **equivalent outdoor air temperature** that accounts not just for the ambient air temperature, but also for the **effects of solar radiation** and **heat exchange with the outdoor environment**. It provides a more comprehensive indicator of how hot or cold an external building surface will become, which is crucial for assessing **heat gains or losses** through the building envelope.

Formula:

Tsol−air=Tair+(α·I−ho·ΔTr)hoT_{sol-air} = T_{air} + \frac{(α \cdot I - h_o \cdot ΔT_r)}{h_o}Tsol−air=Tair+ho(α·I−ho·ΔTr)

Where:

- Tsol−airT_{sol-air}Tsol−air: Sol-air temperature (°C)
- TairT_{air}Tair: Ambient outdoor air temperature (°C)
- ααα: Absorptivity of the surface (dimensionless, typically 0.1–0.95)
- III: Total incident solar radiation on the surface (W/m²)
- hoh_oho: External surface heat transfer coefficient (W/m²·K), typically ~25 W/m²·K for wind-exposed surfaces
- ΔTrΔT_rΔTr: Temperature difference due to long-wave radiation exchange with the sky (can often be approximated or omitted if not significant)

Key Interpretations:

- A **higher absorptivity** surface (like dark colors) absorbs more solar energy, increasing T_{sol-air}.
- When **solar radiation is strong**, T_{sol-air} can be **much higher** than the ambient air temperature.
- This is especially relevant for **building facades, roofs**, and **thermal simulations**.

Practical Use in Design:

- Helps in **designing thermal insulation** and **calculating cooling loads**.
- Used in **HVAC sizing**, especially for **roofs and west-facing walls**.
- Influences selection of **cladding materials** and **shading strategies**.

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where ααα is absorptivity, III is solar radiation, hoh_oho is external heat transfer coefficient.

- **Solar Gain Factor (SGF)**: Ratio of solar radiation transmitted through an element to the incident radiation.

Design Implications:

- Materials with **high thermal mass** can buffer indoor temperatures.
- **Reflective and insulative materials** reduce heat ingress.
- Use of **double glazing** and **thermal breaks** enhances thermal comfort.

CLIMATOLOGY

MODULE –III

THERMAL HEAT GAIN OR LOSS IN BUILDINGS

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  where qqq is heat flux (W/m²), kkk is thermal conductivity (W/m·K), and dTdx\frac{dT}{dx}dxdT is the temperature gradient.

2. Periodic (Transient) Heat Flow

- Heat flow that varies with time, often due to diurnal temperature cycles.
- Important for determining indoor comfort, especially in passive design.
- Time-dependent differential equations are used:

  ρcp∂T∂t=k∂2T∂x2\rho c_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2}ρcp∂t∂T=k∂x2∂2T

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- Particularly important in **hot-arid** and **continental climates** where large swings are observed.

II. Characteristics

Feature	Description
Peak temperature	Occurs mid to late afternoon (~2–4 PM)
Minimum temperature	Just before sunrise (~5–6 AM)
Amplitude	Range of temperature change over 24h
Influences	Solar radiation, humidity, cloud cover, wind, ground cover, urbanization

II. Thermal Properties of Materials

Property	Symbol	Units	Definition
Thermal Conductivity	k	W/m·K	Rate at which heat passes through a material
Thermal Resistivity	r	m·K/W	Reciprocal of conductivity
Thermal Resistance	R	m^2K/W	Resistance to heat flow; $R = \frac{L}{k}$
Thermal Diffusivity	α	m^2/s	Rate of heat propagation; $\alpha = \frac{k}{\rho c_p}$
Thermal Capacity	C	J/K	Amount of heat to raise temperature
Volumetric Heat Capacity	ρc_p	$J/m^3 \cdot K$	Product of density and specific heat

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III. Time Lag and Decrement Factor

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- **Decrement Factor (f)**: Ratio of indoor to outdoor temperature amplitude.
  - Good design = high time lag, low decrement factor.
  - Heavy walls have longer time lags due to thermal mass.

IV. U-Value (Overall Heat Transfer Coefficient)

- Indicates rate of heat transfer through an assembly (W/m^2K).
- Lower U-values = better insulation.

Formula for U-Value (Multilayered Walls or Roofs):

$$U = \frac{1}{R_\text{total}} = \frac{1}{R_i + \sum_{n=1}^{N} \frac{d_n}{k_n} + R_o}$$

Where:

- R_i = internal surface resistance (~0.13 m^2K/W)
- R_o = external surface resistance (~0.04 m^2K/W)
- d_n = thickness of layer n
- k_n = thermal conductivity of layer n

Example:

For a 3-layer wall:

- Brick (0.2 m, 0.72 W/m·K),
- Insulation (0.05 m, 0.04 W/m·K),
- Gypsum board (0.01 m, 0.17 W/m·K)

$$R_{total} = 0.13 + \frac{0.2}{0.72} + \frac{0.05}{0.04} + \frac{0.01}{0.17} + 0.04 = 2.17 \text{ m}^2\text{K/W}$$

$$U = \frac{1}{2.17} \approx 0.46 \text{ W/m}^2\text{K}$$

V. Temperature Gradient

- Temperature change across wall thickness.
- In steady-state, linear for homogeneous material.
- Multilayered walls: gradient slope changes at each interface due to different k values.

VI. Graphical Inference of Time Lag and Temperature Amplitude

- Graphs plot external and internal surface temperatures over time.
- **Time Lag** = Horizontal distance between the peaks.
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□ Walls with high thermal mass (concrete, brick) show a **flattened and delayed** indoor temperature curve compared to light materials.

VII. Construction Techniques for Improved Thermal Performance

1. Increasing Density & Thermal Mass

- Dense materials (e.g., concrete) slow down heat transfer.
- Advantageous in climates with large diurnal temperature variations.

2. Use of Insulation

- Material with low thermal conductivity (e.g., EPS, mineral wool).
- Placement: externally (preferred), internally, or sandwiched.

3. Incorporation of Cavities

- **Air cavities** reduce conduction and convection.
- **Reflective surfaces** inside cavities reduce radiation.

Technique	Effect
Dense materials	↑ time lag, ↓ peak temperature
Insulation	↓ U-value, ↓ heat gain/loss
Cavities	Break thermal bridges, ↑ resistance

OUTCOME

- Understanding and calculating U-values is fundamental for evaluating envelope performance.
- Time lag and decrement factor are essential for **dynamic thermal behavior** of materials.
- Strategic layering and construction material choices drastically improve **thermal comfort** and **energy efficiency**.

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  f=ΔTinsideΔToutsidef = \frac{\Delta T_{\text{inside}}}{\Delta T_{\text{outside}}}f=ΔToutsideΔTinside

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  - **Higher Φ** = better delay in heat gain

These parameters are crucial for **thermal comfort** and **passive design strategies**.

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Where:

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Layers:

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In a **steady-state**, temperature drop across each layer is proportional to its resistance:

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CLIMATOLOGY

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CLIMATOLOGY

MODULE –IV

Shading Devices

Shading devices are **architectural elements** used to control the entry of **solar radiation**, especially for reducing cooling loads during **overheated periods** and allowing beneficial sunlight during **under-heated periods**. Their design must consider **orientation, climate**, and **seasonal variations**.

Objectives of Shading Devices

- Reduce **solar heat gain** in summer.
- Permit **solar penetration** in winter (especially on south-facing walls in the northern hemisphere).
- Improve **visual comfort** and reduce glare.
- Enhance **thermal comfort** without mechanical systems.

Orientation-Based Optimization

Orientation	Sun Path Characteristics	Recommended Shading Devices
South	High sun angles (summer); low in winter	**Horizontal overhangs** effective for summer shading; allows winter sun
East/West	Low sun angles (morning/evening)	**Vertical fins, louvers, screens** required to block horizontal sunlight
North	Minimal direct sunlight (except high-latitude summers)	Often does not require shading; light shelves may be used for daylighting

Design Tools and Techniques

- **Sun Path Diagrams** and **Solar Altitude Charts** to understand solar geometry.
- **Shading Mask Angle (SMA)** analysis for calculating the required projection of shading elements.
- Use of **adjustable or dynamic shading systems** (e.g., louvers, fins) for adaptability across seasons.

Natural Ventilation

Natural ventilation is a **passive cooling technique** that utilizes **natural forces (wind and buoyancy)** to circulate air within a building, thereby enhancing indoor air quality and reducing reliance on mechanical HVAC systems.

A. Functions of Natural Ventilation

- **Temperature regulation** by removing internal heat gains.
- **Air quality improvement** by expelling indoor pollutants.
- **Humidity control**, especially in tropical climates.
- **Enhancement of thermal comfort** without energy expenditure.

Mechanisms of Air Movement

1. Stack Effect (Thermal Buoyancy):

- Caused by temperature differences between indoor and outdoor air.
- Warm air rises and escapes through higher openings, drawing in cooler air through lower openings.
- Most effective in **tall spaces** (e.g., atria, stairwells).

2. Wind-Driven Ventilation:

- Utilizes **wind pressure differentials** across building surfaces.
- Air enters from **windward openings** and exits through **leeward** sides.
- Highly influenced by site orientation, terrain, and building form.

Design Considerations

1. Openings and Internal Layout:

- **Cross ventilation** requires inlet and outlet openings on opposite walls.
- **Positioning of windows, clerestories, and ventilators** affects airflow paths.
- Openings should be located at different heights to promote vertical air movement.

2. External Features:

- **Courtyards, verandahs, wind towers** channel and amplify breezes.
- **Screens, jalis, pergolas** can diffuse wind and control velocity.

3. Wind Shadows:

- Areas of **reduced airflow** formed behind large obstructions (e.g., adjacent buildings, trees).
- **Design Implication:** Avoid placing critical air intake zones within wind shadows.

Enhancing Natural Ventilation

- Use **wing walls** or **ventilation scoops** to redirect air.
- Optimize **aspect ratio of rooms** to facilitate airflow.
- Ensure **unobstructed flow paths** and minimize internal partitions.