ASIA LOW CARBON BUILDINGS TRANSITION PROJECT
Life Cycle Assessment for Transitioning to a Low-Carbon Economy

2.2 Solar Passive Design

November 2024

Supported by:
Federal Ministry for Economic Affairs and Climate Action
INTERNATIONAL CLIMATE INITIATIVE
on the basis of a decision by the German Bundestag

WHAT WILL YOU LEARN?

01 Understanding the Climate

02 Building Massing and Orientation

03 Optimizing Building Envelope – Windows for Better Daylight and Minimum Heat Gain

04 Optimizing Building Envelope – Windows for Better Natural Ventilation

05 Solar Shading

06 Optimizing Building Envelope – Walls and Roofs

07 Building Envelope Features for Different Climates

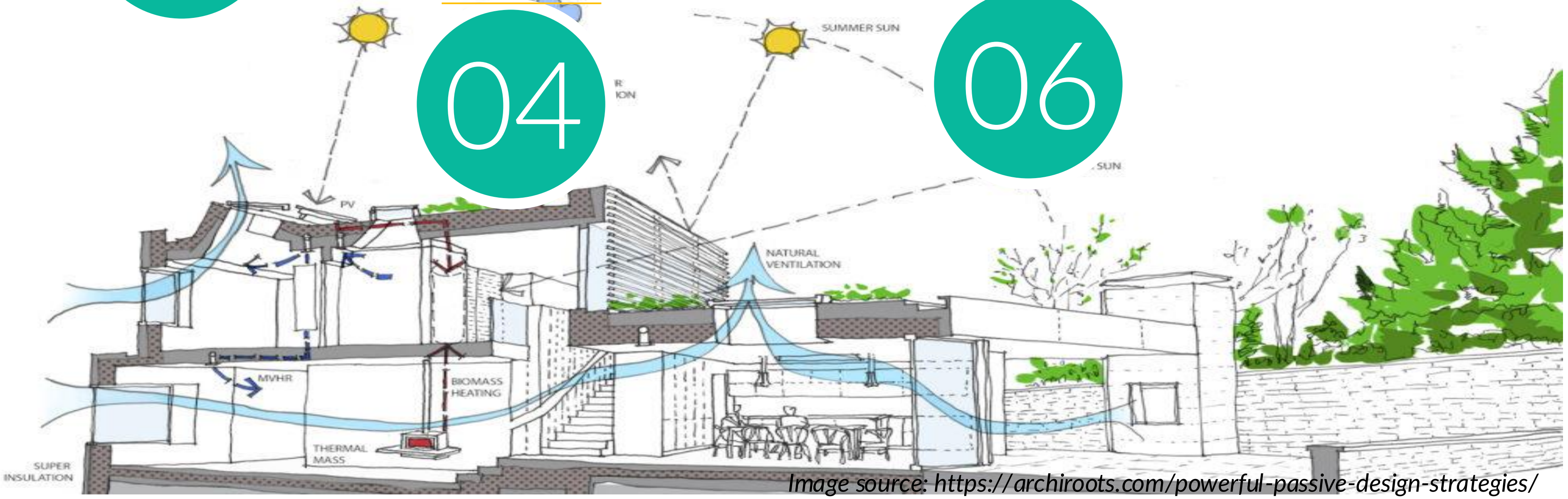


Image source: https://archiroots.com/powerful-passive-design-strategies/

Understanding the Climate

Temperature, Humidity, Wind and Solar Radiation

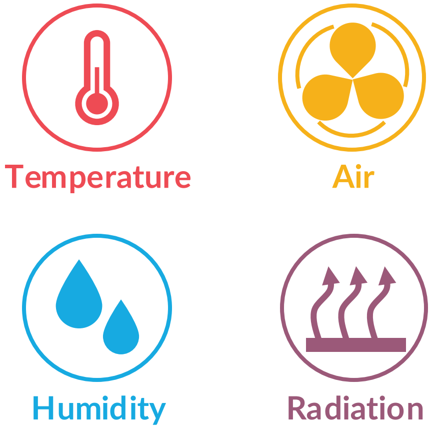
Image source: https://elemental.green/passive-solar-home-design-

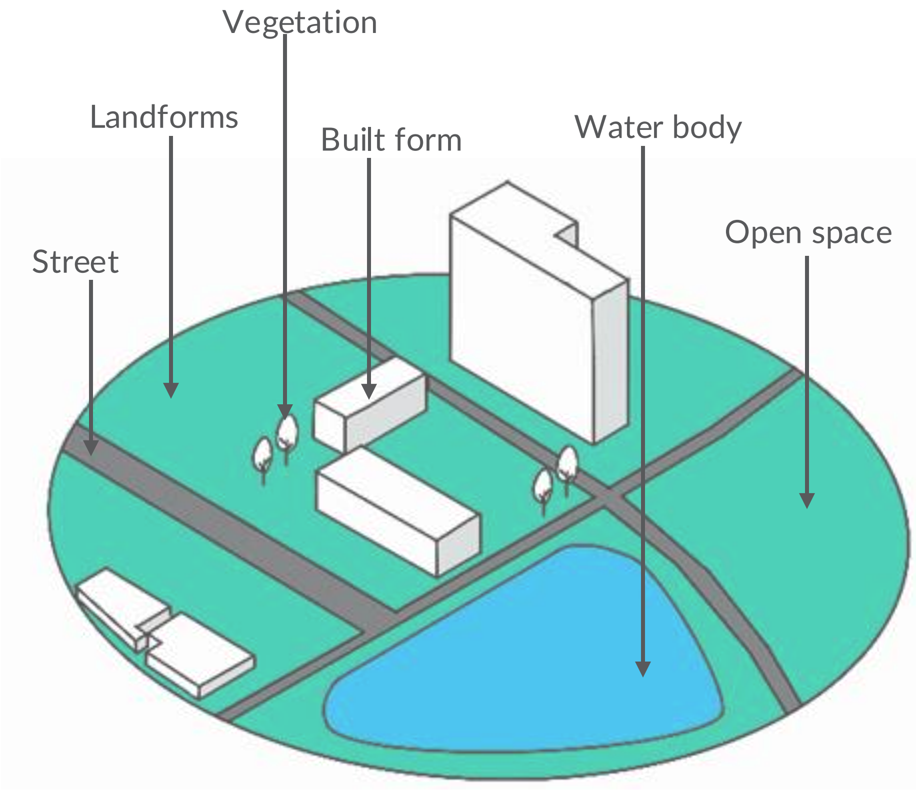
ROLE OF MICROCLIMATE

Determines the overall layout and comfort in buildings

Microclimate of a building affects energy transfer through building and how people respond to it

Local conditions that contribute to microclimate





Factors affecting microclimate of a site

Image source: SM Solutions

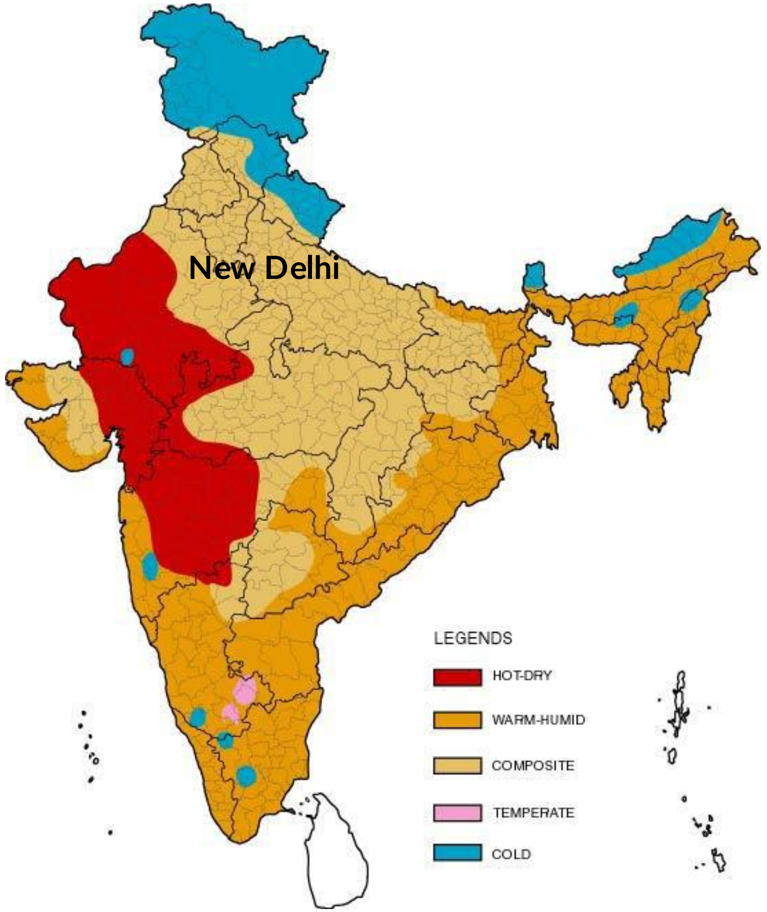
Open courtyards with combination of pervious and impervious materials add character to the building

CLIMATE ANALYSIS

Example: New Delhi, India

- To conduct a climate analysis, representative climate data of the location for the past 10–15 years is needed
- Several tools can assist in climate analysis. These tools use hourly weather data files as input
- The latest available weather files should be used for climate analysis
- One potential source for weather files is https://climate.onebuilding.org/default.html

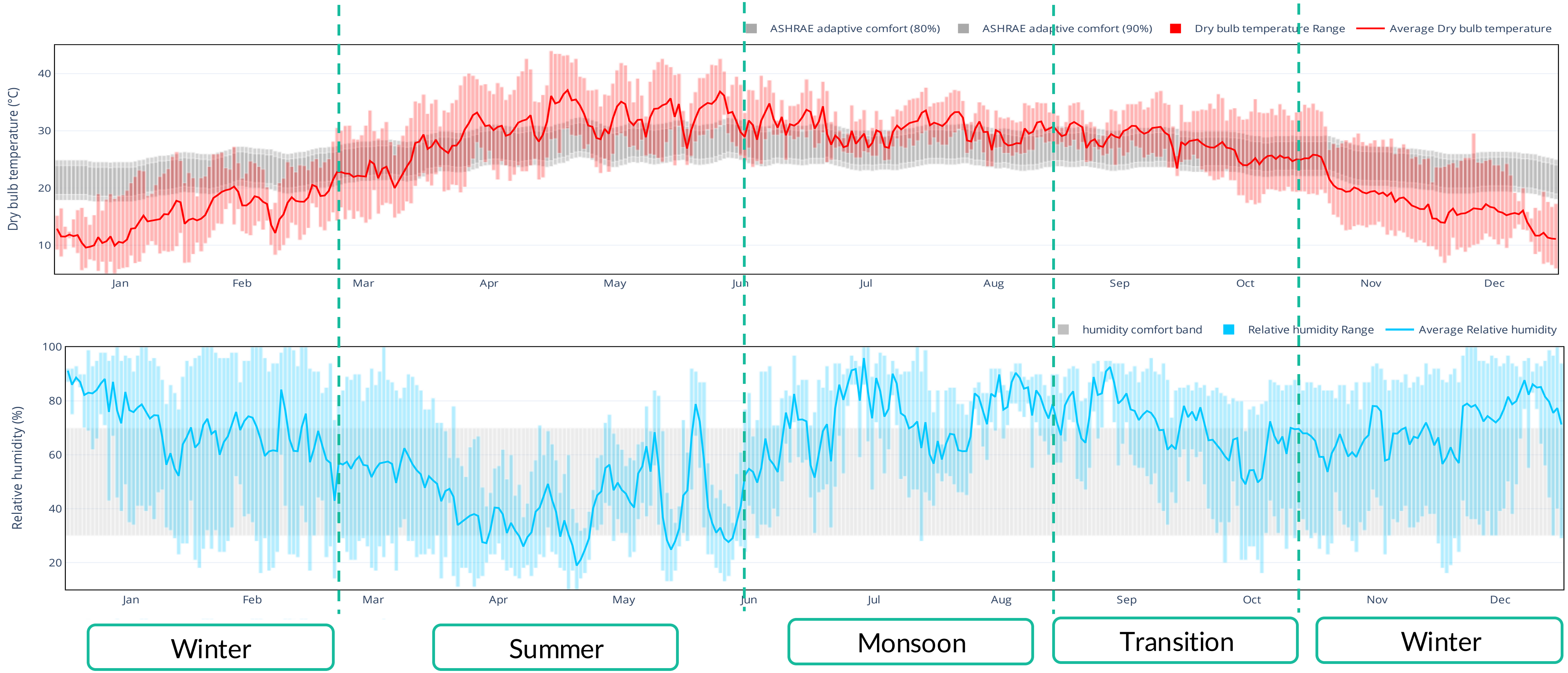
- Location: New Delhi, India
- Latitude: 28.6139° N
- Longitude: 77.2088° E
- Altitude: 216 m
- Climatic zone: Composite
- Climate summary:
  - Average yearly temperature: 24.8 °C
  - Hottest temperature (99%): 40.8 °C
  - Coldest temperature (1%): 7.1 °C
  - Annual cumulative horizontal solar radiation: 1909.09 kWh/m^2



Source: Bureau of Indian Standards, Government of India, 2016b

TEMPERATURE AND RELATIVE HUMIDITY

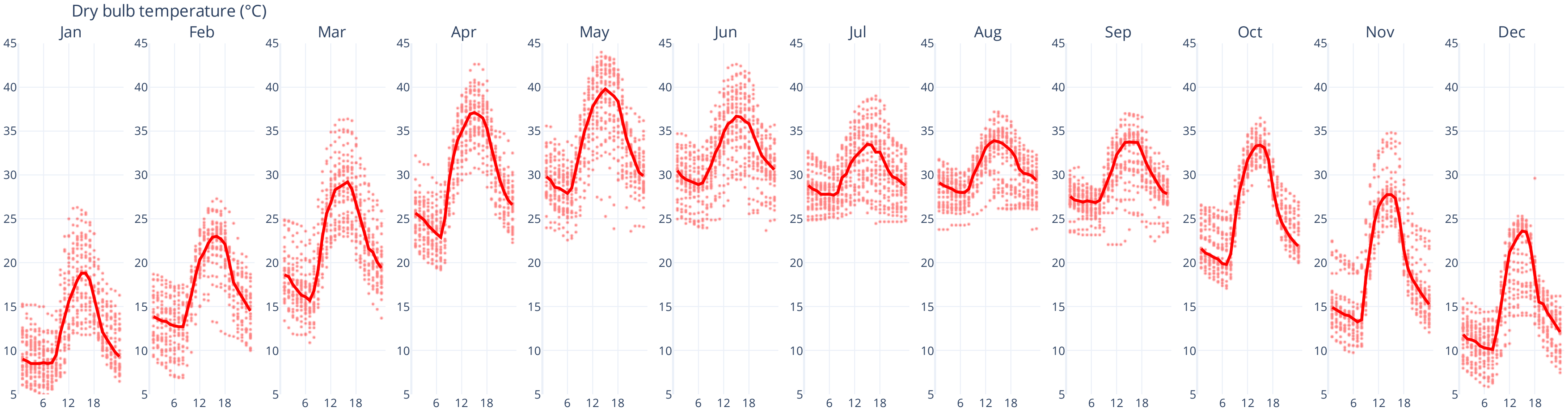
New Delhi, India: Seasonal variations



Source: https://clima.cbe.berkeley.edu/

CLIMATE ANALYSIS

New Delhi, India: Air temperature – hourly diurnal



Overview of month-wise hourly average temperature variations to understand the need for cooling and heating

Source: https://clima.cbe.berkeley.edu/

WIND SPEED AND DIRECTION

New Delhi, India

Winter

Monsoon

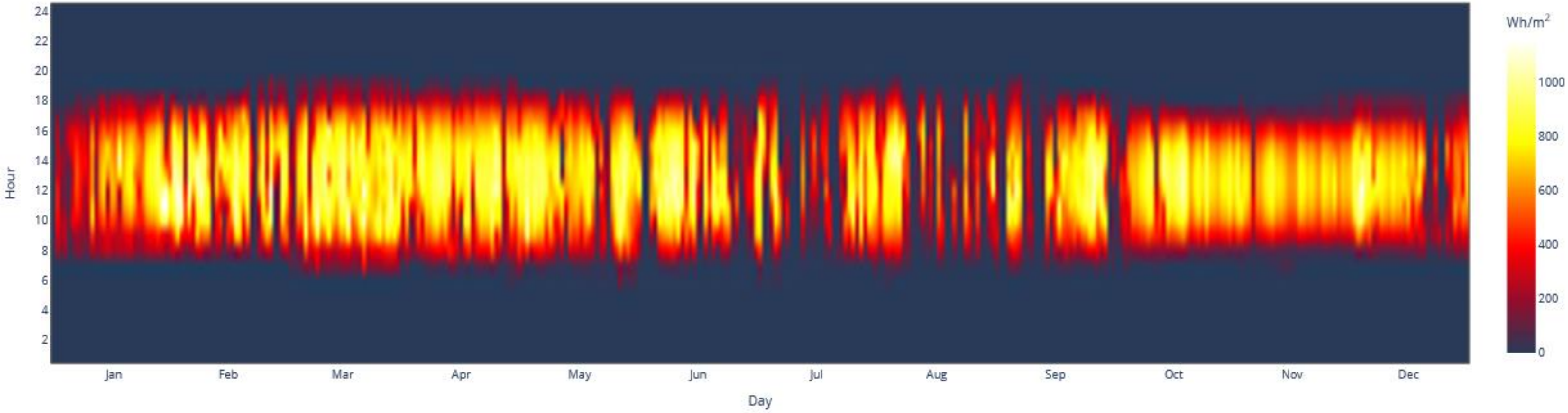
Summer

Overview of wind velocity and direction of wind for different seasons to draw inferences for building orientation and placement of openings for maximizing or minimizing natural ventilation

Source: https://clima.cbe.berkeley.edu/

SOLAR RADIATION

New Delhi, India

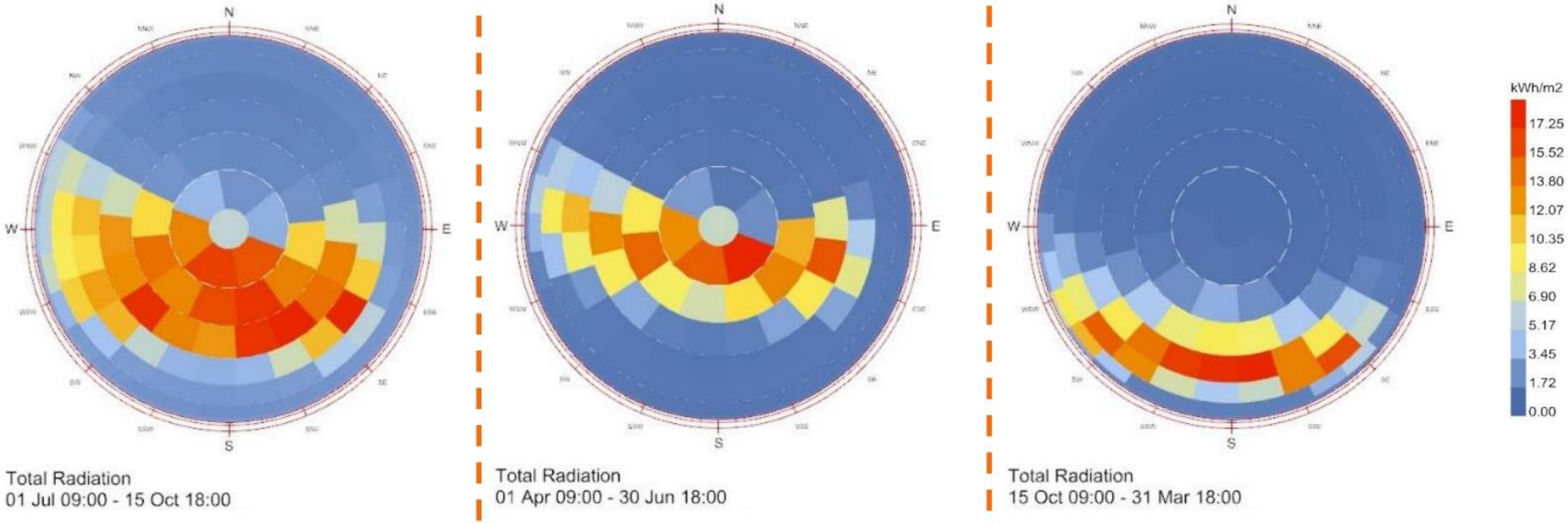


Overview of annual solar radiation for different months helps plan for solar protection or higher solar exposure, and estimates the energy generation potential from solar energy

Source: https://clima.cbe.berkeley.edu/

SOLAR RADIATION

New Delhi, India



Overview of solar radiation on different façades in different seasons, to plan for solar protection strategies

Source: CEPT University, 2022

CLIMATE ANALYSES

New Delhi, India: Inferences from temperature, humidity and wind analyses

Temperature and humidity analysis:

- **Hot and dry summer** season with **temperatures reaching up to 44°C**
- It is followed by the monsoon season with **temperatures ranging from 25°C to 37°C, with average humidity above 70%**
- Winter season last for four months, when **temperatures go below 10°C**
- During the **transition months**, there is **higher diurnal variation** in the outdoor dry bulb temperature. By introducing night purging, the overall cooling demand can be reduced or eliminated
- However, during the winter months, night purging can lead to higher heat loss from the spaces

Wind analysis:

- The wind speed in New Delhi is predominantly from the north-west and northern winds with an average wind velocity of 5.85 m/s. In passive strategies like mix mode and night purging, with the consideration of temperature of wind, openings on the north-west façade can be optimized

CLIMATE ANALYSES

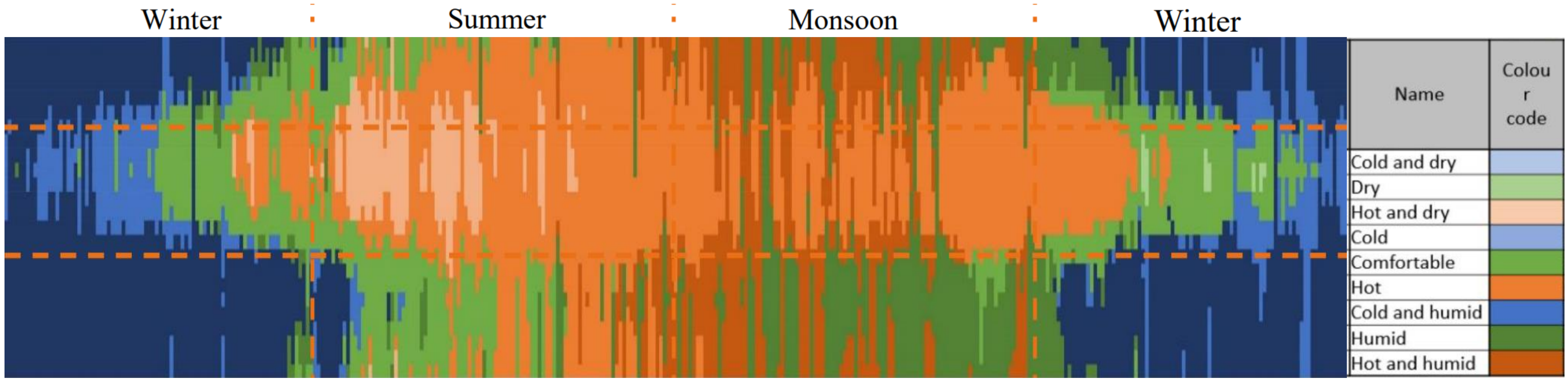
New Delhi, India: Inferences from solar radiation analysis

Solar radiation analysis:

- The average global horizontal radiation is 217.21 Wh/m^2 and maximum global horizontal radiation is 987 Wh/m^2. This shows a **high potential for the installation of solar photovoltaic panels for electricity generation** throughout the year
- During summer, **maximum radiation is received on the west;** this will require a strategy of shading from the lower altitude sun
- In the winter months the south façade will receive higher solar radiation, this can be favorable to cut down the heating load during these months
- By providing overhangs on the south façade windows, we can cut down the higher altitude sun in the summer months and take advantage of the lower altitude sun in the winter months

CLIMATE ANALYSES

New Delhi, India: Thermal comfort analysis



- Based on outdoor dry bulb temperature and relative humidity, 8,760 hours of the year can be divided into nine thermal conditions
- Here, the comfortable condition is at **21.5°C–28.5°C** and **30%–70% relative humidity**
- The graph above indicates that during summer months, the daytime is hot and dry, while during monsoon months, it is warm and humid

Source: CEPT University, 2022

CLIMATE ANALYSES

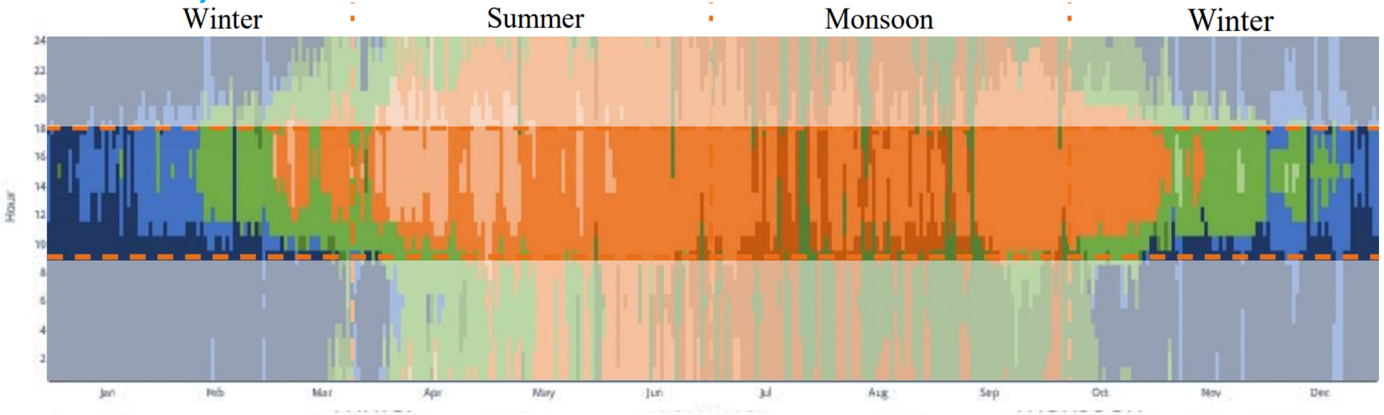
New Delhi, India: Thermal comfort analysis

Correlating the key inferences with the building during operating hours

(9am to 6pm for a typical office):

- Cooling required for 41% of the time
- Heating required for 11% of the time
- Natural ventilation meets the comfort requirement for 17% of the hours
- Cooling and dehumidification required for 11% of the time (mainly during the monsoon months)

*Based on outdoor conditions; with internal loads, these requirements will change



Operating hours (9am–6pm)

No.	Name	Colour code	Quality	Temperature range (°C)	RH range (%)	3650 operating Hours		Strategies Required
						Number of Hours	Hours in %	
1	Cold and dry		Low RH & Low DBT	0 - 21.5	0-30	0	0.0	Humidification & Heating
2	Dry		Low RH & Moderate DBT	21.5 -28.5	0-30	18	0.5	Humidification
3	Hot and dry		Low RH & High DBT	28.5 - 44	0-30	266	7.3	Humidification and Cooling
4	Cold		Moderate RH & Low DBT	0 - 21.5	30-70	393	10.8	Heating
5	Comfortable		Moderate RH & Moderate DBT	21.5 -28.5	30-70	620	17.0	Natural Ventilation
6	Hot		Moderate RH & High DBT	28.5 - 44	30-70	1528	41.9	Cooling
7	Cold and humid		High RH & Low DBT	0 - 21.5	70-100	413	11.3	Dehumidification & Heating
8	Humid		High RH & Moderate DBT	21.5 -28.5	70-100	151	4.1	Dehumidification
9	Hot and humid		High RH & High DBT	28.5 - 44	70-100	261	7.2	Dehumidification & Cooling

Source: CEPT University, 2022

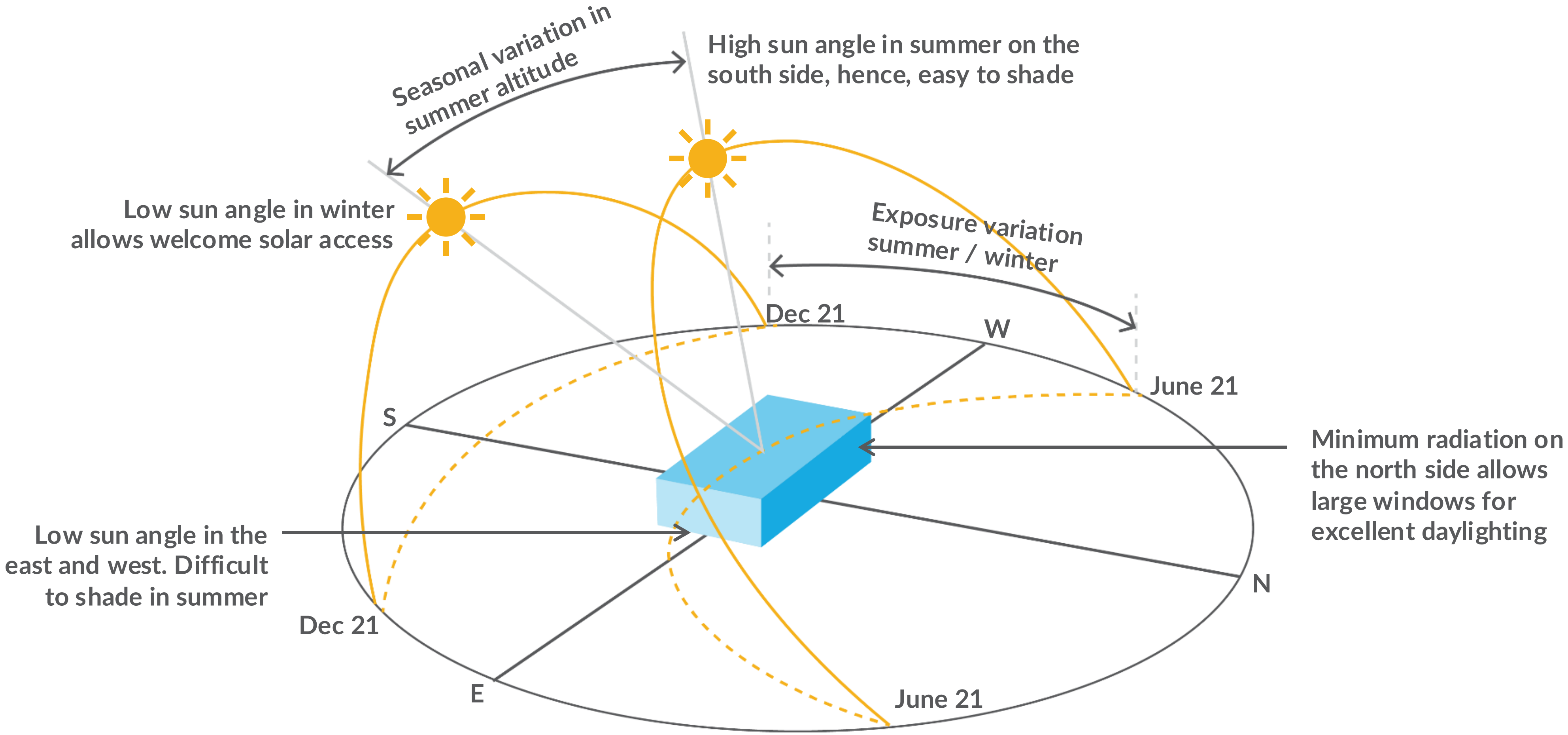
SUN PATH ANALYSIS

For orientation and massing

Understanding of **the sun's movement** around the building

Which **façades** will be exposed to the sun?

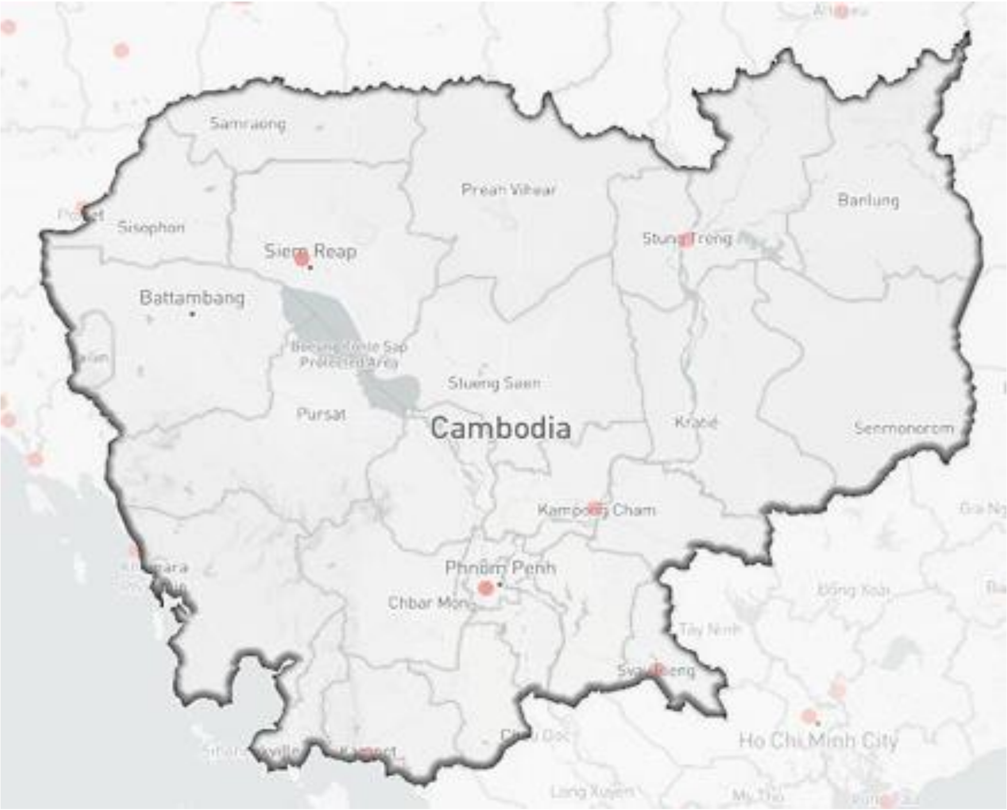
Shadows of the adjoining buildings and the proposed building itself



CLIMATE

Example: Phnom Penh, Cambodia

- Location: Phnom Penh, Cambodia
- Latitude: 13.41100°N
- Longitude: 103.8130°E
- Altitude: 12.2m
- Climatic zone: Hot and humid



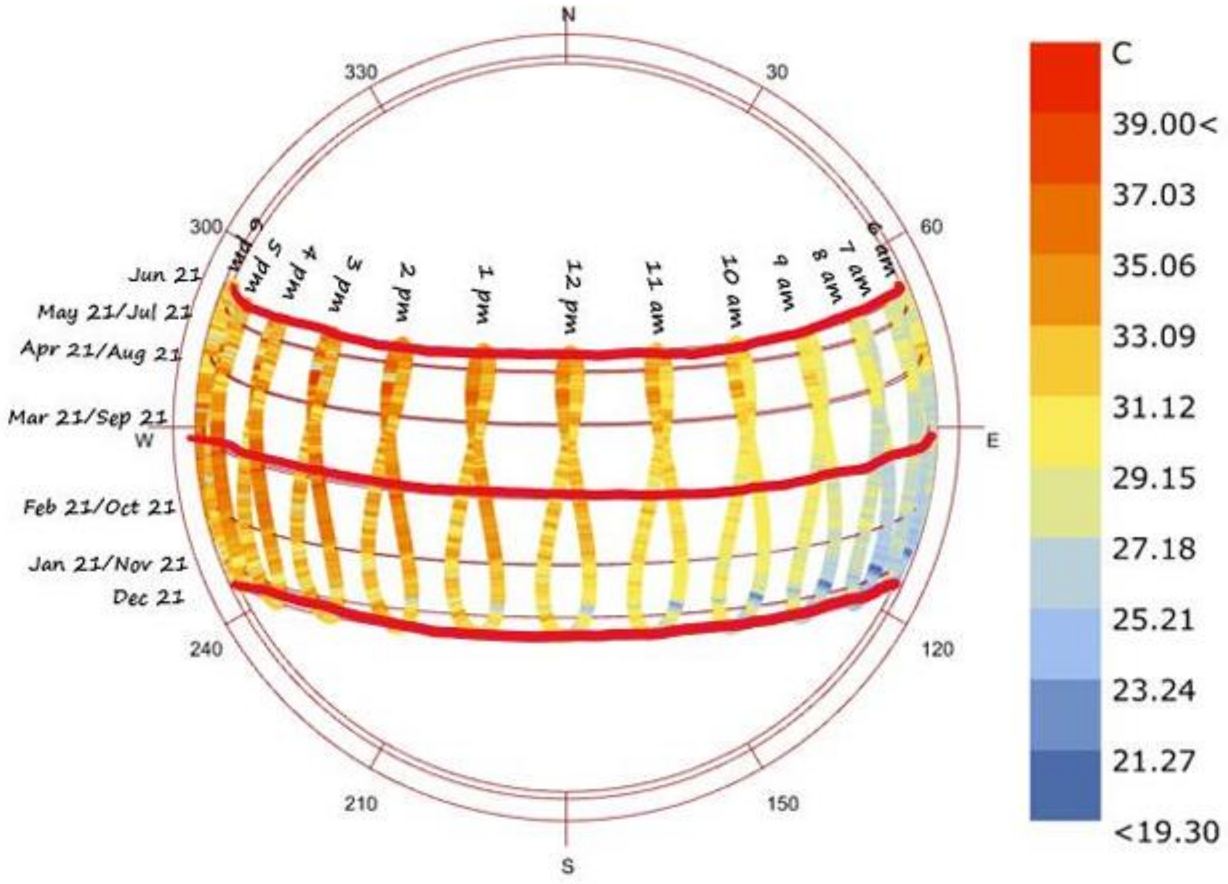
Phnom Penh

Sources: UNEP; ESCAP; Cool Coalition; Ministry of Environment, Government of Cambodia

SUN PATH AND SOLAR RADIATION

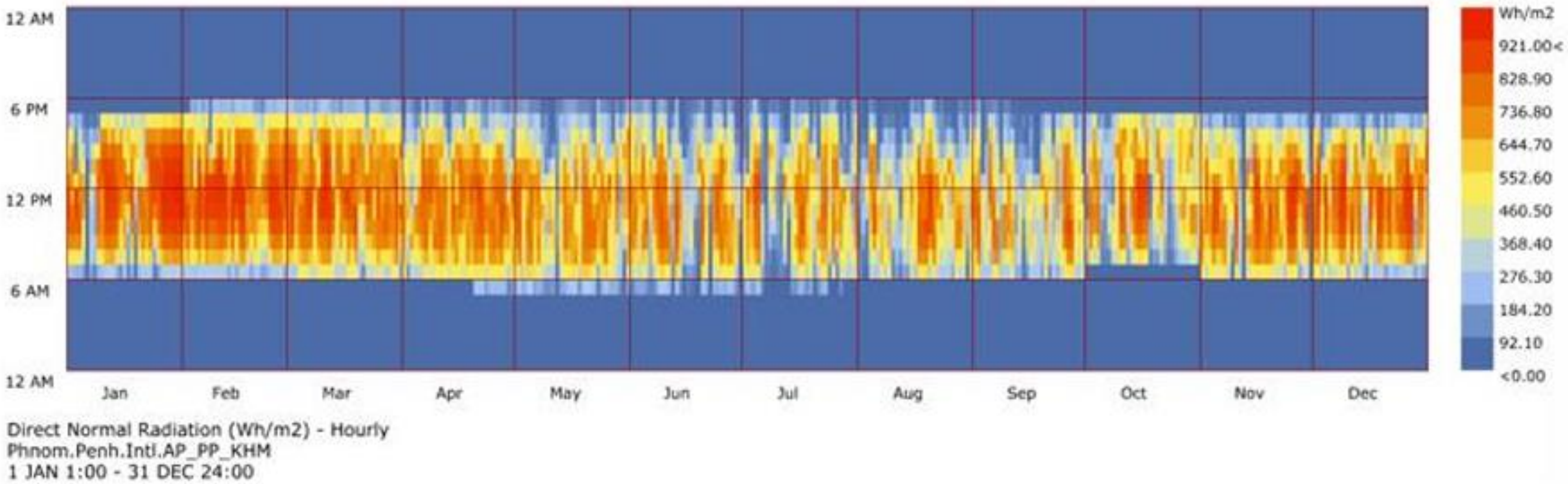
Phnom Penh, Cambodia

- Maximum daily direct solar radiation: 921 Wh/m^2
- Maximum daily diffused solar radiation: 386 Wh/m^2
- Diffused solar radiation higher during the months of June to September, coinciding with a higher level of humidity and cloudiness
- Solar intensity is notably high from 11:00 am to 6:00 pm from February to October, and from 1:00 pm to 6:00 pm from November to January



DIRECT SOLAR RADIATION

Phnom Penh, Cambodia



PRECIPITATION

Phnom Penh, Cambodia

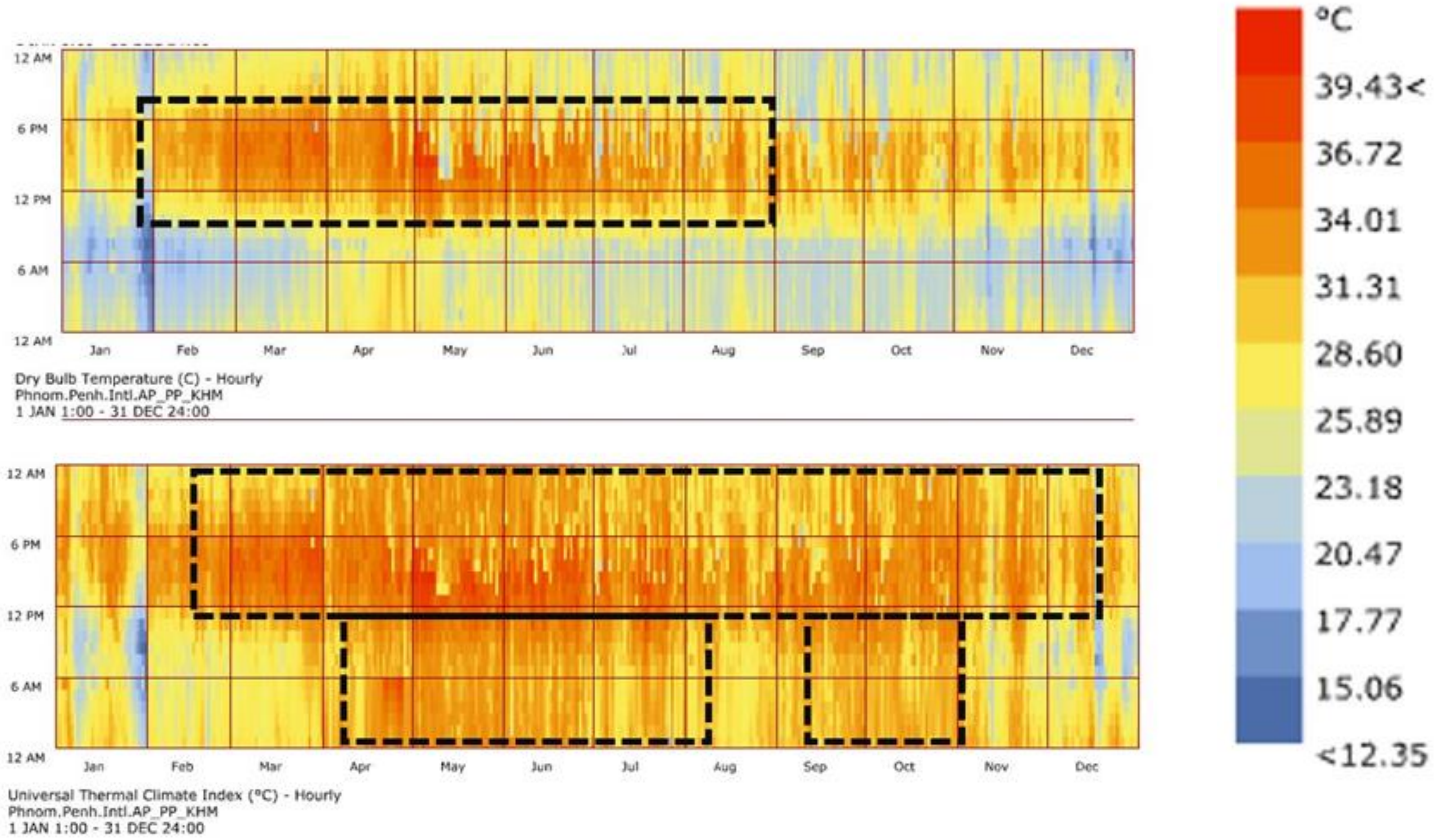
- Average annual precipitation of about **1,432 mm** (56.4 inches)
- **February is the driest** month, with an average precipitation of 9 mm (0.4 inches) recorded over 1.87 days. Conversely, **September** experiences the highest amount of precipitation, with an average of 255 mm (10.0 inches) recorded over 26.07 days

	January	February	March	April	May	June	July	August	September	October	November	December
Precipitation / Rainfall mm (in)	17 (0)	9 (0)	41 (1)	86 (3)	163 (6)	157 (6)	159 (6)	185 (7)	255 (10)	246 (9)	86 (3)	28 (1)
Humidity(%)	60%	57%	60%	66%	75%	77%	77%	78%	82%	83%	76%	66%
Rainy days (d)	2	1	5	11	17	17	18	19	20	18	9	4

CLIMATE ANALYSIS

Phnom Penh, Cambodia: Temperature variation

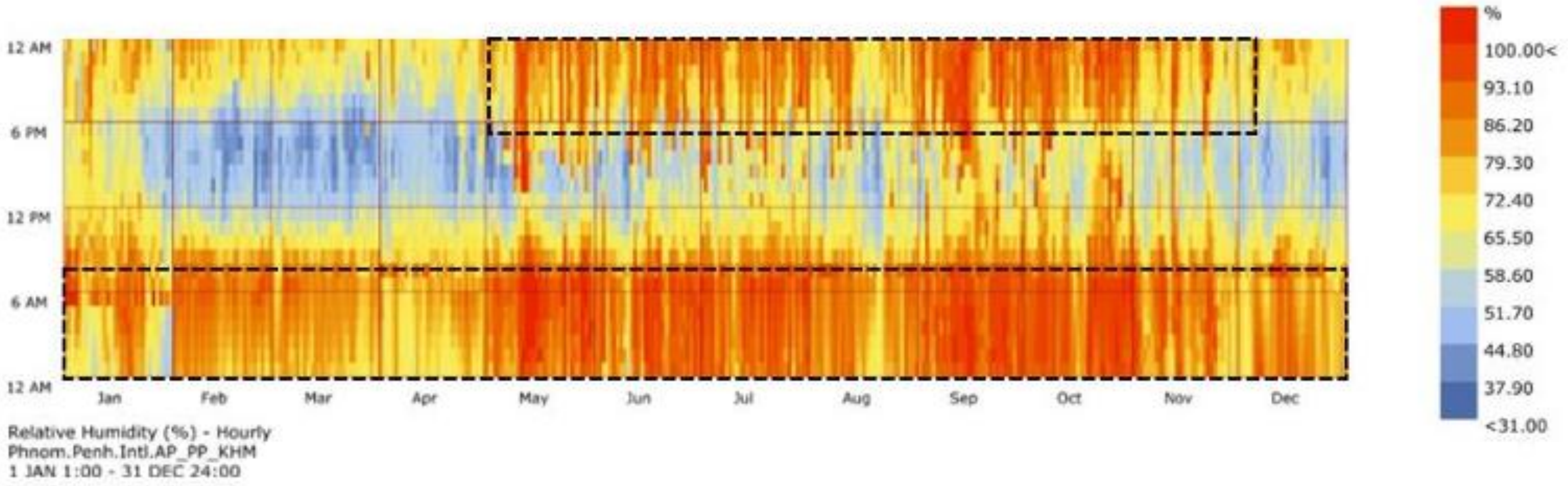
- High dry bulb temperatures exceeding 31°C from February to August
- Universal Thermal Climate Index (**UTCI**), which factors in parameters such as humidity and wind speed, shows that the felt temperature **surpasses 31°C** throughout the day from April to July, September and October



CLIMATE ANALYSIS

Phnom Penh, Cambodia: Relative humidity

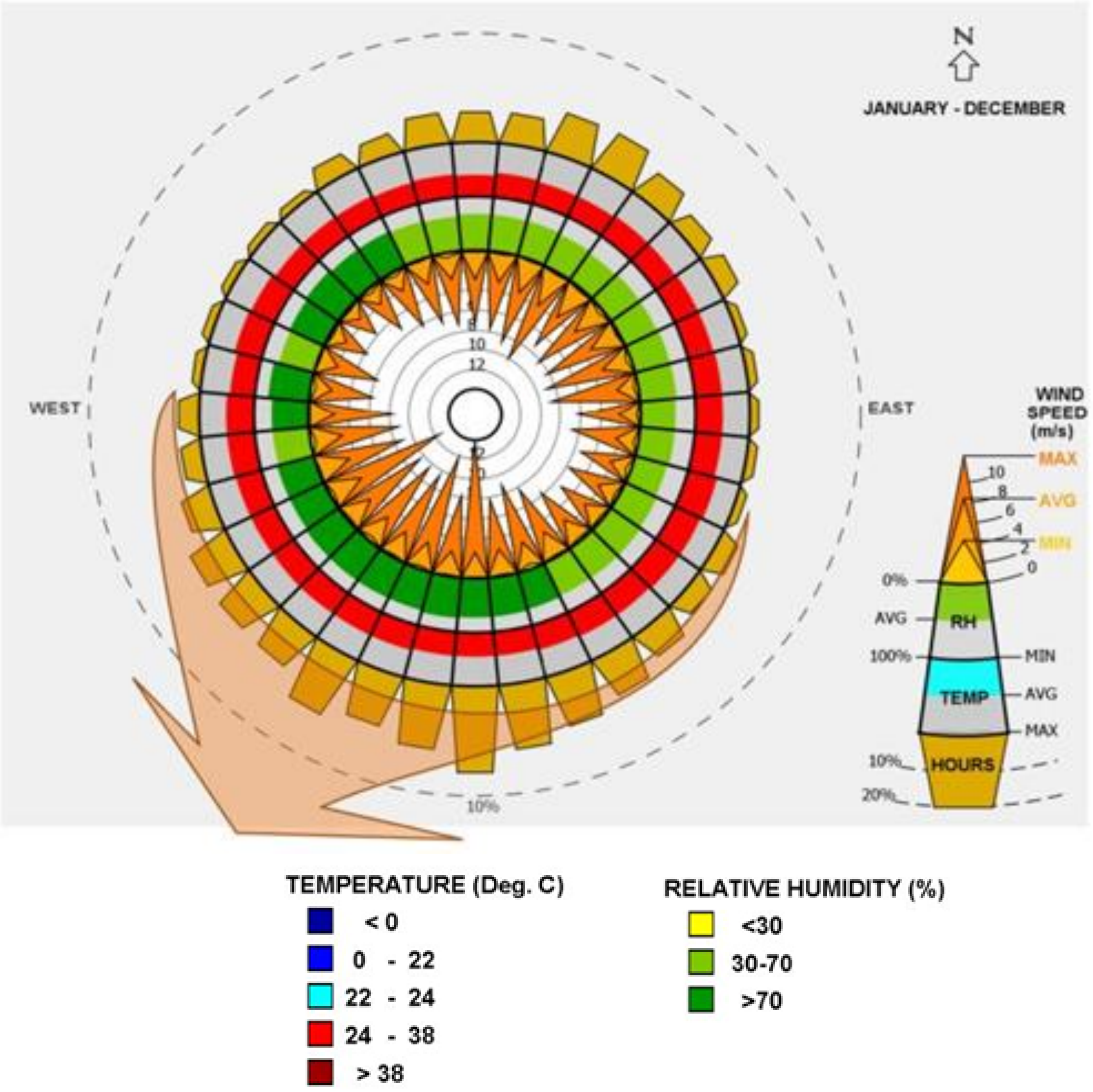
- High levels of relative humidity (RH) throughout the year
- During nighttime, the RH remains consistently above 70%. From 6:00 pm to 12:00 am, elevated RH levels persist between May and November
- On average, humidity remains high from May to November. However, from November to April, the RH ranges between 40% and 70% during the day



CLIMATE ANALYSIS

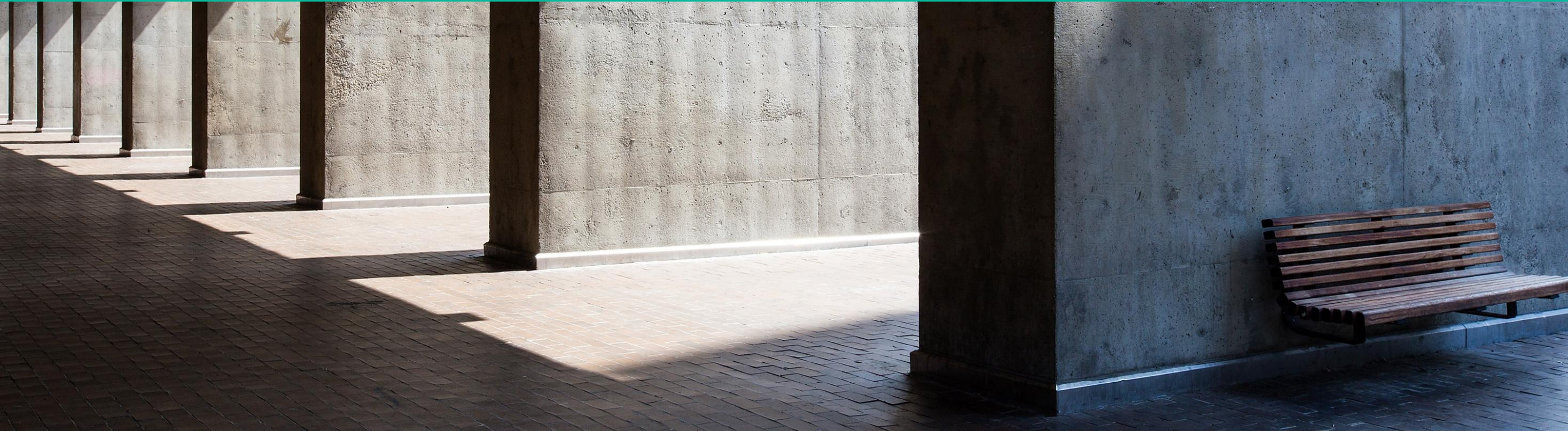
Phnom Penh, Cambodia: Wind analysis

- Generally, wind peaks in the southwest, south and southeast directions from February to September
- From October to January, the wind direction shifts toward the north and northeast
- Relative humidity exceeds 70%
- Average temperature of the wind throughout the year in Phnom Penh ranges from 24°C to 38°C



Building Massing and Orientation

Harnessing Daylight and Natural Ventilation

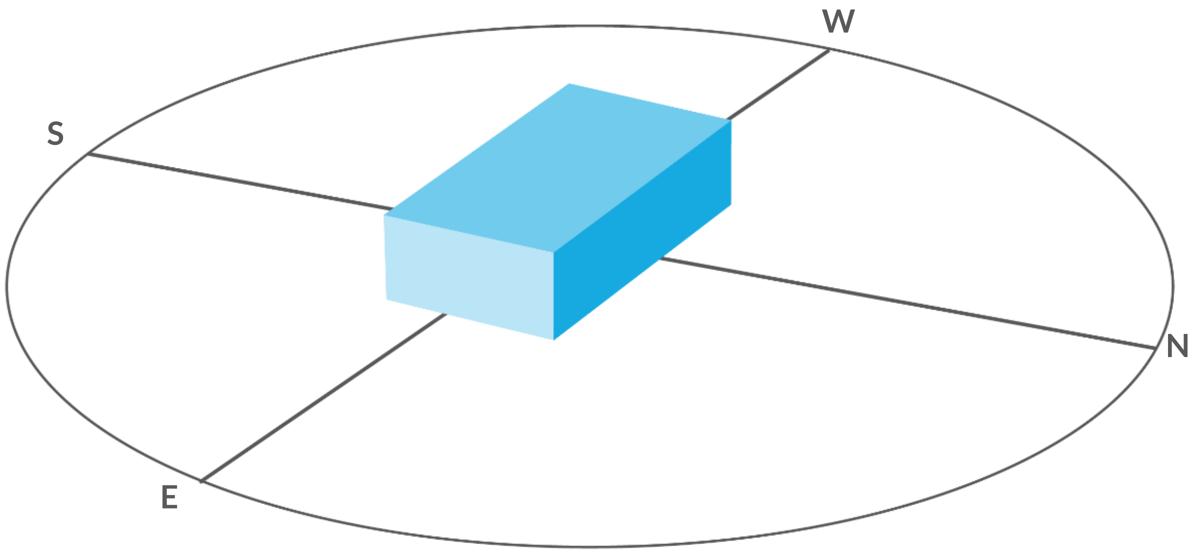


MASSING AND ORIENTATION

For harnessing daylight and natural ventilation

- **Orientation** is the positioning of a building in relation to seasonal variations in the sun's path, as well as prevailing wind patterns
- **Massing** is the overall shape and size of the building

Climate-appropriate building massing and orientation helps harness daylight, solar and wind energy for comfort, and reduce the building's energy dependence

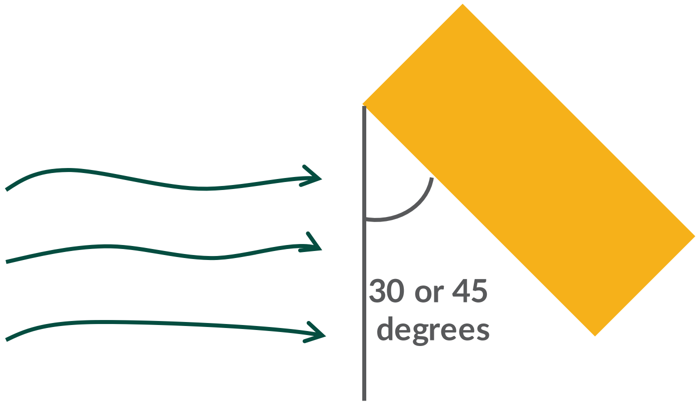


BUILDING ORIENTATION

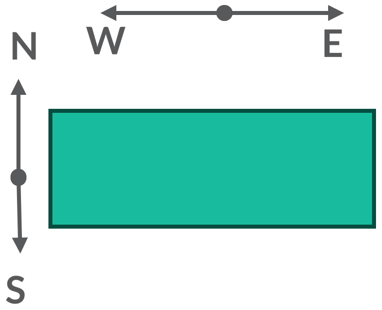
To harness daylight and natural ventilation

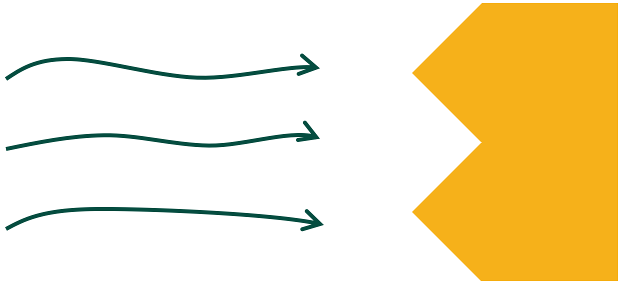
- Requirements to manage solar gains and utilize wind flows may lead to conflicting results
- Designers must **strike a balance** between orientation with respect to the sun and wind flow
- Critical façades and windows should be well-shaded to avoid solar radiation

Longer façades, fenestration and habitable spaces are ideally located in the north and south directions – less solar radiation BUT great for daylight access



East and west façades are kept small





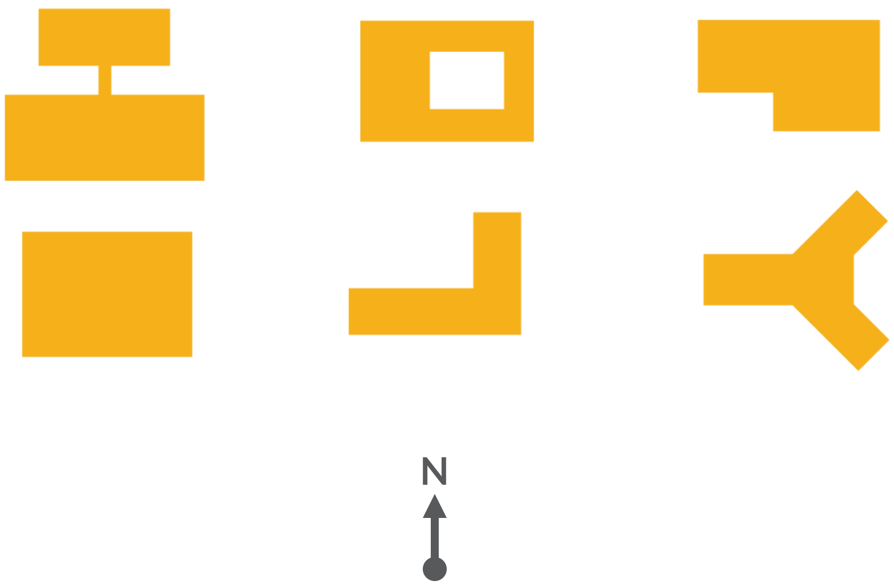
In India, the preferred orientation is toward the north and south directions, with respect to the sun's path

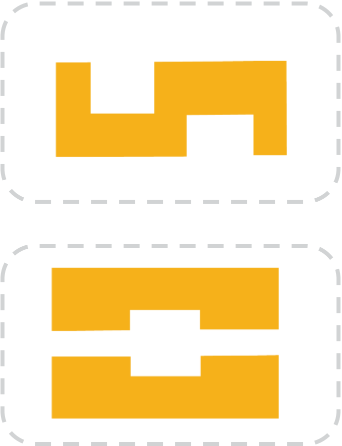
For proper utilization of the wind, the longer façade of the buildings needs to be oriented at an angle (usually ±45 degrees) to the prevailing wind direction

BUILDING FLOOR PLATES

For harnessing daylight and natural ventilation

Different types of building floor plates for good daylight and natural ventilation





North-south orientation can be used in creative ways to generate a variety of built and open spaces

North-south orientation can also be used in case of unfavourable orientation of the land

PASSIVE DESIGN STRATEGIES

Massing strategies

- **Mutual shading** of built forms
- Compact forms are ideal for extreme climates
  - Low surface area to volume **(S/V) ratio**
  - Low perimeter to area **(P/A) ratio**
  - **Compact forms** gain less heat during daytime and lose less heat at nighttime

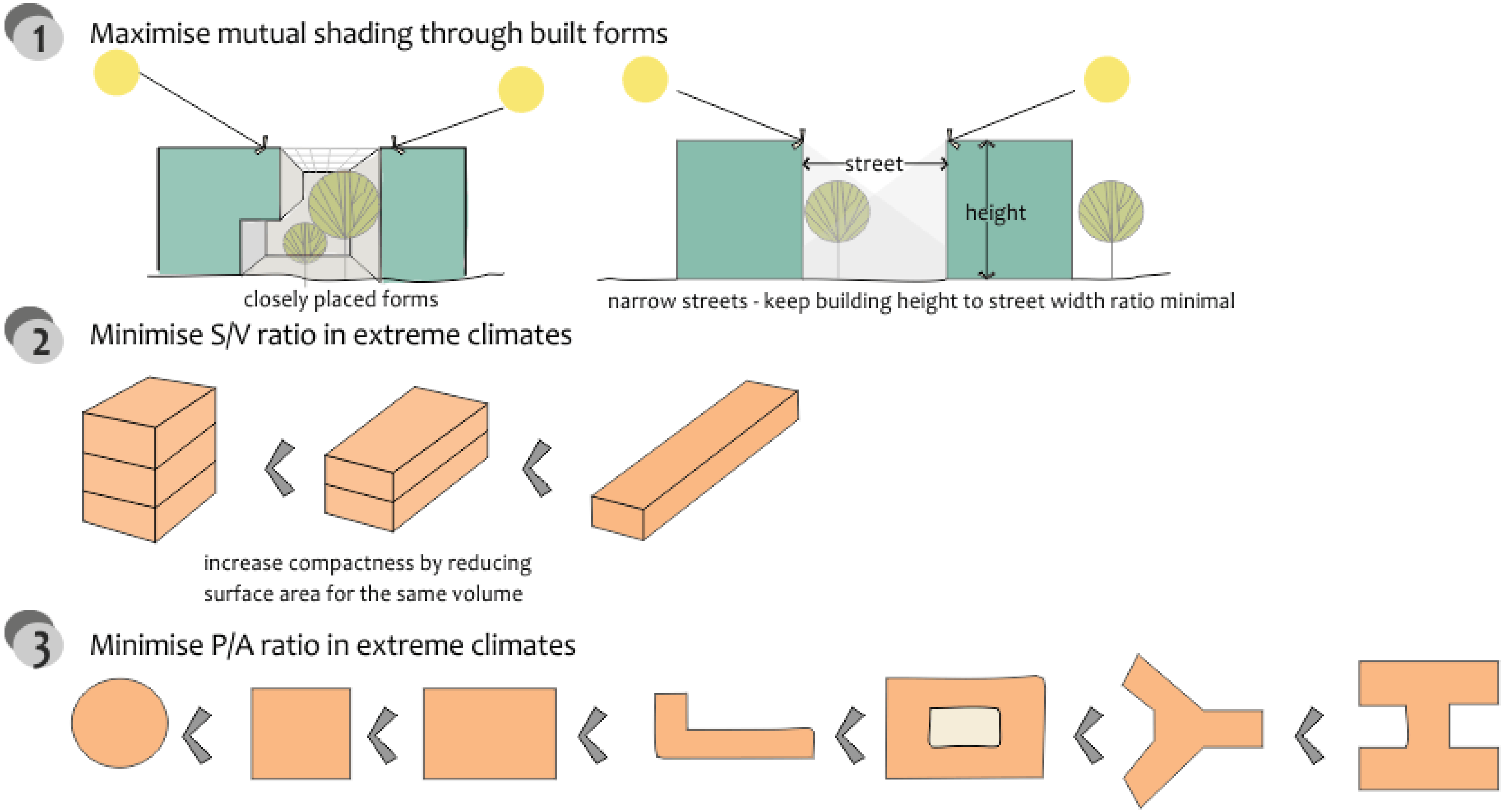


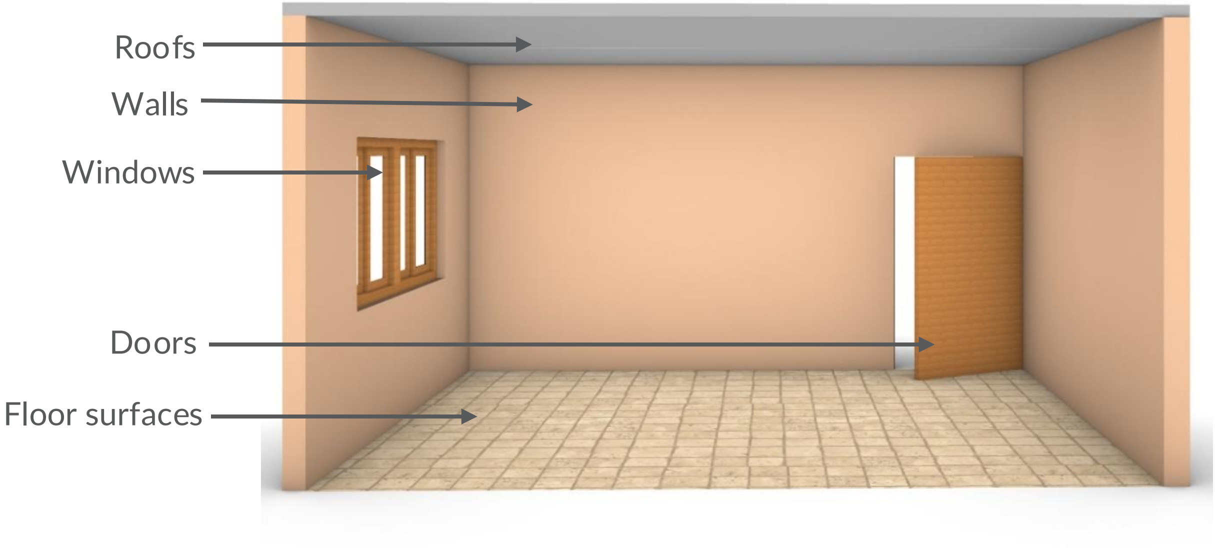
Image source: https://nzeb.in/knowledge-centre/passive-design/form-orientation/

ENVELOPE DESIGN

Significance

- **Envelope design is a major factor in determining the amount of energy a building will use in its operation**
- The overall environmental life cycle impacts, and energy costs associated with the production and transportation of different envelope materials, vary greatly
- The building envelope or 'skin' consists of structural materials and finishes that enclose space, separating inside from outside

Elements of building envelope



Source: ASHRAE Journal

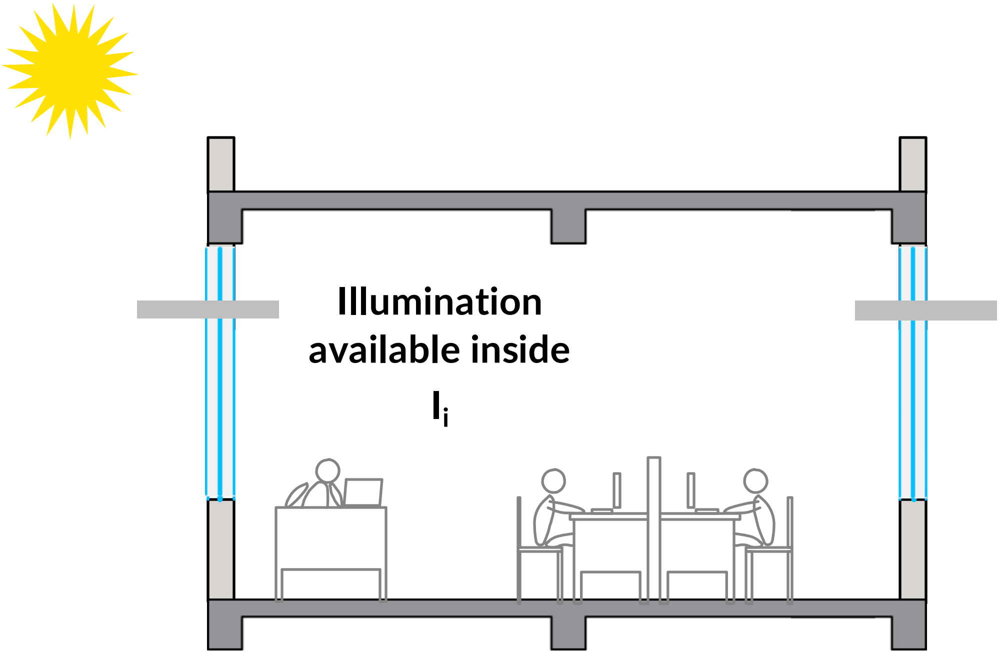
Building envelope design is the key to energy efficient building

Optimizing Building Envelope

Windows for Better Daylight and Minimum Heat Gain

DAYLIGHT FACTOR AND DAYLIGHT AUTONOMY

Key performance indices for daylight



Illumination available outside I_o

Daylight Factor = I_i / I_o

Daylight Autonomy:
Percentage of time-in-use that daylight levels exceed a specified target illuminance or lighting set-point

TIME-IN-USE:
Time when building is being used
e.g., 9 am to 6 pm

TARGET ILLUMINANCE / LIGHTING SET-POINT:
Recommended illuminance (lux) levels
e.g., lighting set-point for standard offices is 300 lux–500 lux

Daylight Autonomy:
Percentage of time that an occupant can work through the use of just daylight without supplemental electric lighting

WINDOWS

Sizing and placement

Building spaces can be zoned to place areas requiring more daylight near the perimeter

Areas requiring less daylight placed in the center of the floor plate

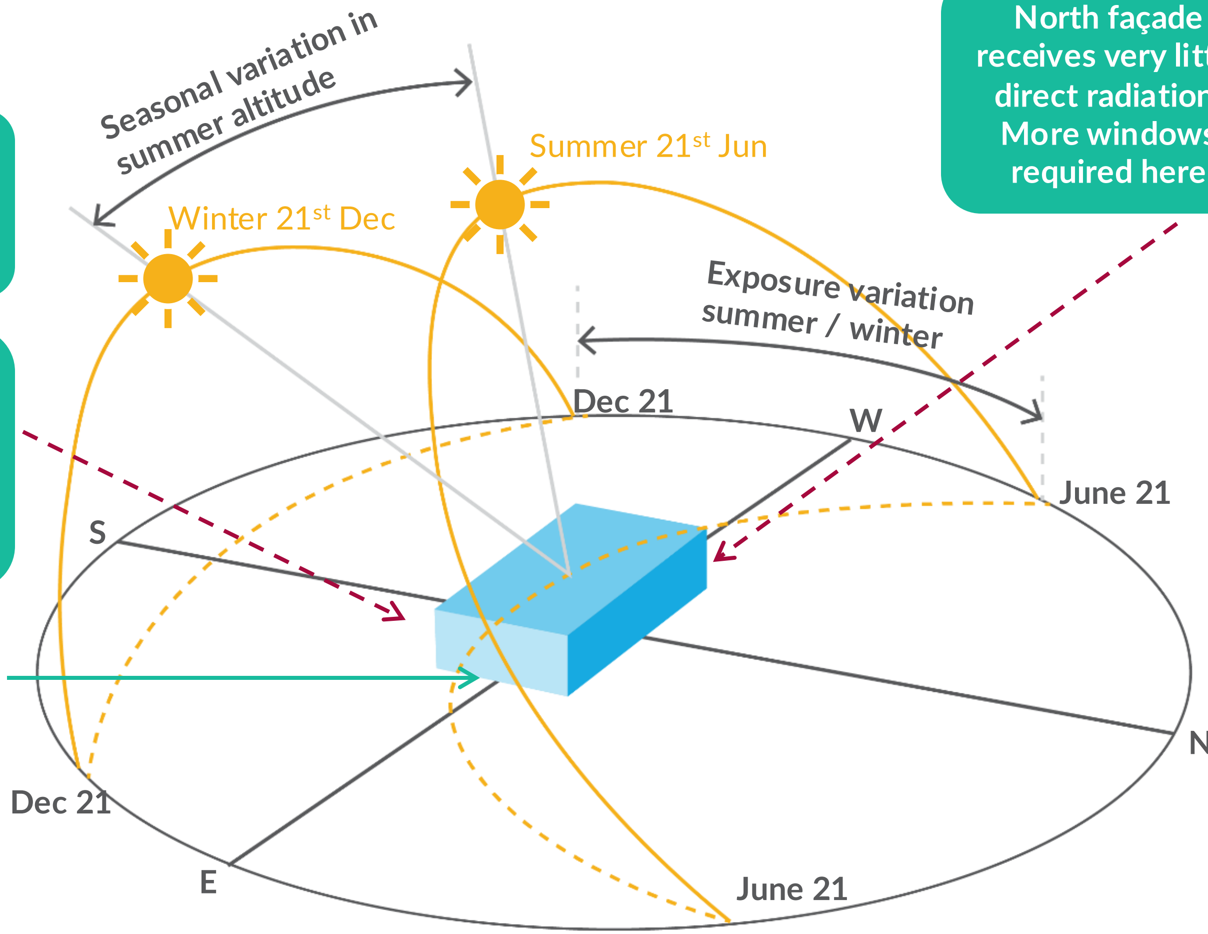
Shallow floor plates provide daylight access to greater floor area

Keep window-to-wall ratio around 20%–30%

South façade is highly exposed in winter, but less in summer. Windows can be easily shaded here

East and west façades receive high amount of radiation. Difficult to shade. Hence, less windows required here

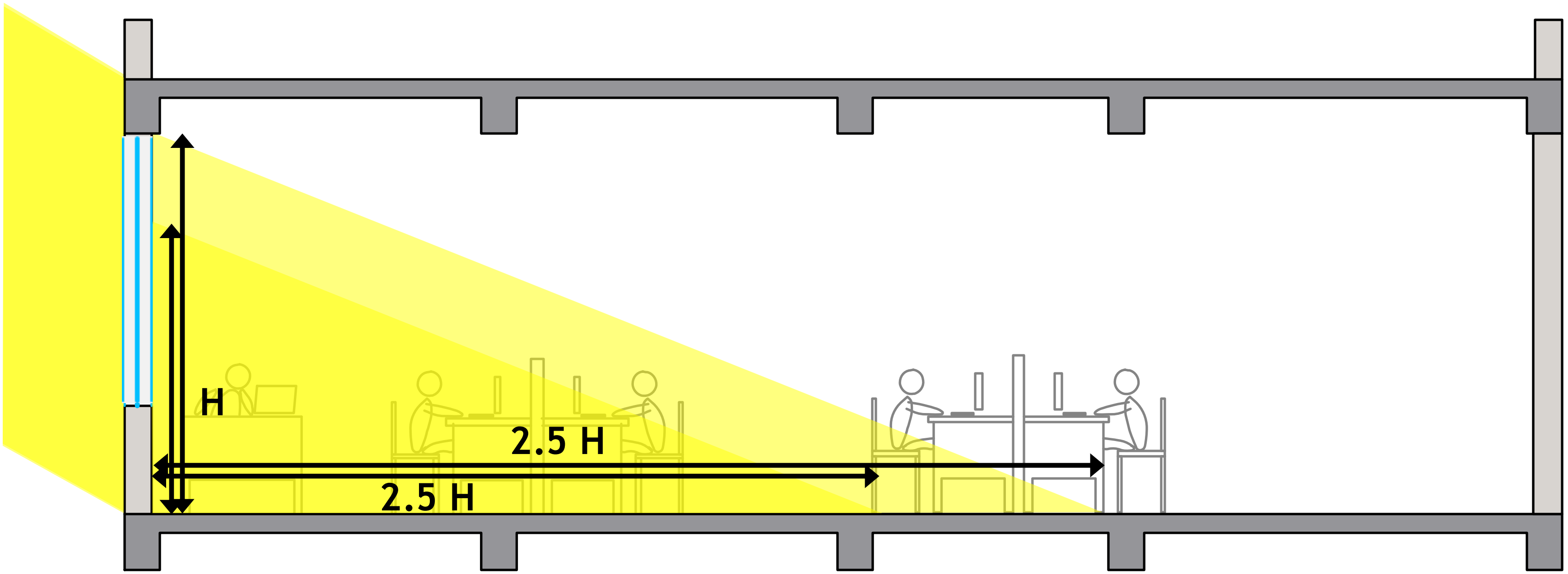
North façade receives very little direct radiation. More windows required here



WINDOWS

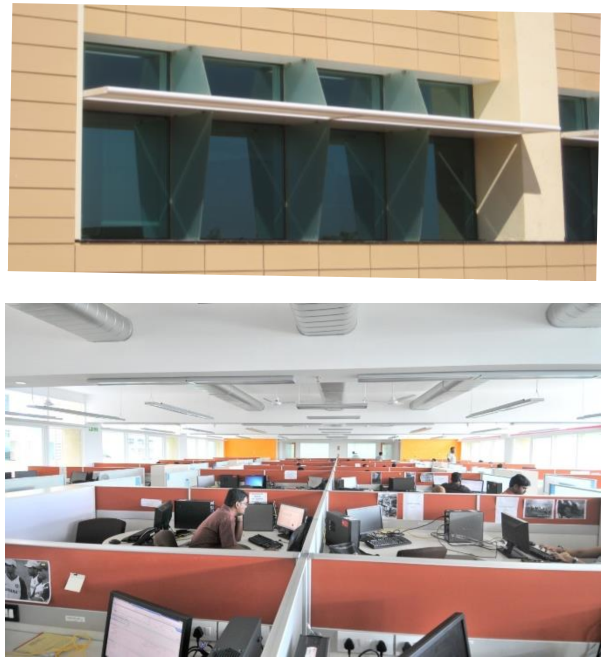
Sizing and placement

- Daylight penetrates into a room roughly 2.5 times the height of the top of the window from the ground
- The higher the window, the deeper the daylight penetration in the room
- Usually, daylight penetration in the room is 6m–8m from the fenestration



BETTER DAYLIGHT ACCESS

Desirable features

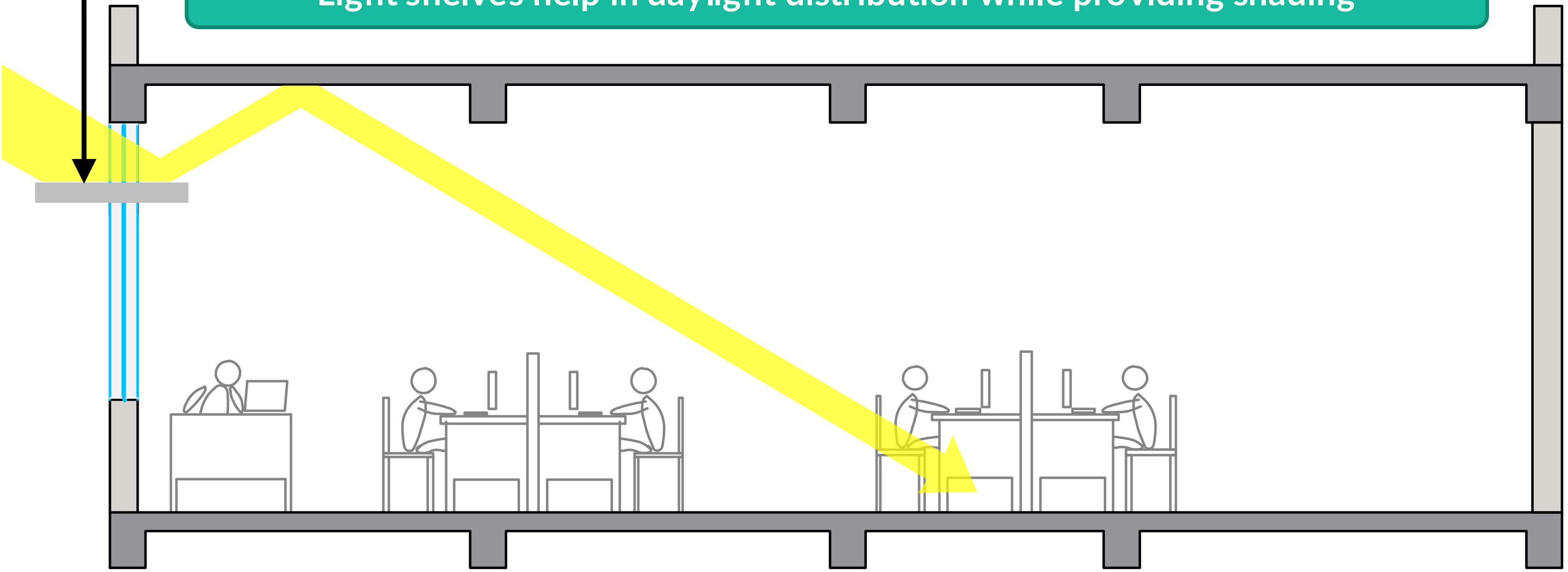


Infosys, Hyderabad Campus

Lighter colors on interior surfaces:

- Reflect light better
- Help in daylight distribution
- Reduce glare

Light shelves help in daylight distribution while providing shading



GLASS PROPERTIES

VLT, SHGC and U-value

VLT is the ratio of visible light that passes through a glazing unit to the total visible light incident on it

Use high VLT glass for better daylight

FACTORS INFLUENCING VLT:

- Color of glass
- Tints and coatings on the glazing
- Number of glass panes

SHGC is the ratio of solar (radiant) heat gain that passes through the fenestration to the total incident solar radiation that falls on it

SHGC is a dimensionless number between 0 and 1. Use low-SHGC for minimum heat gain

FACTORS INFLUENCING SHGC:

- Solar protection or shading
- Type of glass and number of panes
- Tints and coatings on the glazing
- Gas fill between glazing layers

U-value is the overall heat transfer coefficient that indicates the heat transfer from the glass through conduction

Use glass with low U-value for minimal heat gain

FACTORS INFLUENCING U-VALUE:

- Size of the air gap between glass panes
- Coatings on the glazing
- Gas fill between glass panes
- Frame construction

Source: ASHRAE Journal

Optimizing Building Envelope

For Better Ventilation

NATURAL VENTILATION

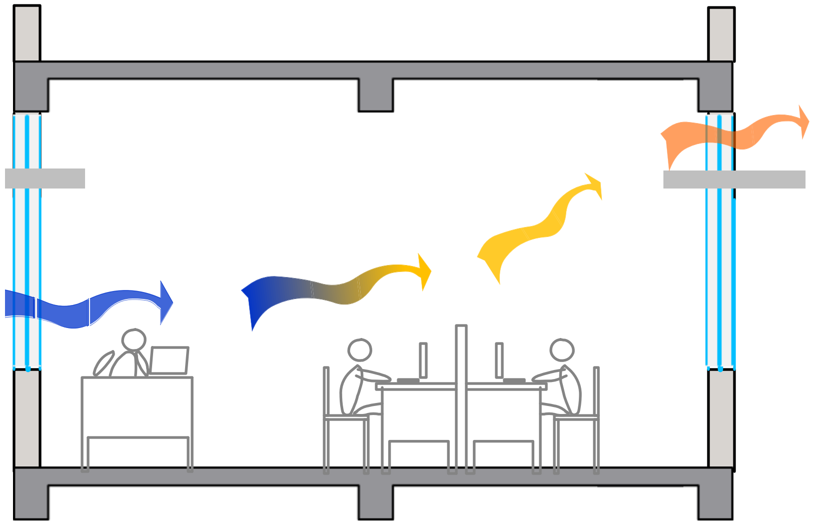
Implications

Natural ventilation (NV) is the process of supplying and removing air through an indoor space without using mechanical systems:

- NV provides acceptable indoor air quality
- NV provides thermal comfort by providing a heat transport mechanism
  - Cooling of indoor air by replacing or diluting it with outdoor air as long as outdoor temperatures are lower than indoor temperatures
  - Cooling of the building structure i.e., thermal mass of building
  - Direct cooling effect over the human body through convection and evaporation

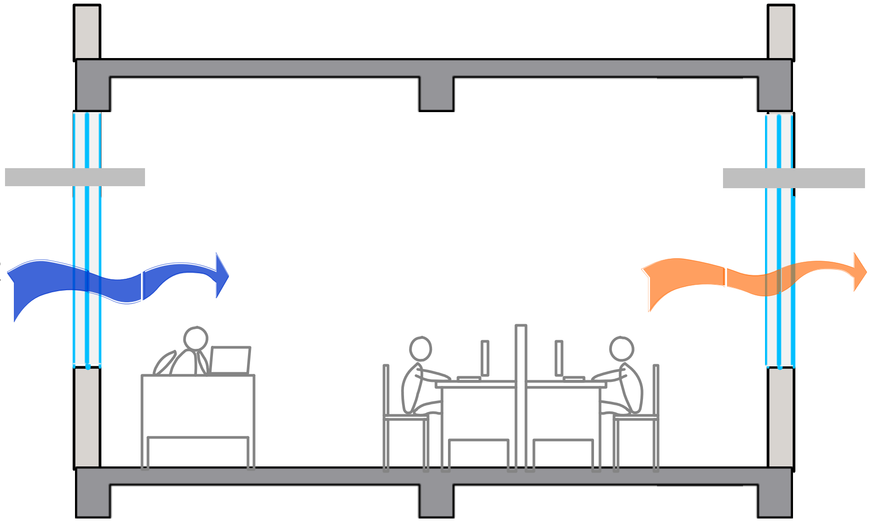
Buoyancy-driven natural ventilation:

- The natural movement of air through a building resulting from differences in vertical pressure developed by temperature differences in the air
- This occurs in a building by warm air escaping from openings at a substantial height on the building envelope, which draws in colder, denser outside air through the lower openings of the building



Wind-driven natural ventilation:

- Relies on wind pressure to drive air movement
- When wind hits the windward façade, it creates a positive pressure on the façade. Similarly, as it flows away from the leeward façade, a region of lower pressure will be created. This pressure difference will force air movement

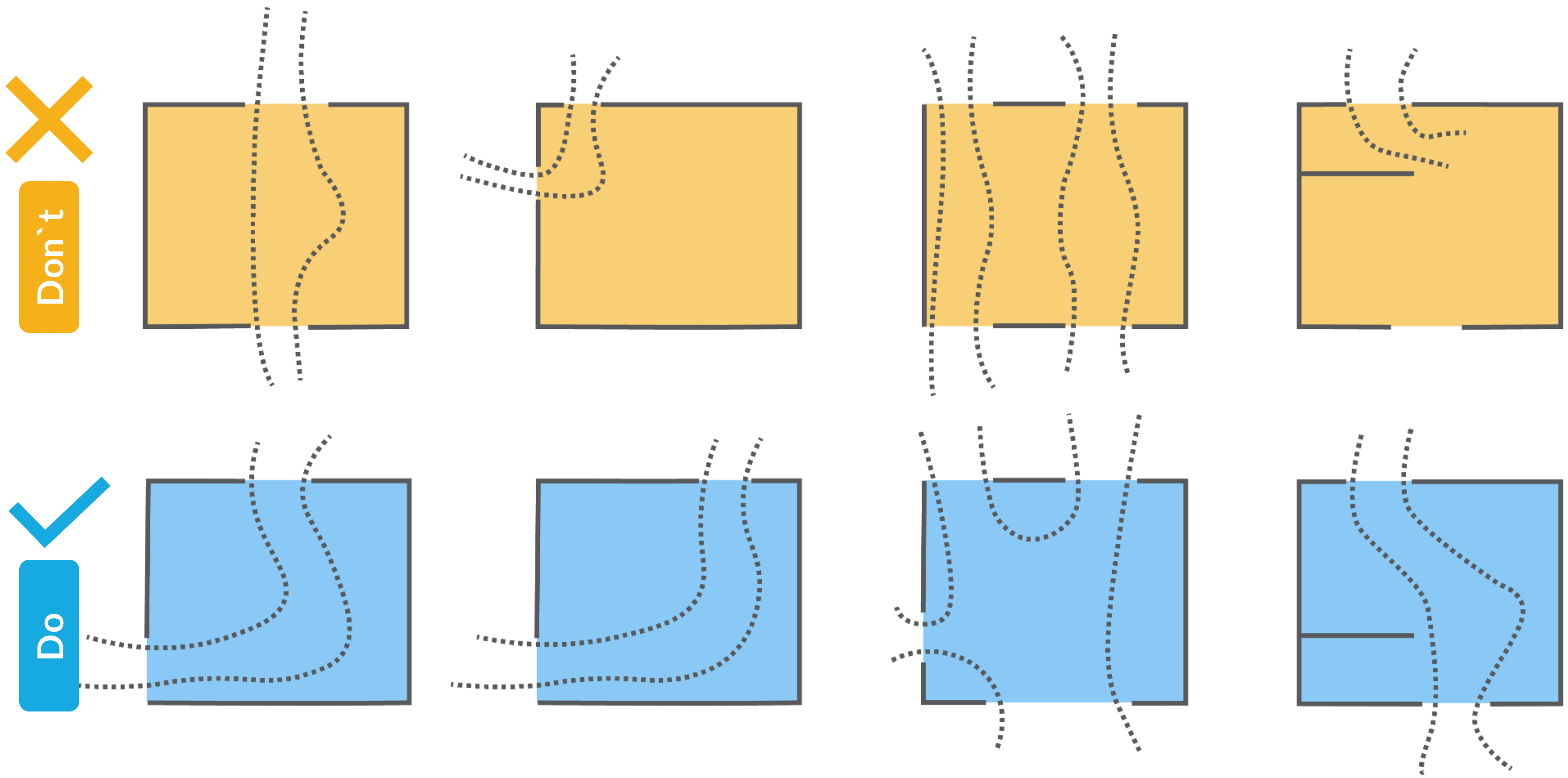


CROSS VENTILATION

Do’s and don'ts

Windows located diagonally opposite to each other with the windward window near to the upstream, offers better performance than other window arrangements

The placement of window openings can alter air movement inside spaces

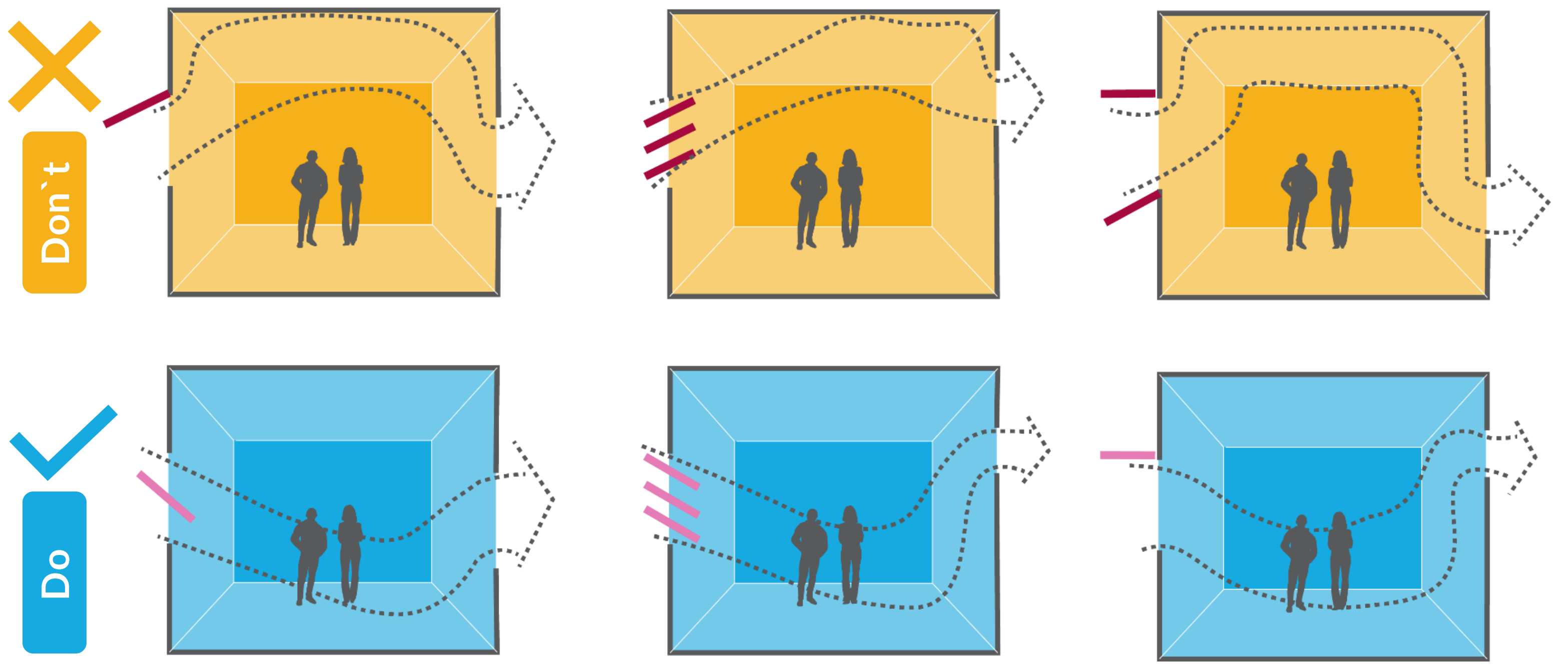


CROSS VENTILATION

Do's and don'ts

- The provision of horizontal sashes at an angle of 45° in the appropriate direction helps in promoting indoor air movement
- Sashes projecting outward are more effective than inward

Position of overhangs and louvers can be used to direct the air inside at the required level and area

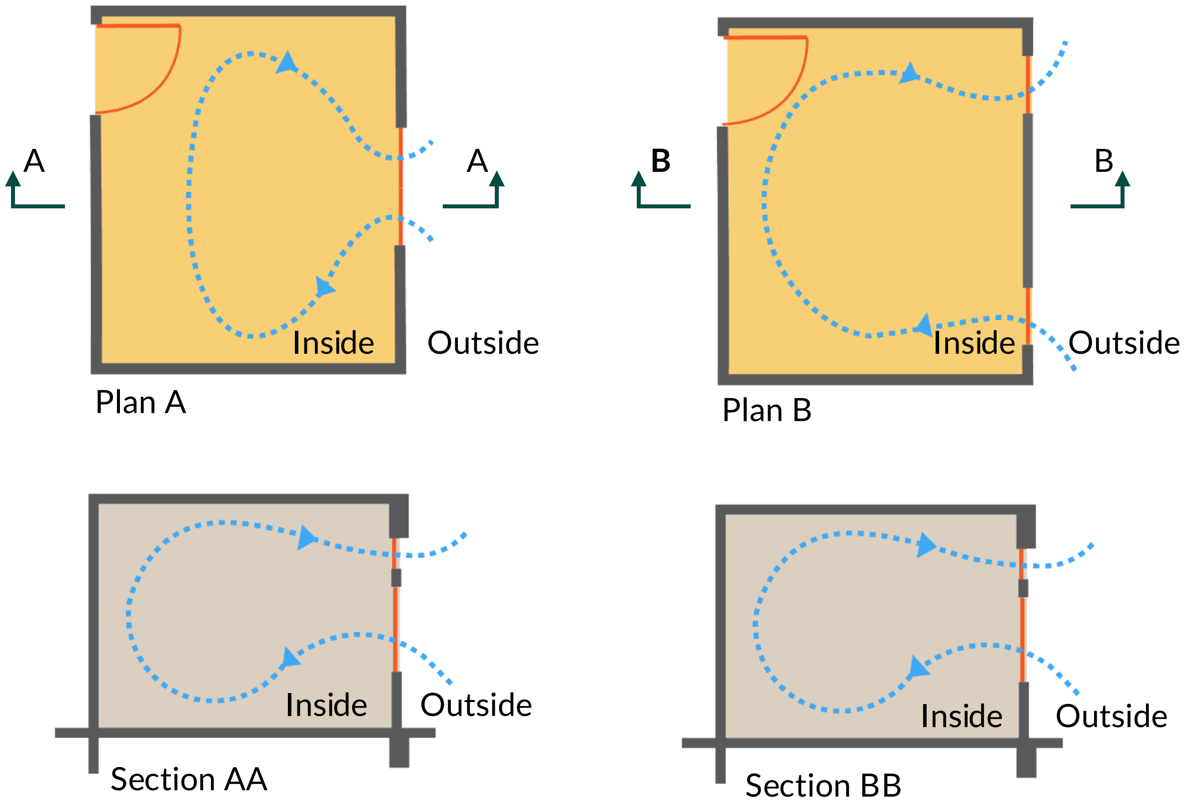


ONE-SIDED VENTILATION

Do’s and don’ts

Single-sided ventilation is the scenario in which only a single façade of the building is exposed to wind and openable windows are located on a single wall. In such cases, it is preferred to provide at least two windows on the façade

Provision of two windows on the same façade

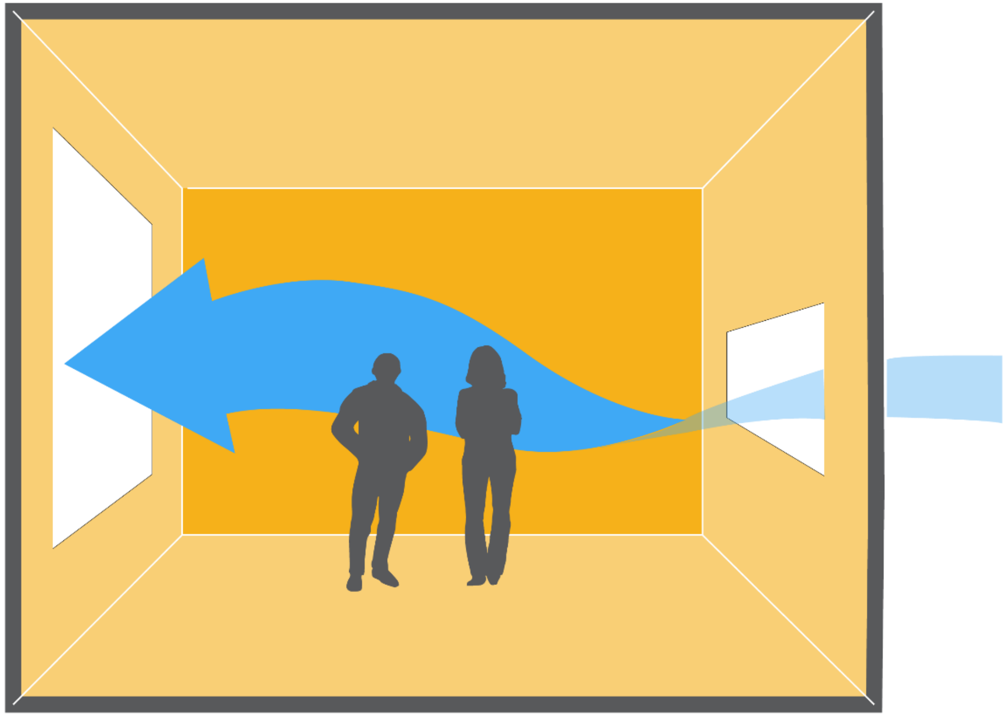


WINDOW SIZING

In naturally-ventilated buildings

- Window size can affect both the amount of air and its speed
- For an adequate amount of air, one rule of thumb states that the area of operable windows or louvers should be 20% or more of the floor area, with the area of inlet openings roughly matching the area of outlets
- To increase cooling effectiveness, a smaller inlet can be paired with a larger outlet opening. With this configuration, inlet air can have a higher velocity

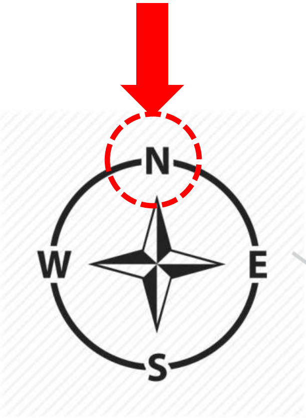
Usually a ratio of 1:2.5 or 1:3 between windward side and leeward side is preferred in tropical areas



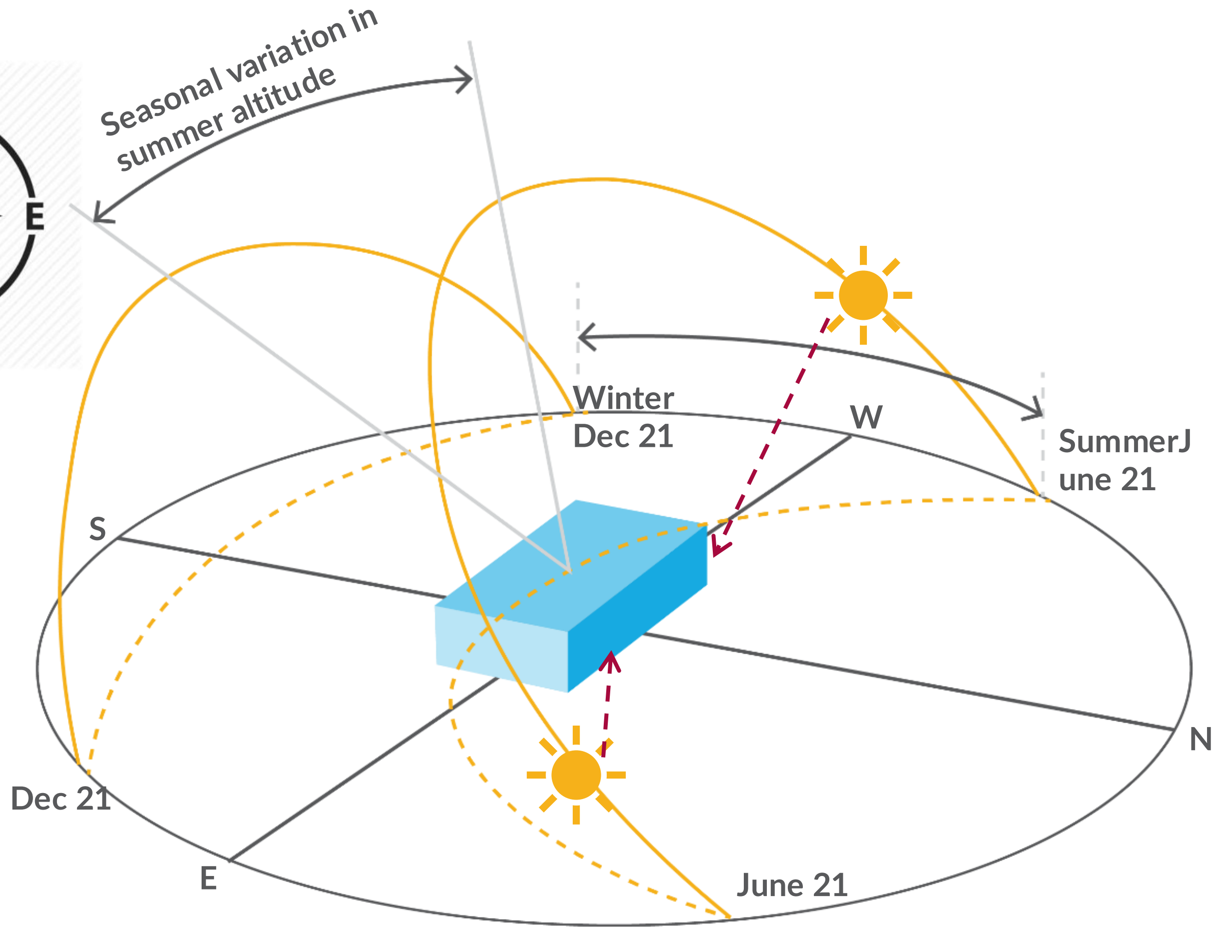
Solar Shading

SOLAR SHADING

North façade

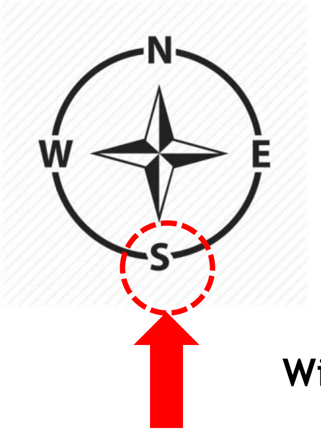


- In the northern hemisphere, north-facing windows receive direct sunlight in summer mornings and evenings
- Vertical fins can shade adequately

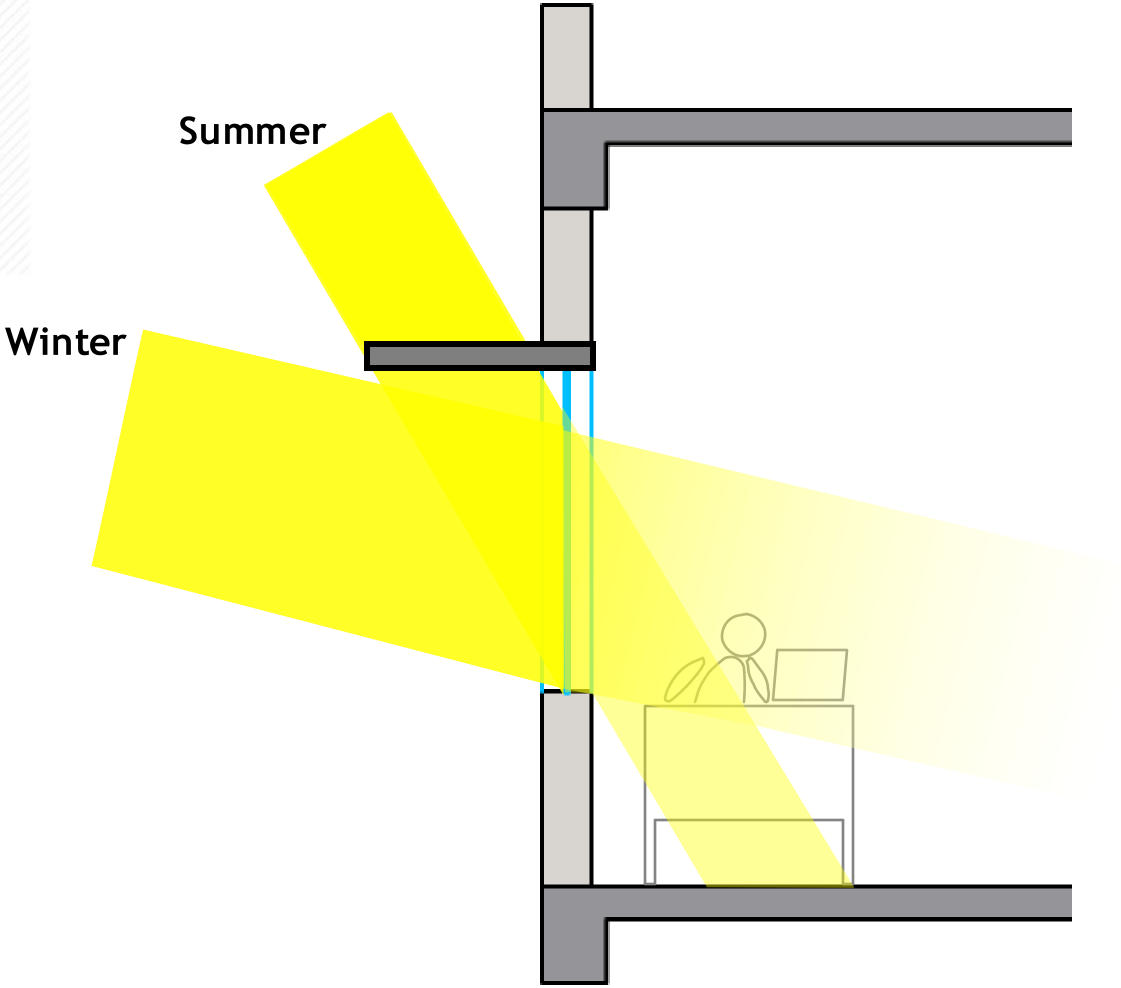


SOLAR SHADING

South façade



In the northern hemisphere, horizontal overhangs can effectively cut direct solar radiation on the south façade in summer



SOLAR SHADING

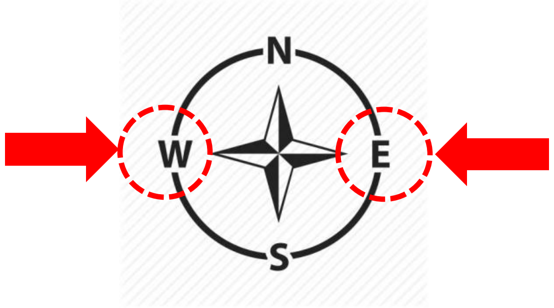
Case examples: South façade

Institute of Rural Research and Development, Gurugram, India

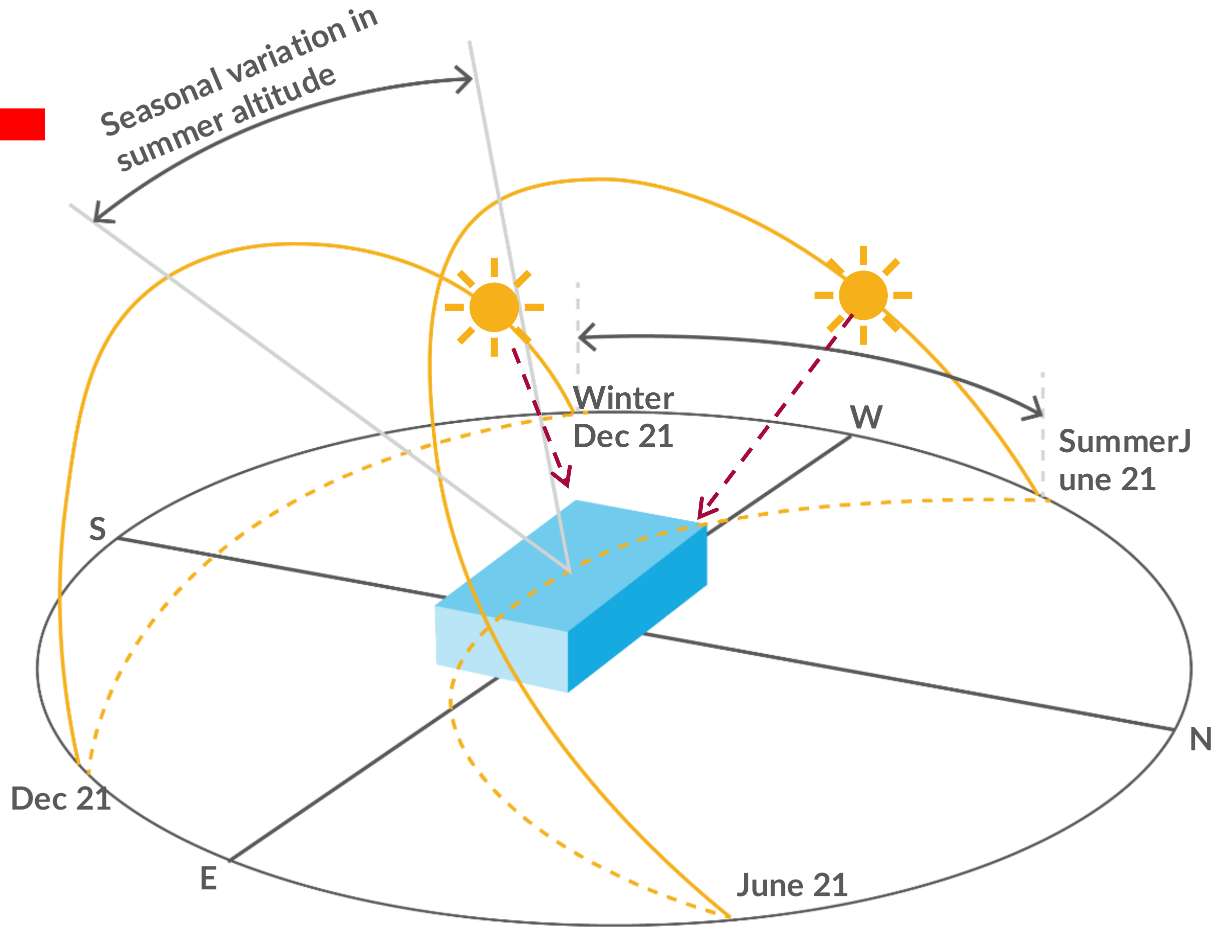
Infosys, Hyderabad, India

SOLAR SHADING

East and west façades



- Low sun on east and west façades
- Solar azimuth angle also changes
- **Dynamic shading** most effective on east and west façades



EXTERNAL MOVABLE SHADING

Case examples: East and west façades

Rolex Learning Centre, Lausanne

Safal Profitaire, Ahmedabad

EXTERNAL MOVABLE SHADING

Reduces solar heat gains by 60%–80%

- Performance monitoring of **two identical flats** on the 10th and 11th floor in Gurugram
- One flat with **external movable shading** and the other with **internal curtains**
- Monitored for both **naturally-ventilated (NV) and air-conditioned (AC)** cases

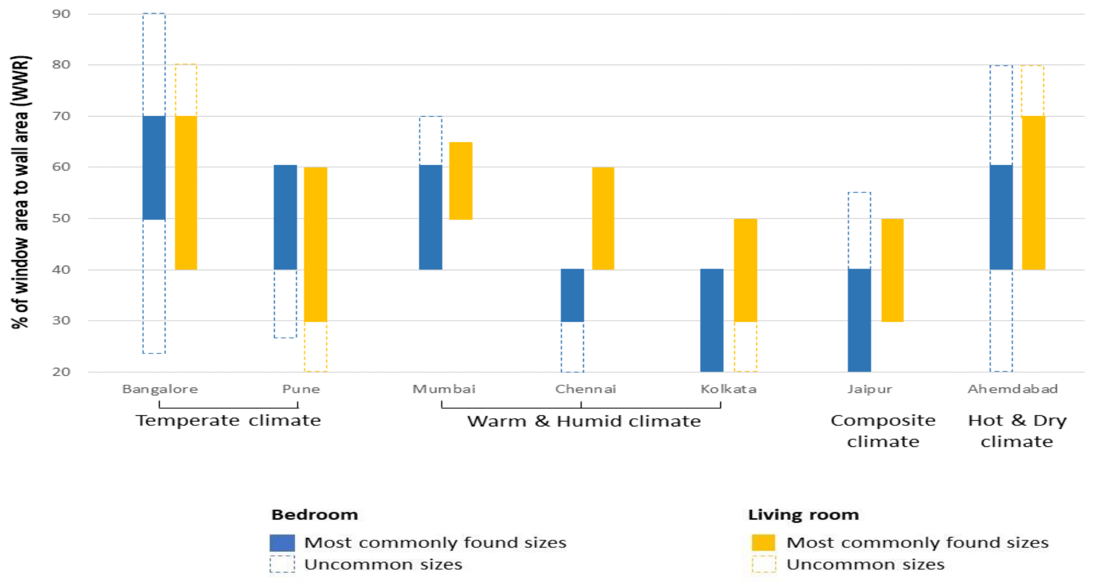
NV

A difference of **~3.5°C** was observed in peak inside operative temperature in naturally-ventilated case

AC

A difference of **~32%** was observed in cumulative cooling demand (thermal) in air-conditioned case

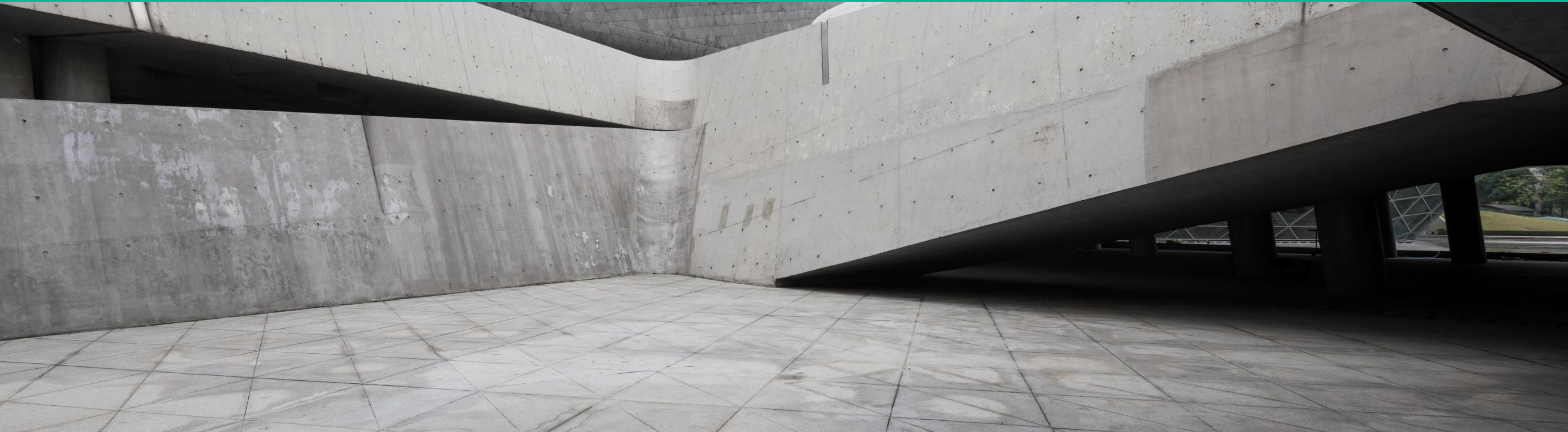
Source: Ministry of Power, Government of India, 2022b



- Trends **of increasing window areas** in residential buildings
- Window-to-wall ratio of 50 buildings spread over 7 cities measured
- Low-income, middle-income and high-income housing covered in study
- **High-income houses showed the largest window sizes across all cities and climate zones**

Optimizing Building Envelope

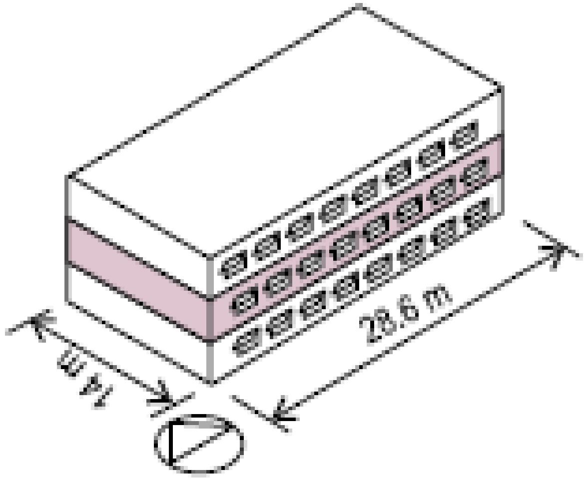
Walls and Roofs



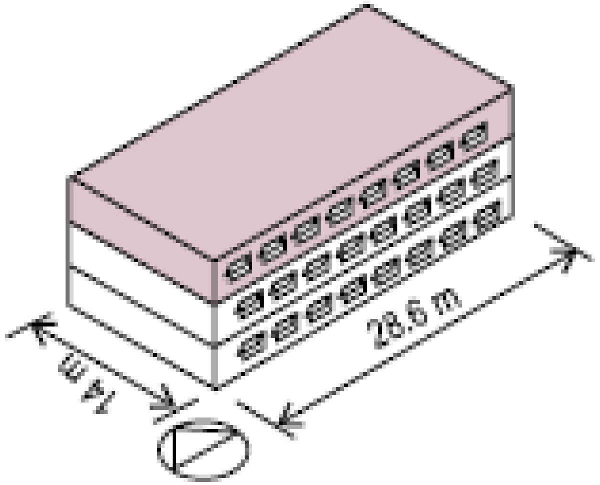
WALLS AND ROOFS

Reducing solar heat gains

- Walls with **high thermal mass and low U-value**
- Use of insulation
  - **Roofs** - All climates
  - **Walls** – All climates, excluding warm-humid climates



Level: Intermediate floor 6 inch RCC slab with plaster (U-value: 3.8 $W/m^2.K$)



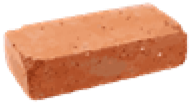
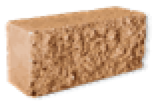
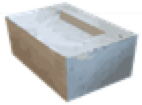
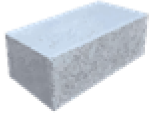
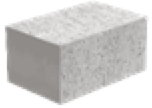
Roof: 150mm RCC slab with plaster (U-value: 3.8 $W/m^2.K$)

In case of an intermediate floor, heat gain from window is highest

In case of top floor, heat gain from roof is highest

WALLING MATERIALS

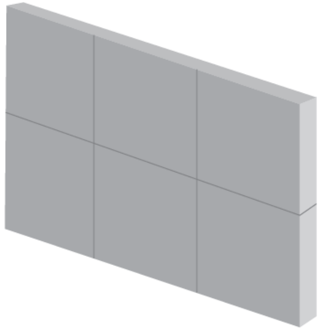
Comparative thermal properties and embodied carbon

	Type	U-Value (W/m.K)	Thermal Mass	Embodied Energy
	Solid Fired Clay Brick	Medium (0.4–1.0)	Medium to High	1,616 MJ/m^2
	Hollow Clay Fired Block	High (0.3)	Low to Medium	814 MJ/m^2
	Compressed Stabilized Earth Brick	Medium (0.6–1.0)	High	203 MJ/m^2
	Fly Ash Brick	Medium (0.4–0.9)	Medium to High	466 MJ/m^2
	Concrete Block	Poor (1.0–1.5)	High	407 MJ/m^2
	Autoclaved Aerated Concrete Block	High (0.2)	Low to Medium	317 MJ/m^2

Sources: Bureau of Energy Efficiency, Government of India, 2024; EDGE

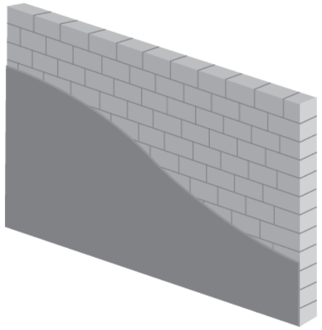
TYPES OF WALLING ASSEMBLIES

U-values



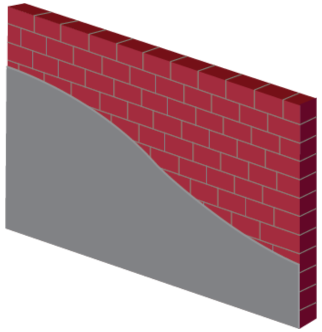
150 mm RCC (no plaster)

U-value
3.77 $W/m^2.K$



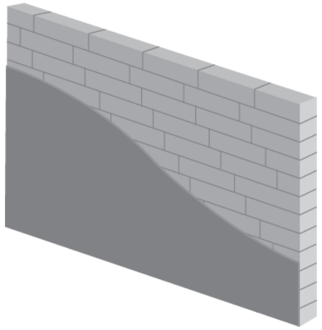
200 mm solid concrete block with 15 mm plaster on both sides

U-value
2.8 $W/m^2.K$



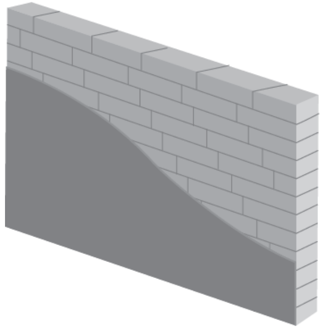
230 mm brick with 15 mm plaster on both sides

U-value
1.72–2.24 $W/m^2.K$



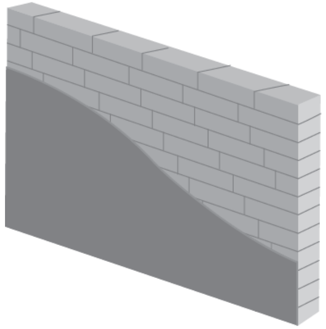
200 mm autoclaved aerated concrete with 15 mm plaster on both sides

U-value
0.77 $W/m^2.K$



300 mm autoclaved aerated concrete with 15 mm plaster on both sides

U-value
0.54 $W/m^2.K$



230 mm thick cavity wall of bricks (115 mm outer wall, 75 mm inner wall with 40 mm cavity)

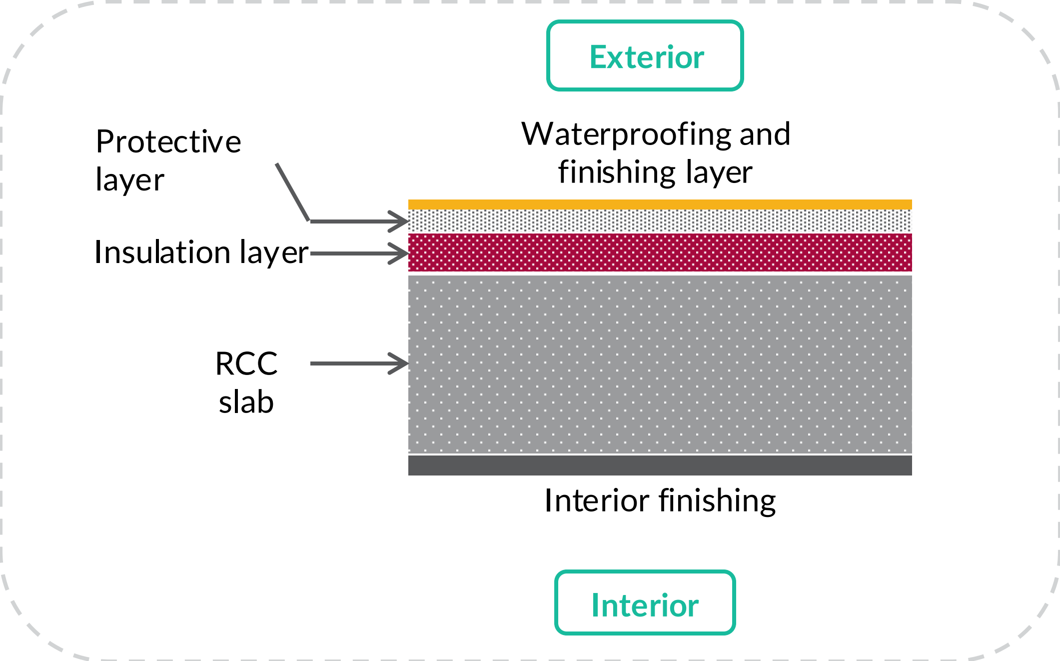
U-value
0.62 $W/m^2.K$

Source: Bureau of Energy Efficiency, Government of India, 2024

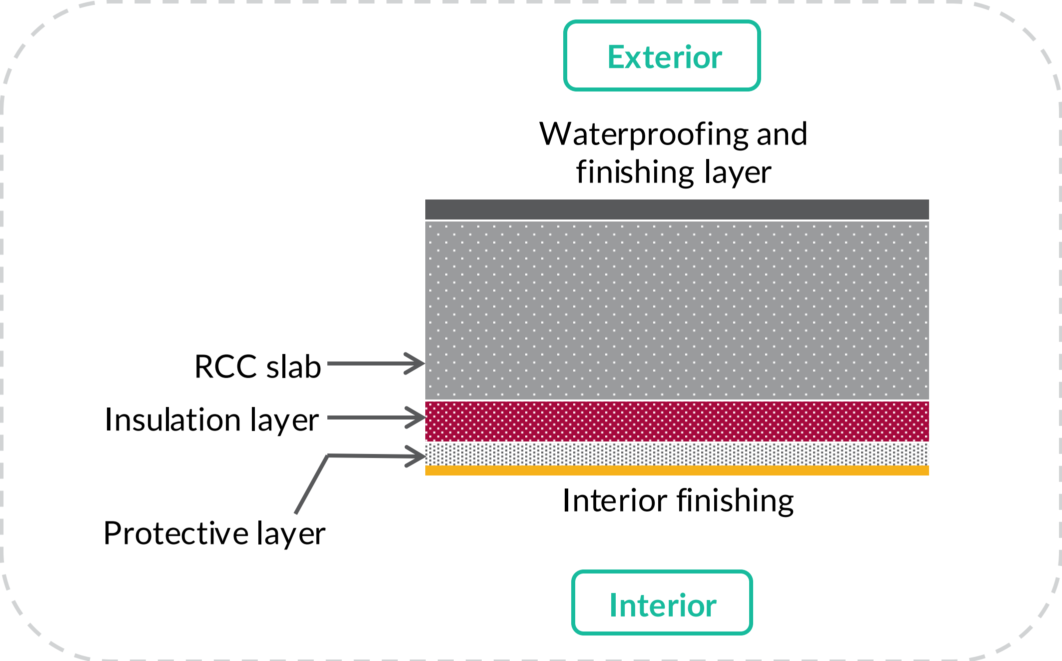
ROOF INSULATION

Methods of application

Thermal conductivity of common insulation materials usually range from 0.03–0.05 W/m.K which is 1/10th to 1/20th that of fired clay brick



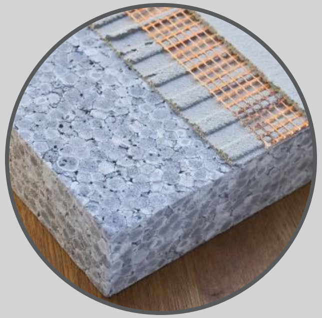
Roof with over-deck insulation



Roof with under-deck insulation

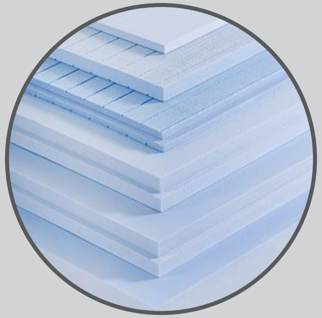
BUILDING INSULATION

Rigid insulation materials



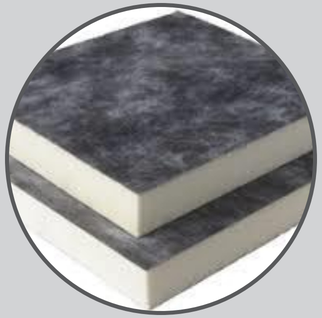
Expanded Polystyrene (EPS)

- Composed of small beads of polystyrene that are fused together
- Colorless and transparent thermoplastic material



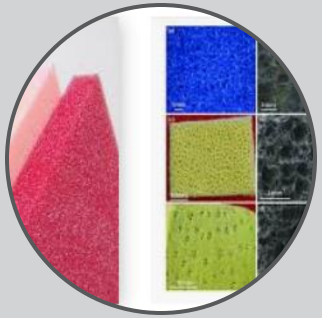
Extruded Polystyrene (XPS)

- Made of polystyrene, in which molten polystyrene is pressed out of a form into sheets



Polyisocyanurate (PIR)

- Thermosetting type of plastic, closed-cell foam that contains in its cells a hydro-chlorofluorocarbon-free gas of low conductivity
- Available as liquid, sprayed foam and rigid foam board



Polyurethane (PUR)

- Foam insulation material that contains in its cells a gas of low conductivity

INSULATION MATERIALS

Fibrous insulation materials

Glass Wool

- Made from extremely fine fibers of glass
- Arranged into a texture similar to wool by using a binder
- Small air pockets between the glass, which ensures high thermal insulation
- Available in three different forms – blanket (batts and rolls), loose-fill and rigid boards

Mineral Wool

- Rock wool, a synthetic material consisting of natural minerals like basalt or diabase
- Slag wool, a synthetic material from blast furnace slag (the scum that forms on the surface of molten metal)

INSULATION MATERIALS

Natural organic materials

Hemp Insulation

- Made from hemp wool
- Hemp wool is strong and woody fibers that are derived from the hemp plant

Cellulose Insulation

- Plant fiber used in wall and roof for insulation purposes
- Modern cellulose insulation is made from either ground recycled paper or recycled denim

Straw Insulation

- Straw bales are made from agro-waste. Once the edible part of the grain has been harvested (such as wheat or rice), the remaining waste is compressed to make insulation panels

COOL ROOF

Reflective external roof surfaces

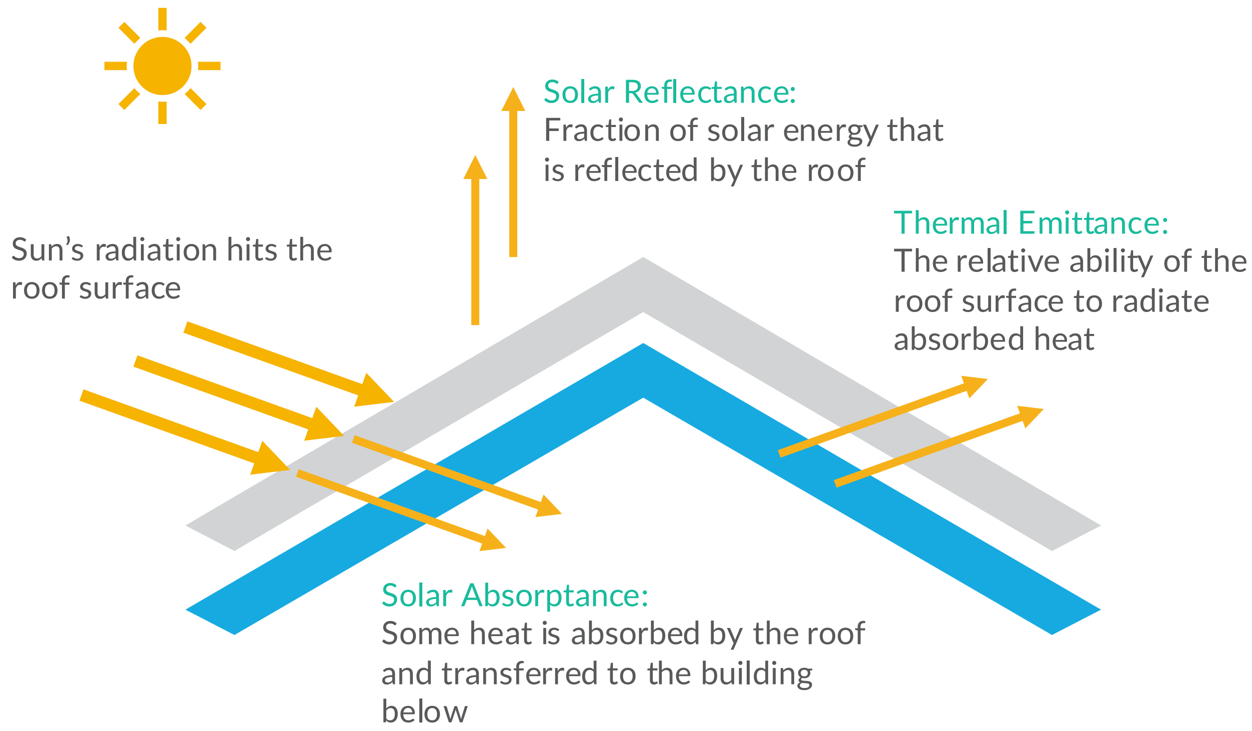
- High Solar Reflectance Index finishes on roofs
- Use of **insulation in all climates** (preferably over-deck)

Cool roofs reflect sunlight back to the atmosphere to a greater extent than regular roof surfaces

When solar radiation falls on a roof, the roof surface performs three functions:

- Reflects a part of the incident solar radiation back into the atmosphere
- Conducts a part of the heat through itself into the buildings
- Transfers a part of the heat to the ambient air (external and internal)

Cool roofs emit a part of the absorbed heat to internal surfaces and the rest back to the sky

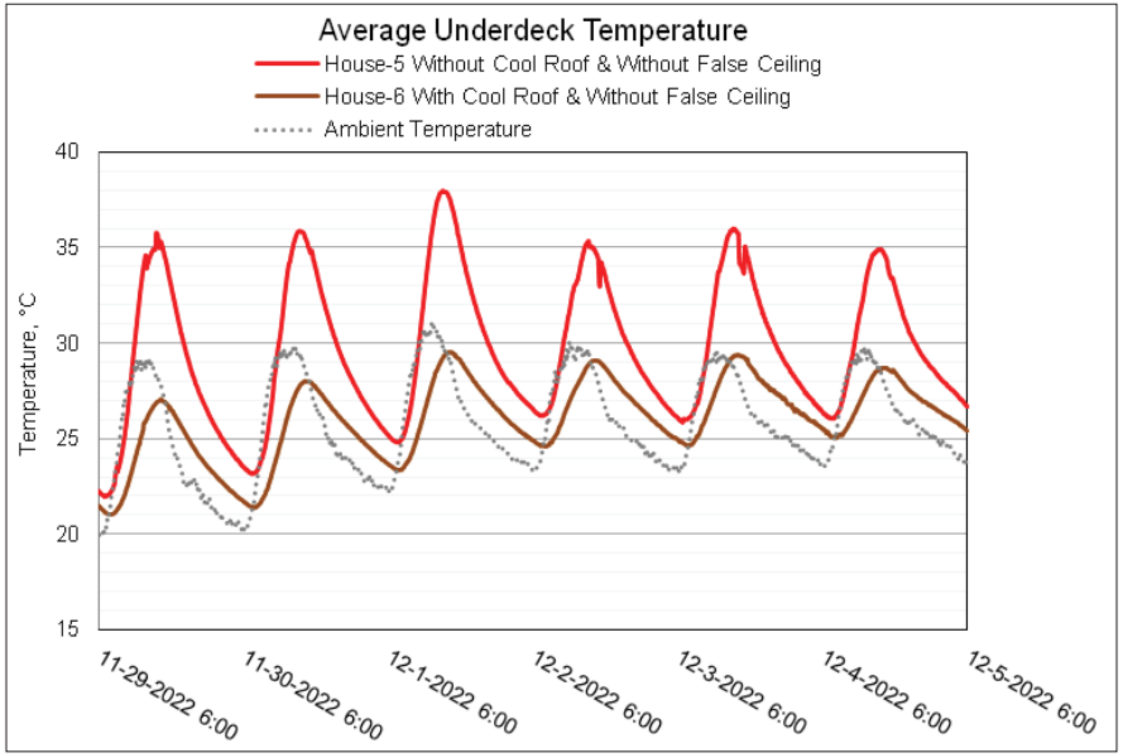


COOL ROOF

Case study: Affordable Housing Project, Andhra Pradesh, India

Comparative performance monitoring to monitor the impact of cool roofs in Andhra Pradesh. Total 12 houses in 3 locations were monitored – half of the houses with cool roof and other half without the cool roof

Reduction of around 6°C–9°C in under-deck temperatures was found with cool roof application (without any false ceiling)



Building Envelope Features

Recommendations for Different Climates

HOT AND DRY CLIMATE

Key recommendations

OBJECTIVES	PHYSICAL MANIFESTATION
1) Resist heat gain	
• Decrease exposed surface area	• Orientation and shape of building
• Increase thermal resistance	• Insulation of building envelope
• Increase thermal capacity (time lag)	• Massive structure
• Increase buffer spaces	• Air locks, lobbies, balconies, verandas
• Decrease air exchange rate (ventilation during daytime)	• Weather stripping and scheduling air changes
• Increase shading	• External surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	• Pale color, glazed china mosaic tiles, etc.
2) Promote heat loss	
• Ventilation of appliances	• Provide windows and exhausts
• Increase air exchange rate (ventilation during nighttime)	• Courtyards, wind towers, arrangement of openings
• Increase humidity level	• Trees, water ponds, evaporative cooling

Source: Nayak and Prajapati, 2006

WARM AND HUMID CLIMATE

Key recommendations

OBJECTIVES	PHYSICAL MANIFESTATION
1) Resist heat gain	
• Decrease exposed surface area	• Orientation and shape of building
• Increase thermal resistance	• Roof and wall insulation. Reflective surface of roof
• Increase buffer spaces	• Balconies and verandas
• Increase shading	• Walls and glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	• Pale color, glazed china mosaic tiles, etc.
2) Promote heat loss	
• Ventilation of appliances	• Provide windows and exhausts
• Increase air exchange rate (ventilation throughout the day)	• Ventilated roof construction, courtyards, wind towers, and arrangement of openings

Source: Nayak and Prajapati, 2006

TEMPERATE CLIMATE

Key recommendations

OBJECTIVES	PHYSICAL MANIFESTATION
1) Resist heat gain	
• Decrease exposed surface area	• Orientation and shape of building
• Increase thermal resistance	• Roof insulation and east and west wall insulation
• Increase shading	• East and west walls and glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	• Pale color, glazed china mosaic tiles, etc.
2) Promote heat loss	
• Ventilation of appliances	• Provide windows and exhausts
• Increase air exchange rate (ventilation)	• Courtyards and arrangement of openings

Source: Nayak and Prajapati, 2006

COMPOSITE CLIMATE

Key recommendations

OBJECTIVES	PHYSICAL MANIFESTATION
1) Resist heat gain in summer and resist heat loss in winter	
• Decrease exposed surface area	• Orientation and shape of building. Use of trees as wind barriers
• Increase thermal resistance	• Roof and wall insulation
• Increase thermal capacity (time lag)	• Thicker walls
• Increase buffer spaces	• Air locks and balconies
• Decrease air exchange rate	• Weather stripping
• Increase shading	• Walls and glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	• Pale color, glazed china mosaic tiles, etc.
2) Promote heat loss in summer and monsoon	
• Ventilation of appliances	• Provide exhausts
• Increase air exchange rate (ventilation)	• Courtyards, wind towers, arrangement of openings
• Increase humidity level in dry summer	• Trees and water ponds for evaporative cooling

Source: Nayak and Prajapati, 2006

COLD CLIMATE

Key recommendations

OBJECTIVES	PHYSICAL MANIFESTATION
1) Resist heat gain in summer and heat loss in winter	
• Decreased exposed surface area	• Orientation and shape of building. Use of trees as wind barriers
• Increase thermal resistance	• Roof insulation, wall insulation and double glazing
• Increase thermal capacity (time lag)	• Thicker walls
• Increase buffer spaces	• Air locks and lobbies
• Decrease air exchange rate	• Weather stripping
• Increase air absorptivity	• Darker colors
2) Promote heat loss in summer and monsoon	
• Reduce shading	• Walls and glass
• Utilize heat from appliances	
• Trapping heat	• Sun walls, green houses, Trombe walls, etc.

Source: Nayak and Prajapati, 2006

Thank you!

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