RACHNA 2.0

RESILIENT, AFFORDABLE AND COMFORTABLE HOUSING THROUGH NATIONAL ACTION

THERMAL COMFORT IN AFFORDABLE HOUSING

Climate Smart Buildings (CSB)

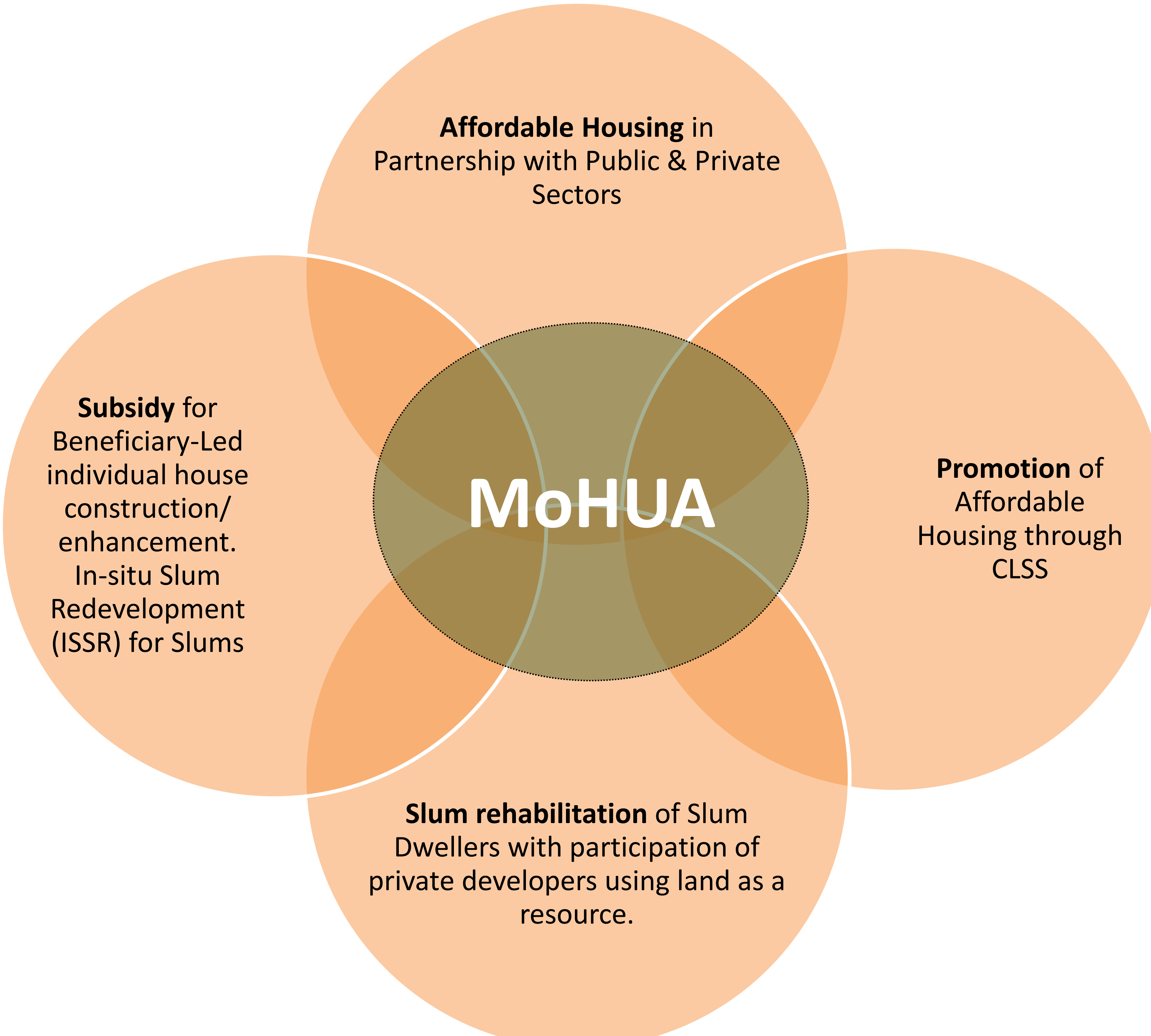
Cluster cell Indore, Madhya Pradesh under Global Housing Technology Challenge - India (GHTC-India)

INTRODUCTION - MoHUA

'Housing for All' by 2022.

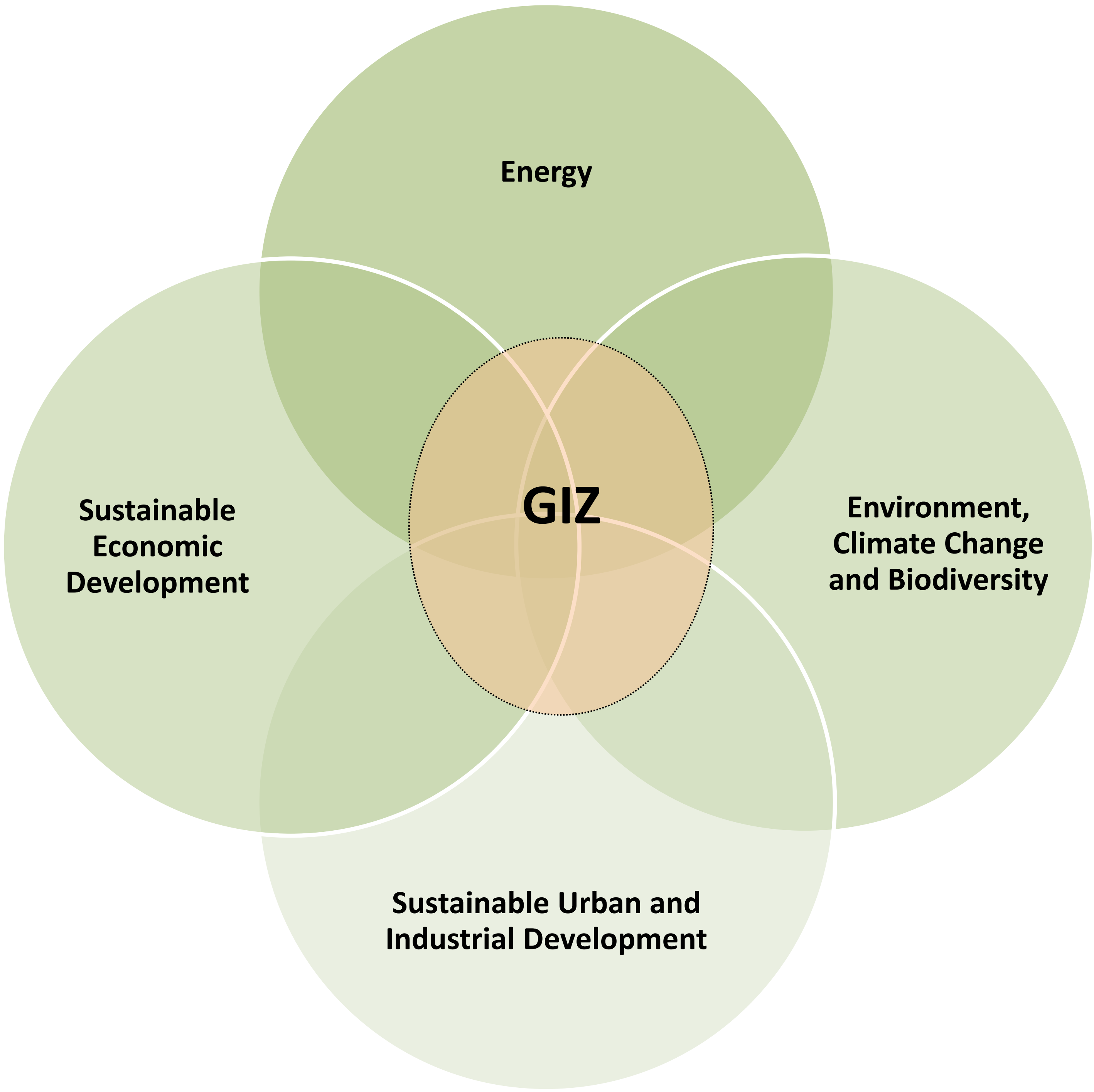
Under the Mission, Ministry of Housing and Urban Affairs (MoHUA), provides Central Assistance to implementing agencies through States and Union Territories for providing houses to all eligible families/beneficiaries by 2022.

Addressing the affordable housing requirement in urban areas through:



INTRODUCTION - GIZ

- GIZ is an international cooperation enterprise for sustainable development which operates worldwide, on a public benefit basis.
- GIZ is fully owned by the German Federal Government, GIZ implement development programs in partner country on behalf of the German Government in achieving its development policy objectives.
- For over **60 years**, the GIZ has been working jointly with partners in India for **sustainable economic, ecological, and social development.**



TASKS PLANNED WITH MoHUA

The Climate Smart Buildings (CSB) programme is aligned with the commitments made by the Indian Government to meet its objectives submitted under SDG 11.

IGEN's programme, Climate Smart Buildings (CSB) proposes to extend technical assistance and cooperation for the following:

- Technical assistance in developing thermal comfort action plan for climate resilience building for mass scale application in selected states for Affordable Housing
- Technical support in implementation of Global Housing Technology Challenge-India (GHTC-India)

CLIMATE SMART BUILDING

Climate Smart Buildings

Map showing states under central cluster cell

- Madhya Pradesh
- Maharashtra
- Goa
- Telangana
- Chhattisgarh

AIM & CONCEPT

7 AFFORDABLE AND CLEAN ENERGY
Ensure access to affordable, reliable, sustainable, and modern energy for all

9.INDUSTRY, INNOVATION AND INFRASTRUCTURE
Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation

11.SUSTAINABLE CITIES AND COMMUNITIES
Make cities and human settlements inclusive, safe, resilient, and sustainable

13. PROTECT THE PLANET
Take urgent action to combat climate change and its impacts

DESIGN
↓
CONSTRUCTION
↓
POST OCCUPANCY (O & M)

INTEGRATION IN BY-LAWS

AIM & CONCEPT

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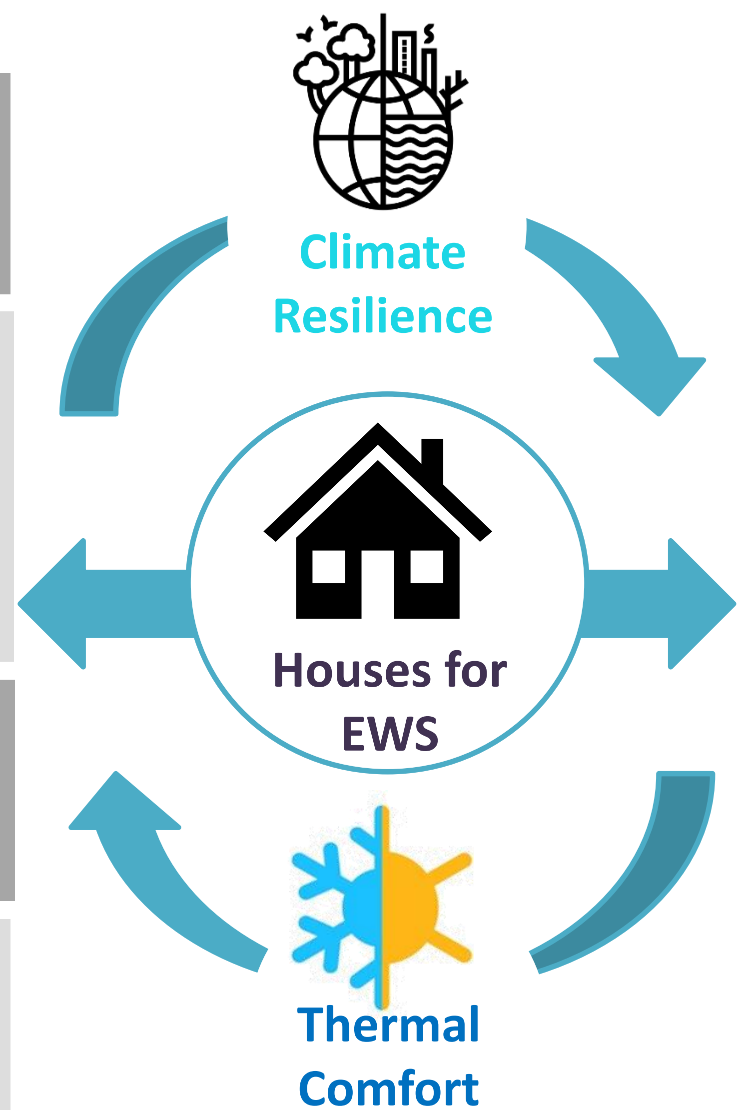
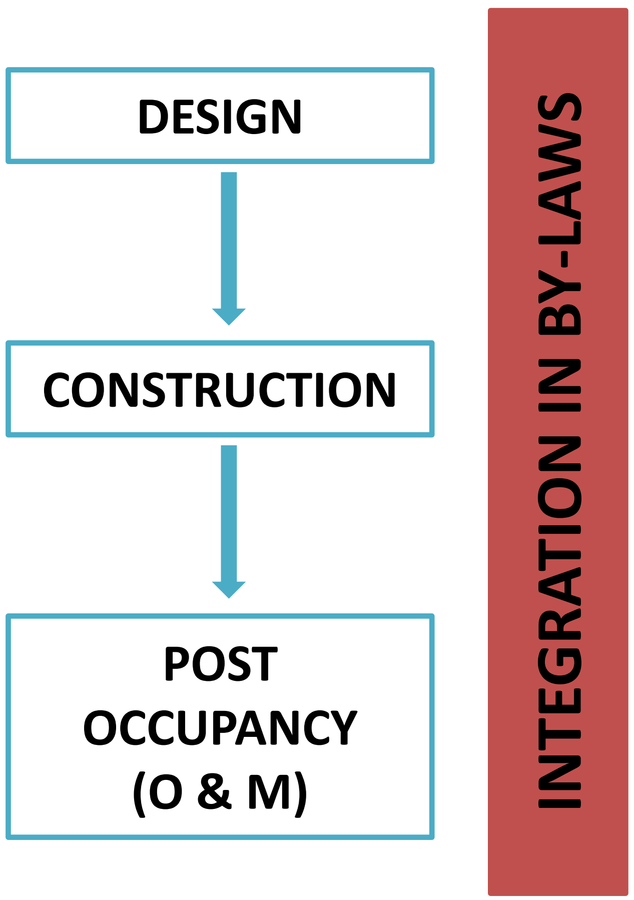




LHP INTRODUCTION

6 LHP's ACROSS INDIA

Map showing six different LHP Locations

LHP's shall serve **as LIVE Laboratories** for different aspects of **Transfer of technologies**

6 LHPs

1. Indore, Madhya Pradesh

- Prefabricated Sandwich Panel System

2. Rajkot, Gujarat

- Monolithic Concrete Construction using Tunnel Formwork

3. Chennai, Tamil Nadu

- Precast Concrete Construction System – Precast Components Assembled at Site

4. Ranchi, Jharkhand

- Precast Concrete Construction System – 3D Volumetric

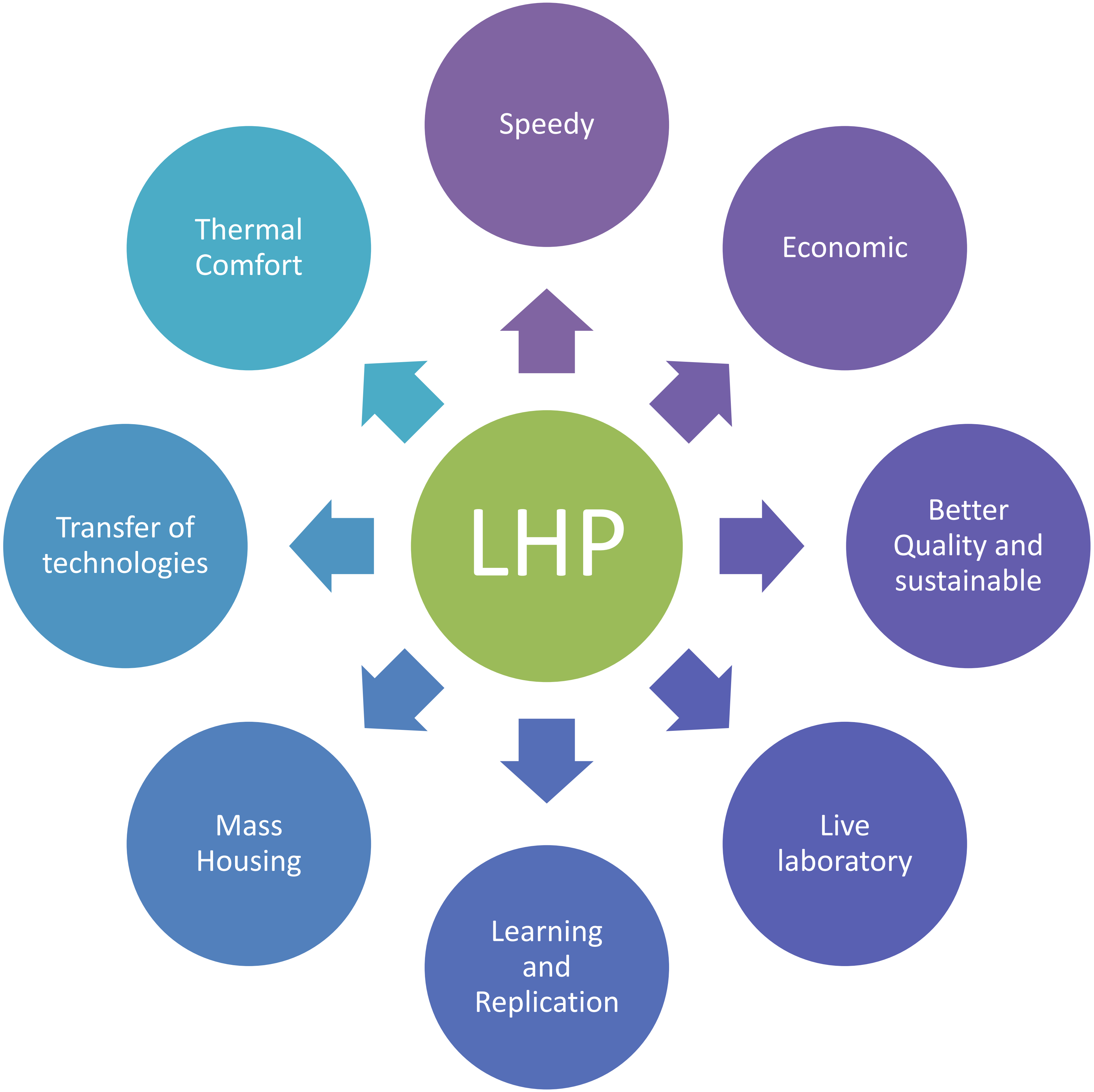
5. Agartala, Tripura

- Light Gauge Steel Structural System & Pre-engineered Steel Structural System

6. Lucknow, Uttar Pradesh

- PVC Stay In Place Formwork System

6 LHPS – FOCUSES ON



6 LHPS – Via Video

DEMONSTRATION HOUSING PROJECTS

DHP- Showcasing the field level application of new and alternate technologies

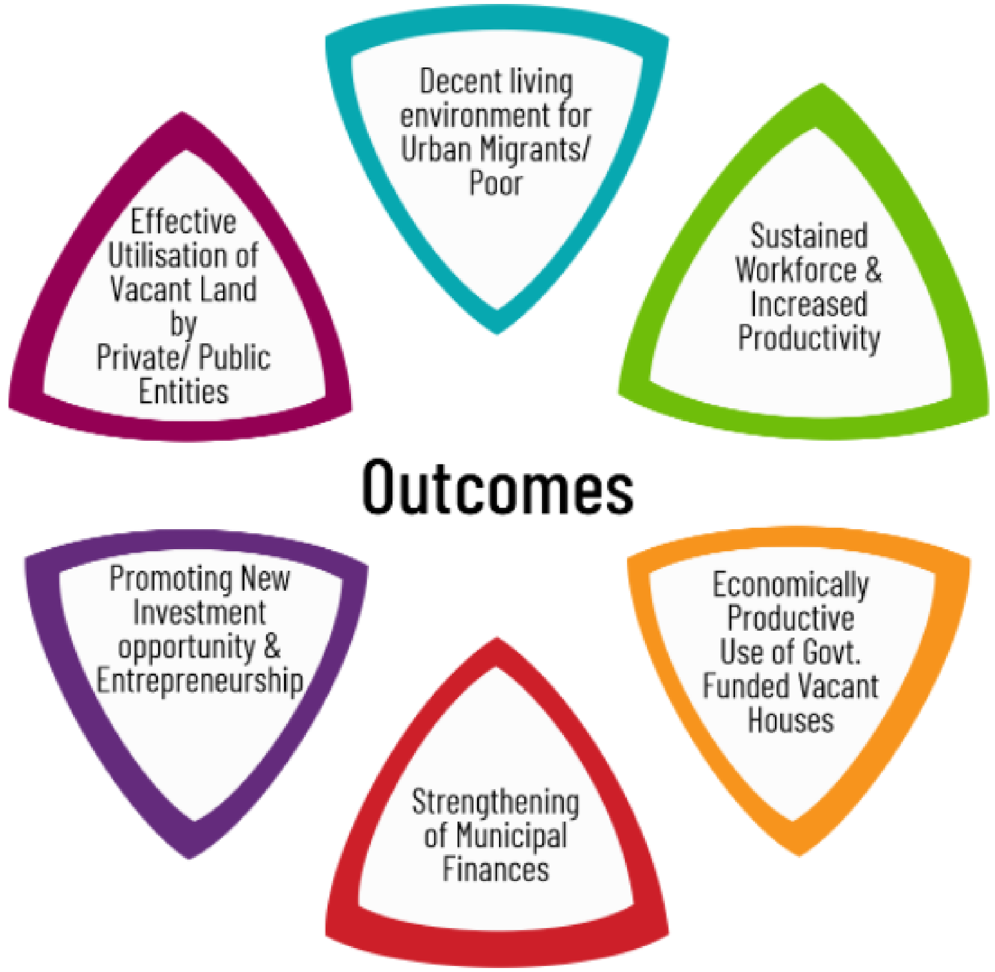
DEMONSTRATION HOUSING PROJECTS

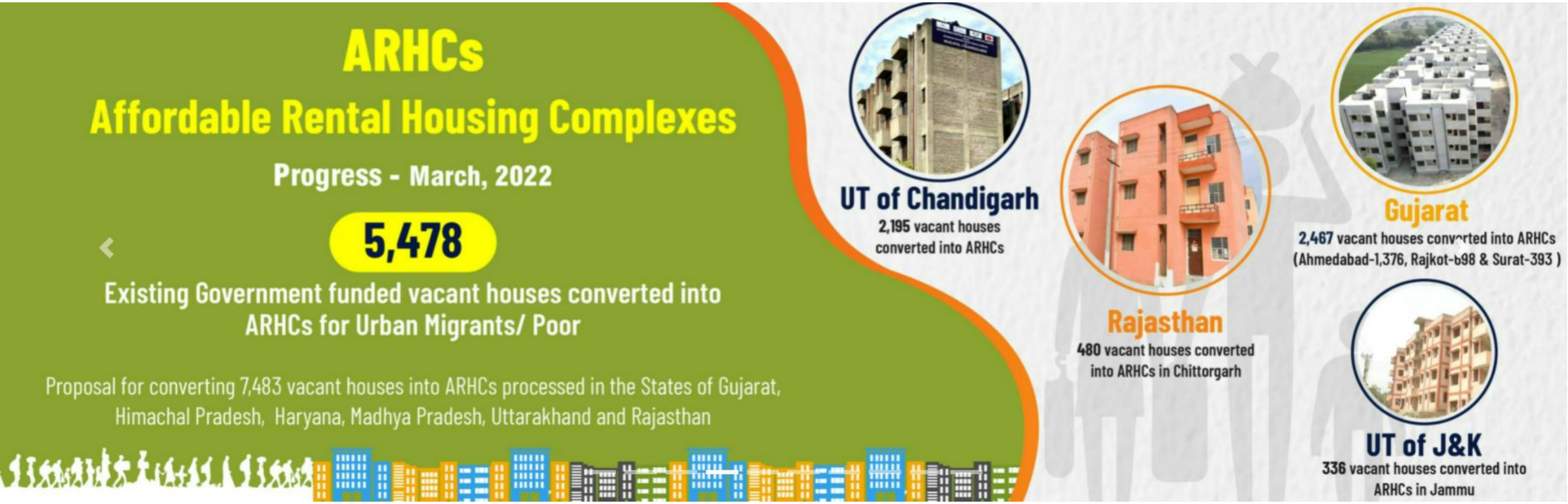
DHP Location	Technology Used	Usage & Number of Houses
Bhubaneswar, Odisha	PREFABRICATED SANDWICH PANEL SYSTEM – Reinforced Expanded Polystyrene sheet core with sprayed concrete as wall & slab	PMAY(U) Beneficiaries 32 (G+3)
Lucknow, Uttar Pradesh	STAY IN PLACE FORMWORK SYSTEM- Stay in place EPS based double walled panel system with infill concrete	Rental basis to Hospital patients & their attendees 40 (G+1)
Hyderabad, Telangana	• LIGHT GAUGE STEEL STRUCTURAL SYSTEM (LGSF) - 16 Units • STAY IN PLACE FORMWORK SYSTEM - Structural Stay In Place Steel Formwork System - 16 Units	Training Hostel 32 (G+3)
Bihar Shariff Bihar	STAY IN PLACE FORMWORK SYSTEM – Structural Stay In Place Steel Formwork System	Sports Hostel & other social welfare activities 36 (G+2)
Nellore Andhra Pradesh	STAY IN PLACE FORMWORK SYSTEM – Glass Fibre Reinforced Gypsum Panel (GFRG)	Social welfare activities 36(G+1)
Panchkula Haryana	Light Gauge Steel Framework System (LGSF) with Cement Fibre board on both side of walls and infill of rock wool	Working women hostel (on rental basis) 40(G+3)
Agartala West Tripura	Structural Stay In Place Steel Formwork System	Shelter for Destitute Women 40(G+1)
Ahmedabad Gujarat	PRECAST CONCRETE CONSTRUCTION SYSTEM - Integrated Hybrid Solution-One	PMAY (U) Beneficiaries 40(G+3)
Chimbel Goa	Light Gauge Steel Framed Structure with Precast Concrete Panels on both side of Wall and Light Weight Concrete as Infill	Old Age Homes 28 (G+1)
Bhopal MP	Insulated concrete formwork	Sports Hostel 40 (G+3)

AFFORDABLE RENTAL HOUSING COMPLEXES

The ARHC scheme will be implemented through two models:

1. **Utilizing existing Government funded vacant houses to convert into ARHCs through Public Private Partnership or by Public Agencies**
2. **Construction, Operation and Maintenance of ARHCs by Public/ Private Entities on their own available vacant land**

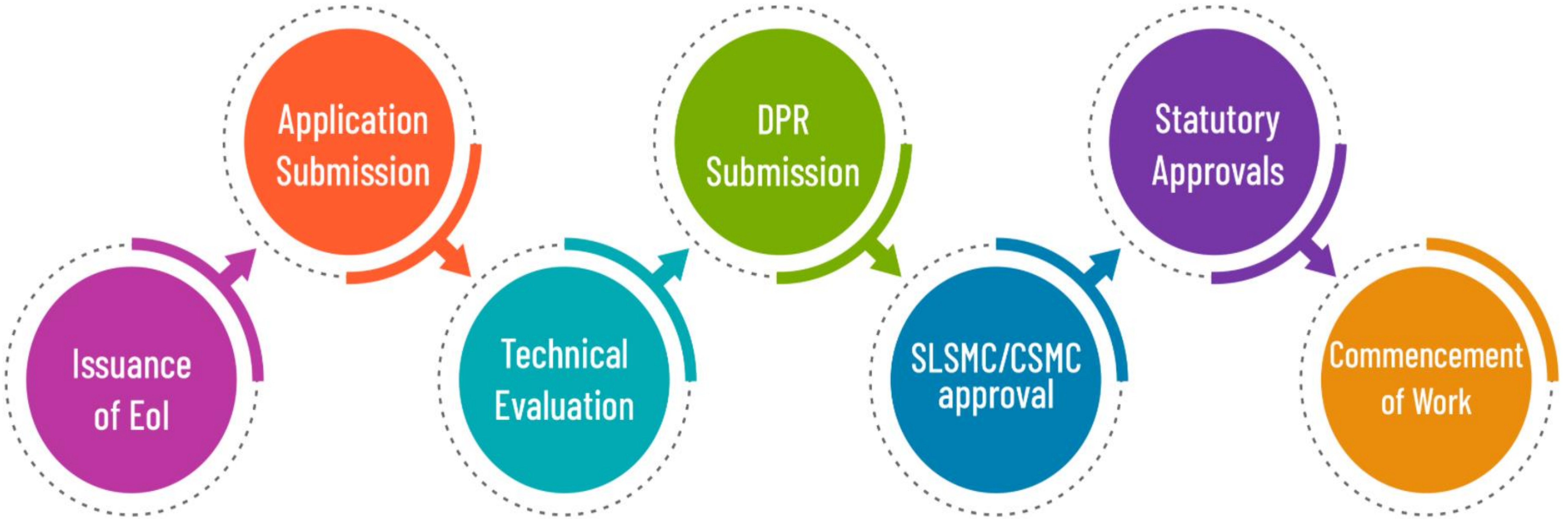




AFFORDABLE RENTAL HOUSING COMPLEXES

MODEL 1

MODEL 2

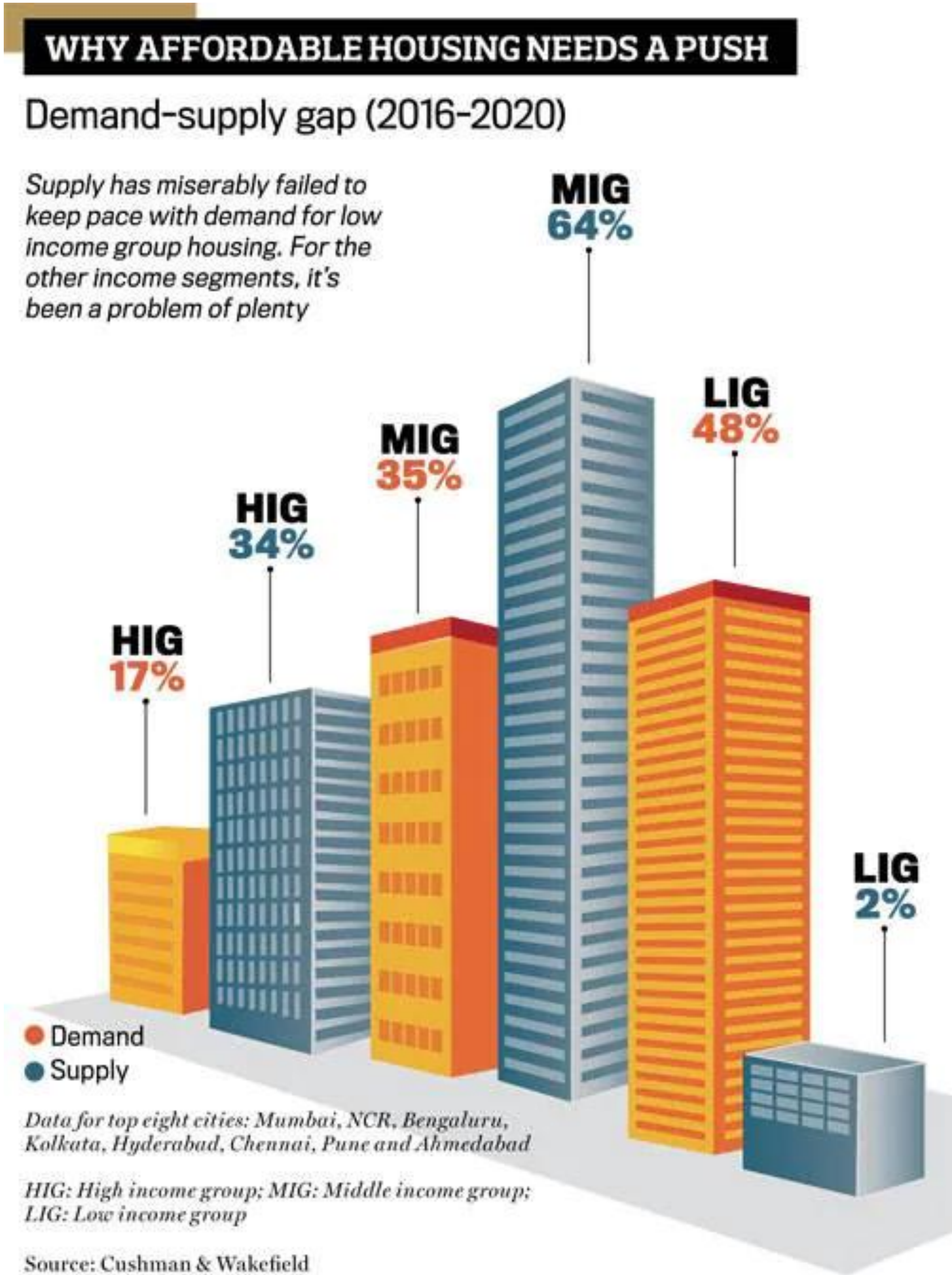


AFFORDABLE RENTAL HOUSING COMPLEXES via Video

THERMAL COMFORT & AFFORDABLE HOUSING

AFFORDABLE HOUSING

Affordable housing refers to housing units that are affordable by that section of society whose income is below the median household income.



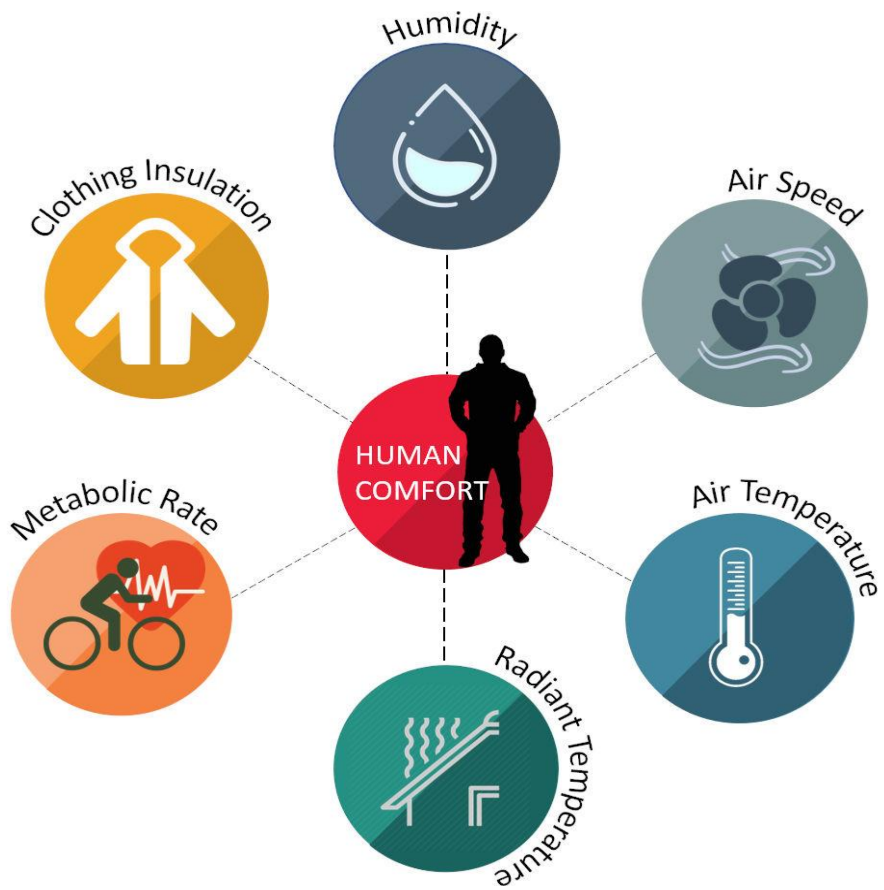
IMPORTANCE OF THERMAL COMFORT

What is Thermal Comfort

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55)

Thermal comfort is difficult to measure because it is highly subjective. It depends on the air temperature, humidity, radiant temperature, air velocity, metabolic rates, and clothing levels.

Factors Affecting Thermal Comfort



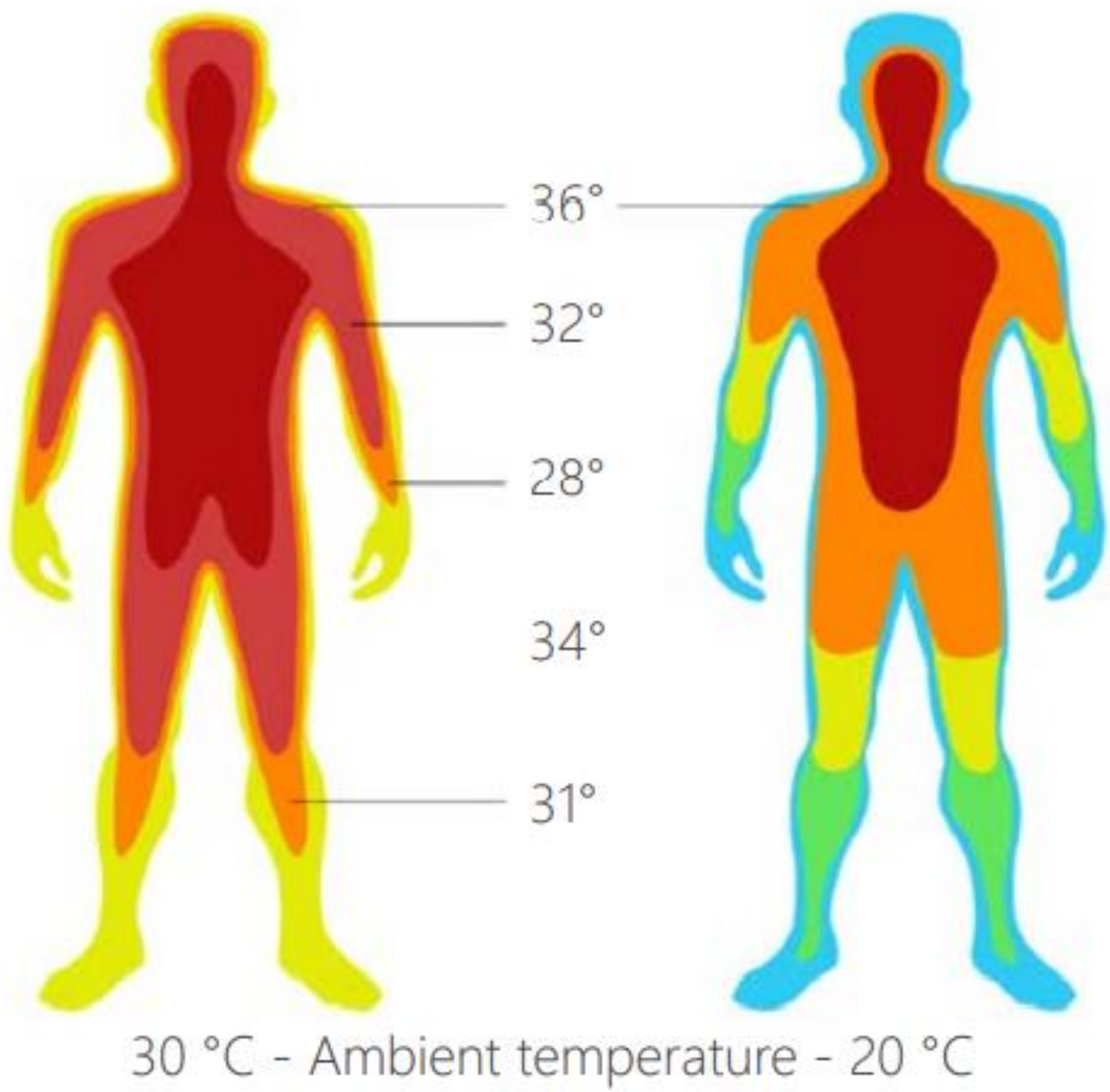
Personal factor

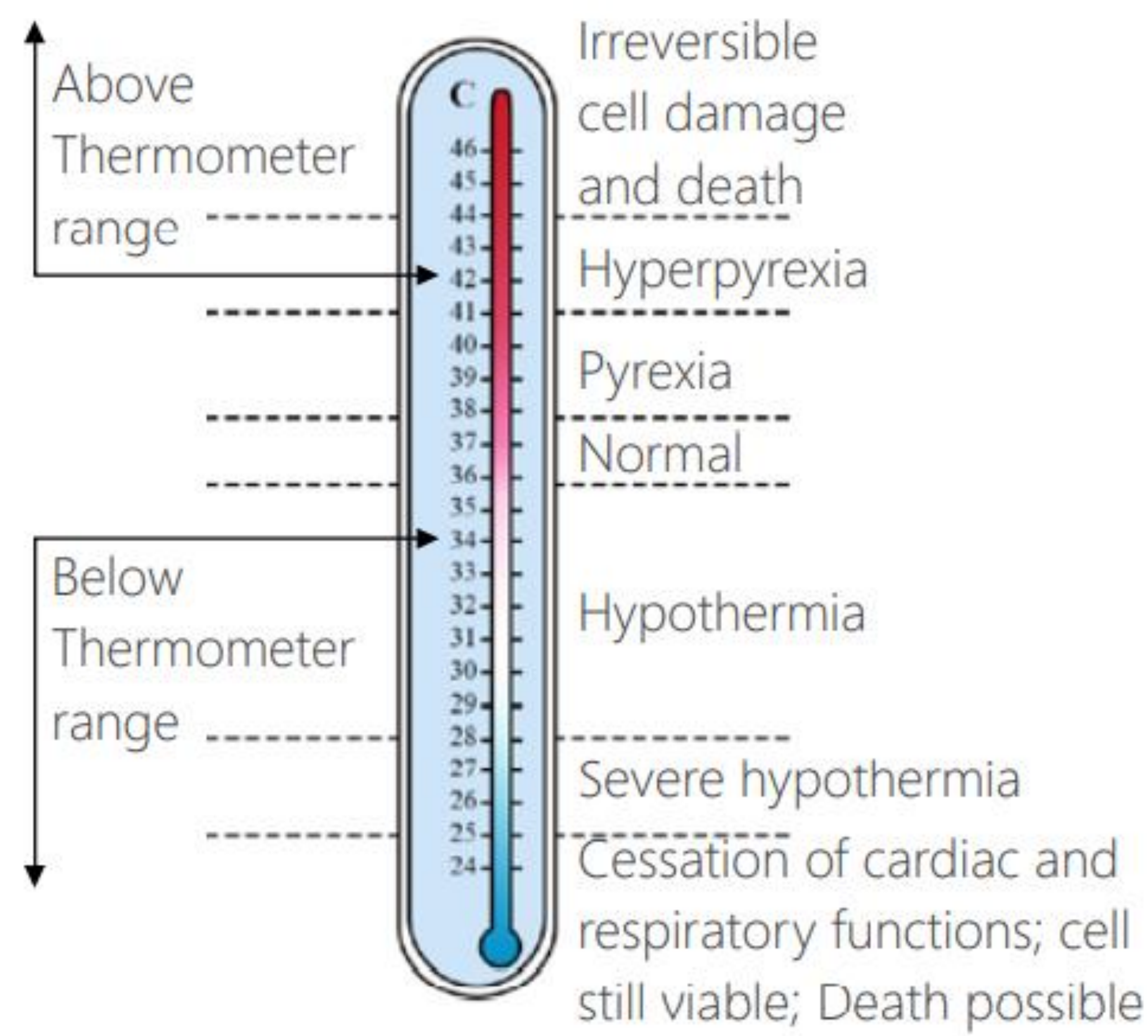
- ✓ Clothing insulation
- ✓ Metabolic Rate(met)

Environmental factor

- ✓ Humidity
- ✓ Air Speed
- ✓ Air Temperature
- ✓ Radiant Temperature

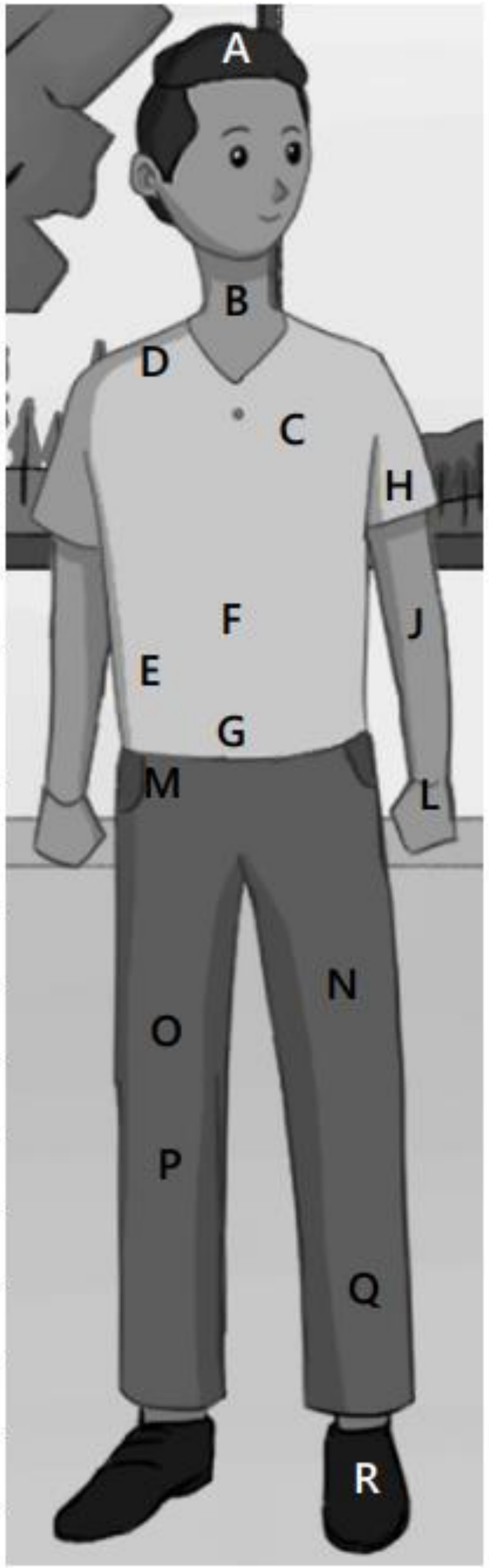
Comfort Band of Human Body





Skin surface temperatures of human body at various body parts in ambient temperature of 30°C vs 20°C; (Right) Comfort band of human body

FACTORS AFFECTING THERMAL COMFORT - INDOOR ENVIRONMENT



Body Part	Skin Location	Cold (15 °C)	Neutral (27 °C)	Hot (47 °C)
A	Forehead	31.7	35.2	37
B	Back of Neck	31.2	35.1	36.1
C	Chest	30.1	34.4	35.8
D	Upper Back	30.7	34.4	36.3
E	Lower Back	29.2	33.7	36.6
F	Upper Abdomen	29	33.8	35.7
G	Lower Abdomen	29.2	34.8	36.2
H	Tricep	28	33.2	36.6
J	Forearm	26.9	34	37
L	Hand	23.7	33.8	36.7
M	Hip	26.5	32.2	36.8
N	Side thigh	27.3	33	36.5
O	Front thigh	29.4	33.7	36.7
P	Back thigh	25.5	32.2	36
Q	Calf	25.1	31.6	35.9
R	Foot	23.2	30.4	36.2

- ✓ The thermal comfort of occupants is influenced by various parameters at play.
- ✓ The factors affecting thermal comfort can be mainly categorized into environmental and personal factors.

Environmental Factors

- ✓ Air Temperature
- ✓ Relative Humidity

Mean radiant Temperature (MRT)

- ✓ Air Speed

FACTORS AFFECTING THERMAL COMFORT - INDOOR ENVIRONMENT

Environmental Factors
Air Temperature
Relative Humidity
Mean radiant Temperatur
(MRT)
Air Speed

Factors affecting thermal comfort- Air Temperature (Tair) and Relative Humidity (RH)

Factors affecting thermal comfort- Mean Radiant Temperature (MRT) and Air Speed

Moving air facilitates the evaporation of sweat from the skin surface, thereby contributing to thermal comfort.

FACTORS AFFECTING THERMAL COMFORT - INDOOR ENVIRONMENT

Personal Factors - Clothing Value, Metabolic Rate

Factors affecting thermal comfort: Clothing Value (CLO)

- The amount and type of clothing worn by an individual affects the transfer of heat from the skin to the surrounding environment.
- Clothing acts as a barrier or resistance to sensible heat transfer.
- The degree of resistance depends on material of the clothing and number of layers in the ensemble

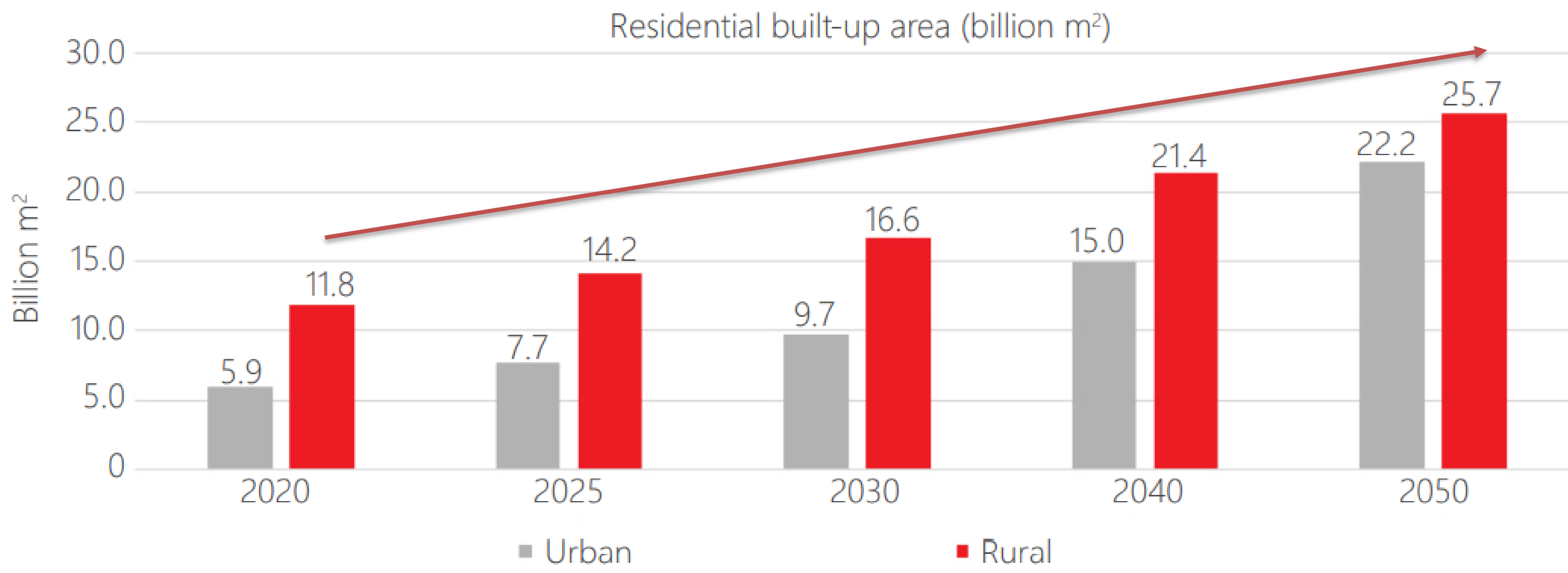
FACTORS AFFECTING THERMAL COMFORT - INDOOR ENVIRONMENT

Other Factors - Short term physiological adjustment, Long term physiological adjustment, Body shape and fat, Age and gender, State of health

Factors affecting Thermal Comfort: Metabolic Rates (MET)

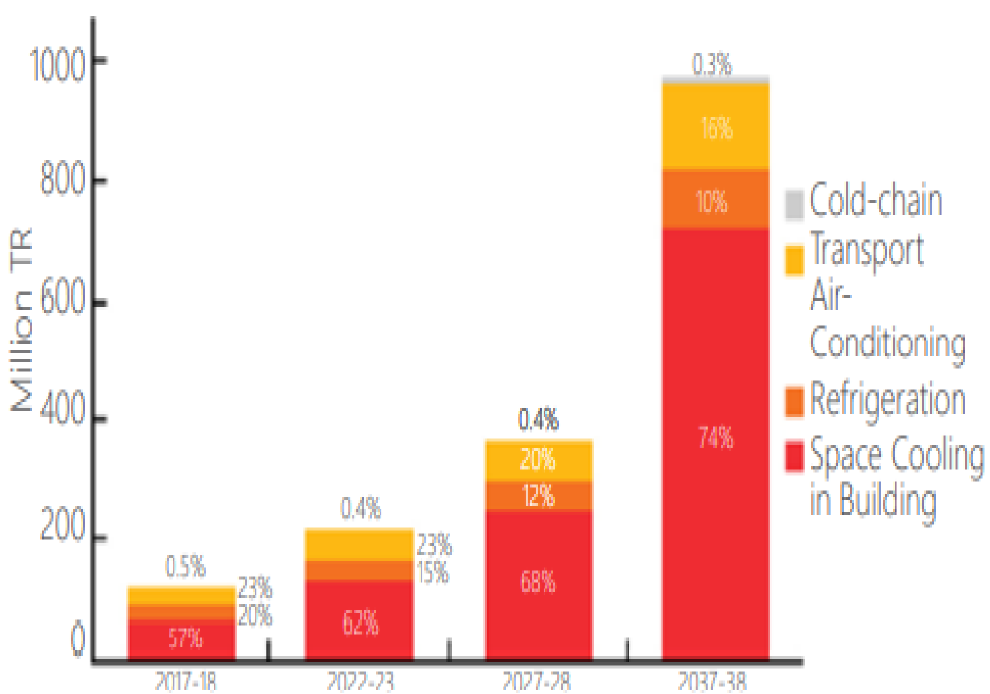
Other factors affecting Thermal Comfort Left: short term physiological adjustments; Right: Long term physiological adjustments

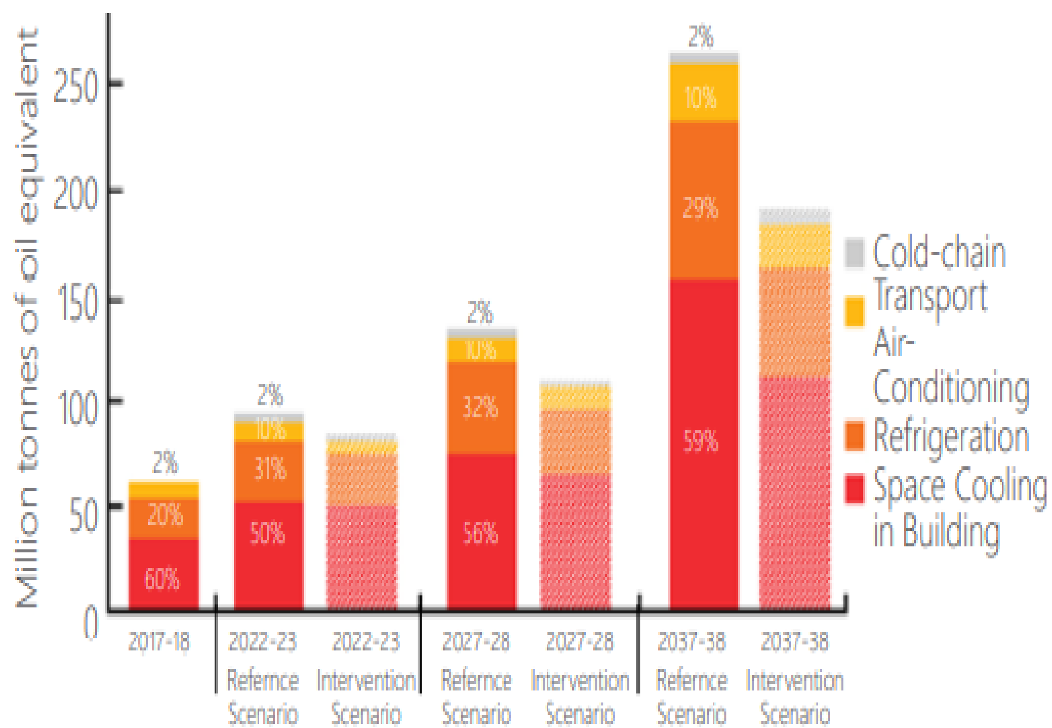
COOLING DEMAND GROWTH & ITS MITIGATIONS



The total increase in urban residential built-up area is estimated to be greater than threefold between 2020 and 2050.

It is projected to rise from 5.9 billion sq. m. to 22.2 billion sq. m. over three decades (2020-2050)





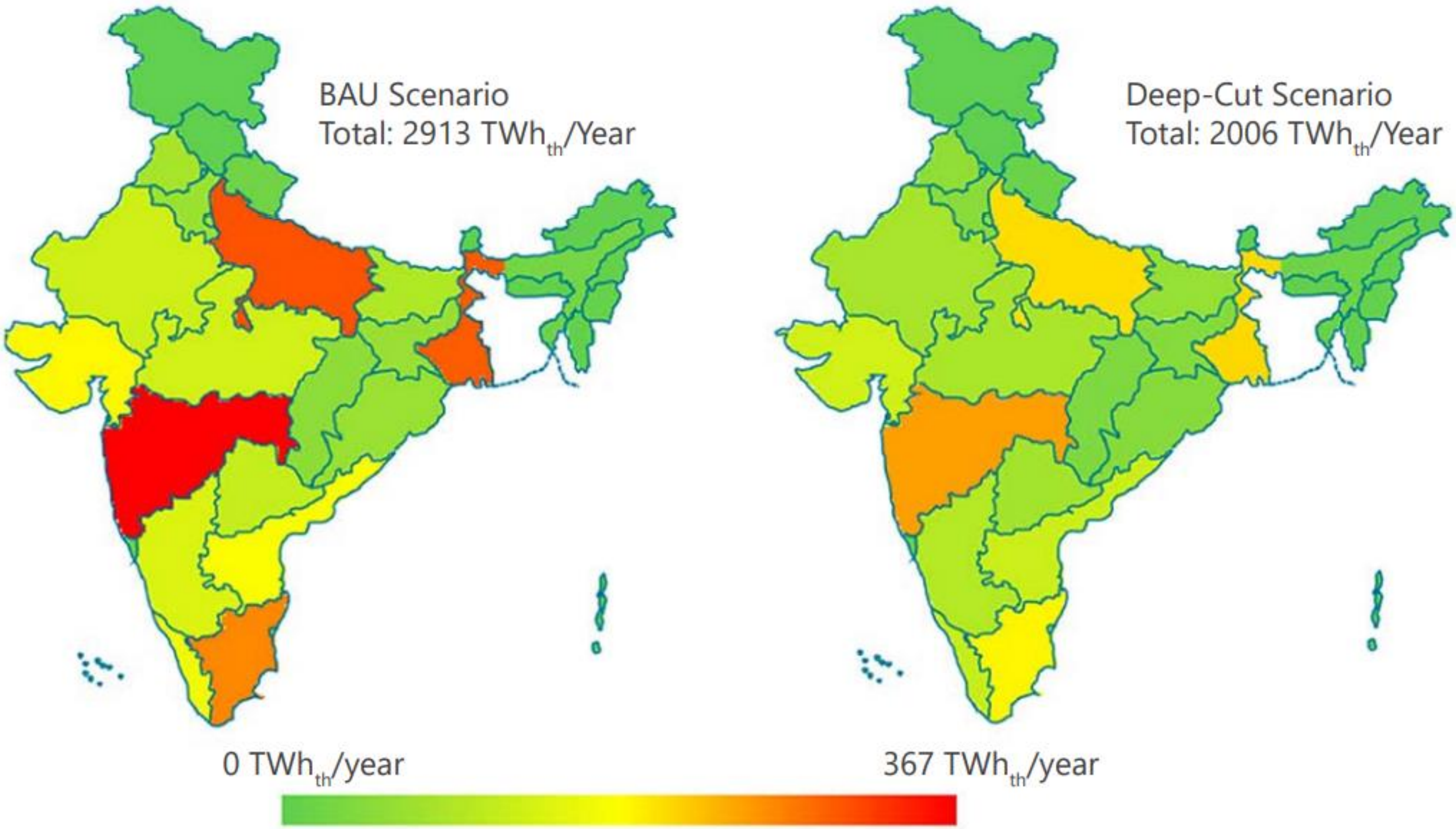
For buildings sector alone, Cooling demand will swell up to 11 times from the baseline over a span of mere two decades.

Up to a 30% reduction is possible in the Total Primary Energy Supply (TPES)

COOLING REQUIREMENT SCENARIOS

COOLING REQUIREMENT IN BAU Vs DEEP-CUT SCENARIOS

TWhth/ year is a unit to measure the amount of thermal energy that must be removed from the building to maintain thermal comfort for occupants



BAU – Business As Usual

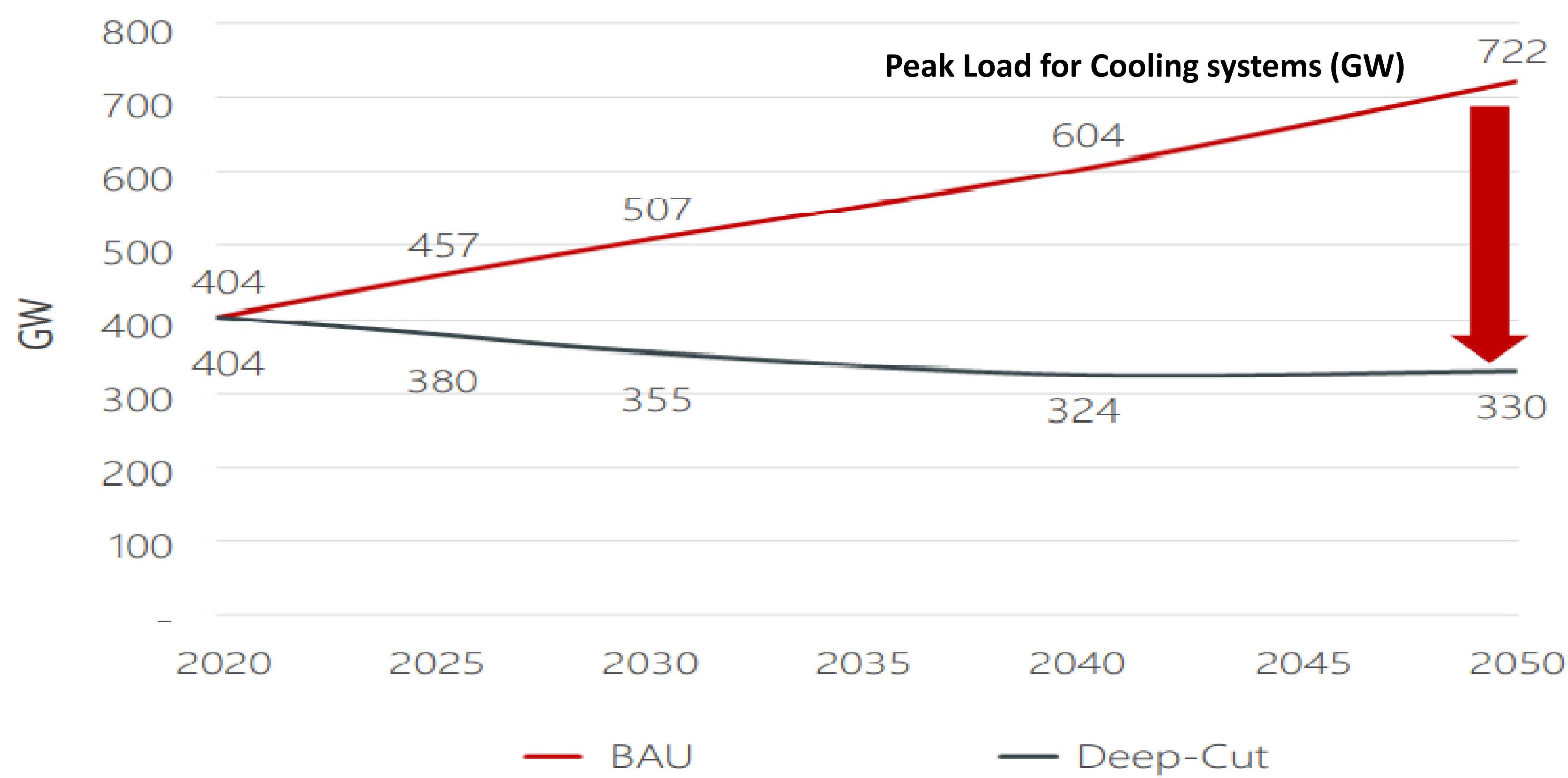
Deep Cut Scenario - The deep-cut scenario refers to a proposition of implementing aggressive measures such as improvements in building envelope technologies and cooling technologies to reduce the cooling demand

Urban residential space cooling energy requirement map of India, 2050

- the space cooling requirement in urban residential buildings was estimated to be 896 TWhth/year in 2020 in India
- The same demand races upwards of 2914 TWhth/year by 2050 in Business-As-Usual (BAU) scenario
- However, it is possible to redefine the curve of rising space cooling demand in urban residential India in a deep-cut scenarios to a 30% reduced value of 2006 TWhth/year

COOLING REQUIREMENT SCENARIOS

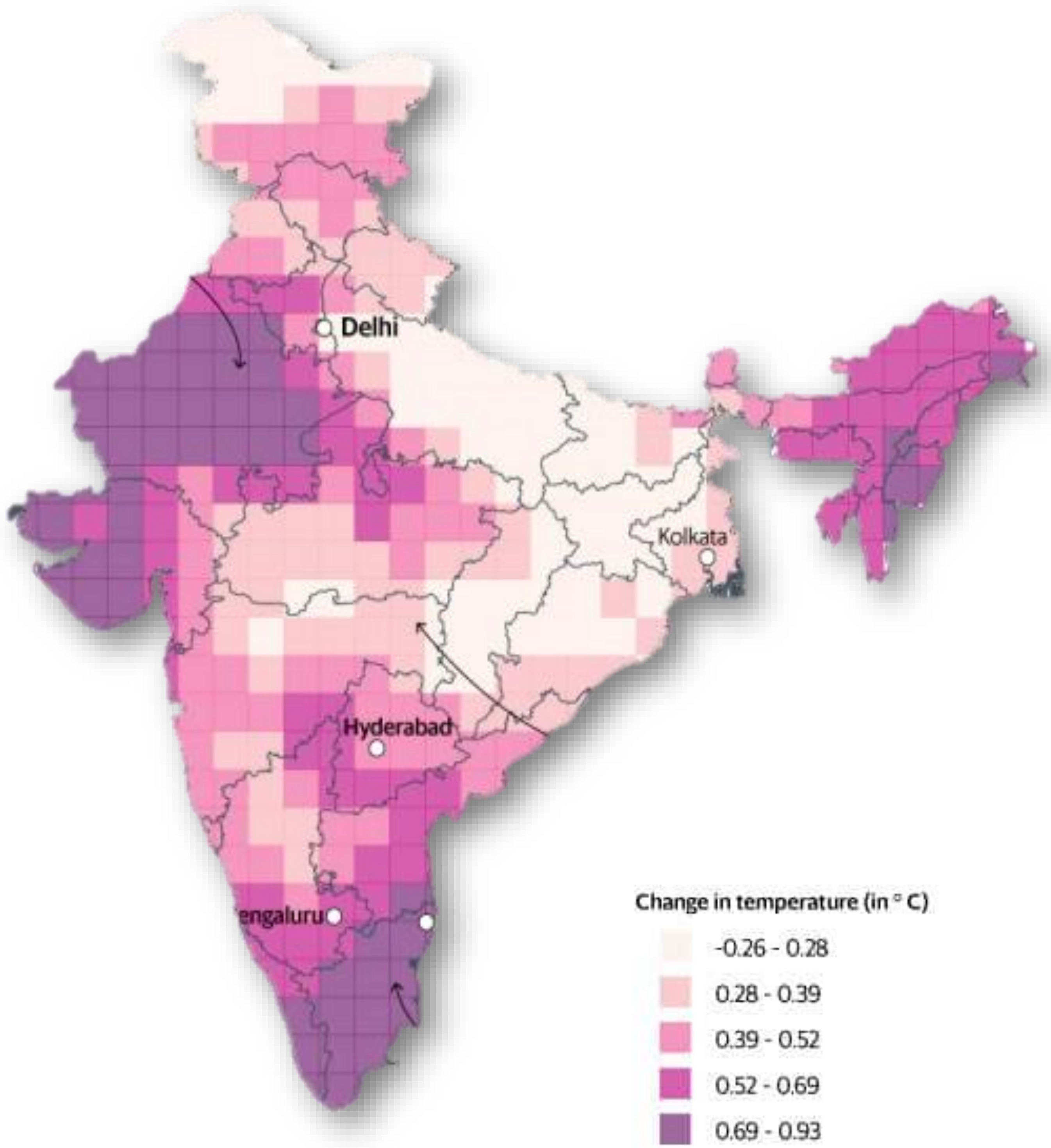
IMPACT OF BUILDING ENVELOPE

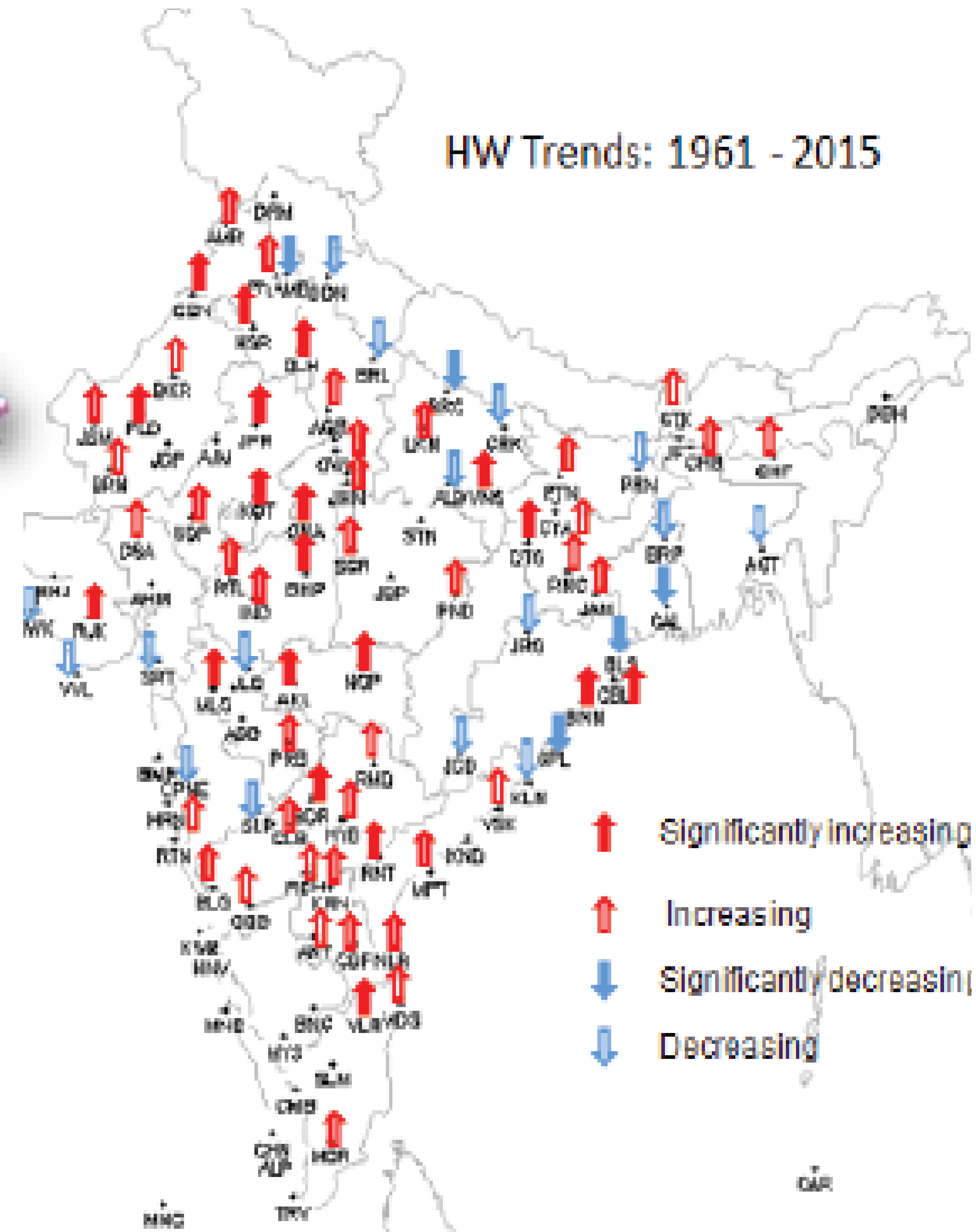


In India, buildings typically have a lifespan of 60-80 years

- ✓ scope of reducing energy impact of the systems is limited until it is time to retrofit with more efficient alternatives
- ✓ the envelope of a building undergoes retrofitting at much greater intervals. This translates into higher energy and environmental costs for decades if the envelope assembly is not developed to reduce cooling loads during the design phase of the project
- ✓ Therefore, it becomes crucial to ensure optimized building envelope design before construction as it presents two-fold benefit
- ✓ Optimizing building envelope as a standalone strategy with respect to its RETV value demonstrates opportunity to significantly reduce cooling demand by decreasing the discomfort degree hours (DDH)

NEED FOR THERMAL COMFORT AND HOW IT IMPACT US – QUALITATIVE AND QUANTITATIVE





India could lose the equivalent of 34 million jobs in 2030 due to global warming, says ILO

A lack of thermal comfort makes us feel **stressed**, annoyed, distracted, feel sleepy, tired and lacking concentration.

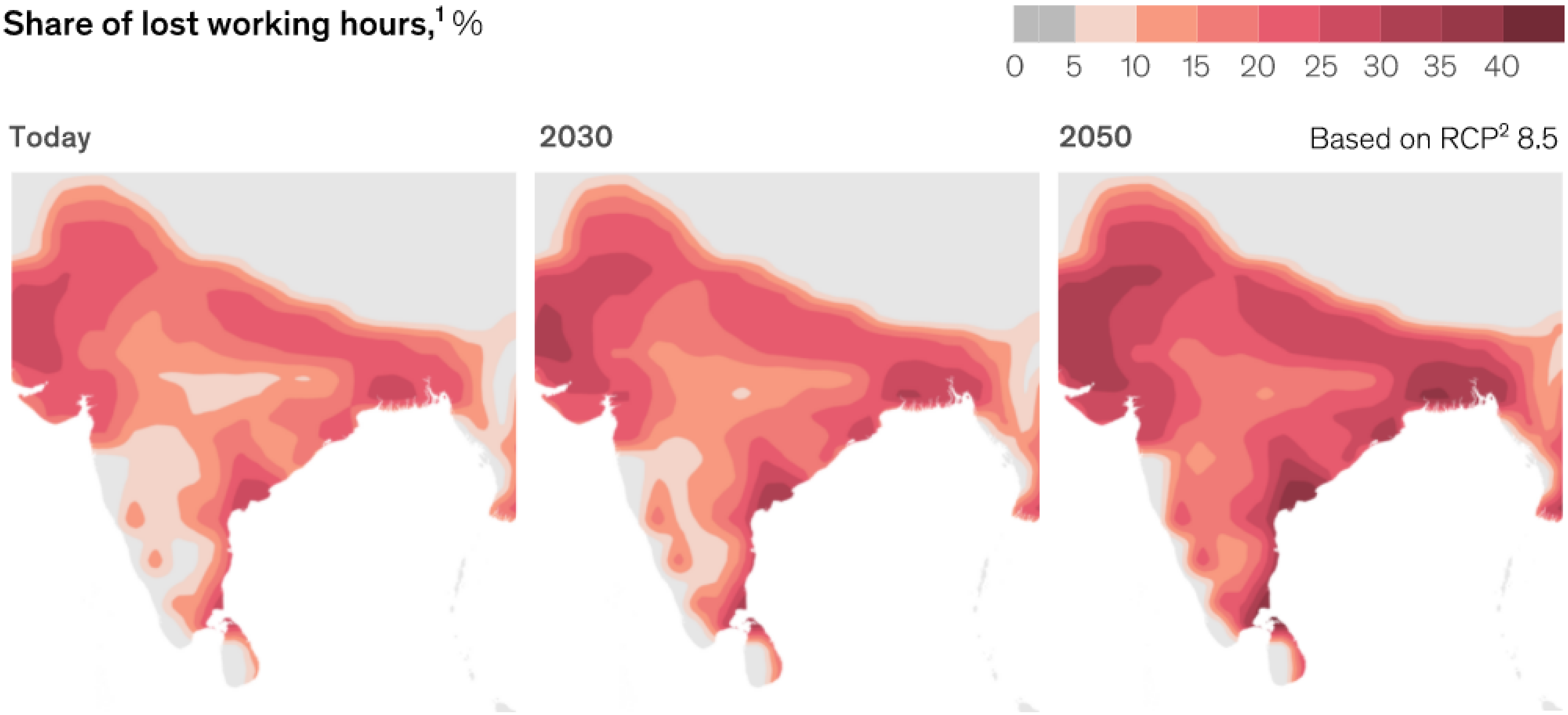
In turn, thermal comfort inevitably has an impact on well-being, productivity

Source Biannial update report India

NEED FOR THERMAL COMFORT AND HOW IT IMPACT US – QUALITATIVE AND QUANTITATIVE

The affected area and intensity of extreme heat and humidity is projected to increase, leading to a higher expected share of lost working hours in India.

Share of lost working hours,[1] %



Note: See the technical appendix to the report for why we chose Representative Concentration Pathway (RCP) 8.5. All projections are based on the RCP 8.5 and Coupled Model Intercomparison Project 5 multimodel ensemble. Corrected for heat-data bias. Following standard practice, future (ie, 2030 and 2050) states as the average climatic behavior over multidecade periods. Climate for today is the average between 1998 and 2017; for 2030, the average between 2021 and 2040; and for 2050, the average between 2041 and 2060.

[1]Lost working hours include loss in worker productivity as well as breaks, based on an average year that is an ensemble average of climate models.

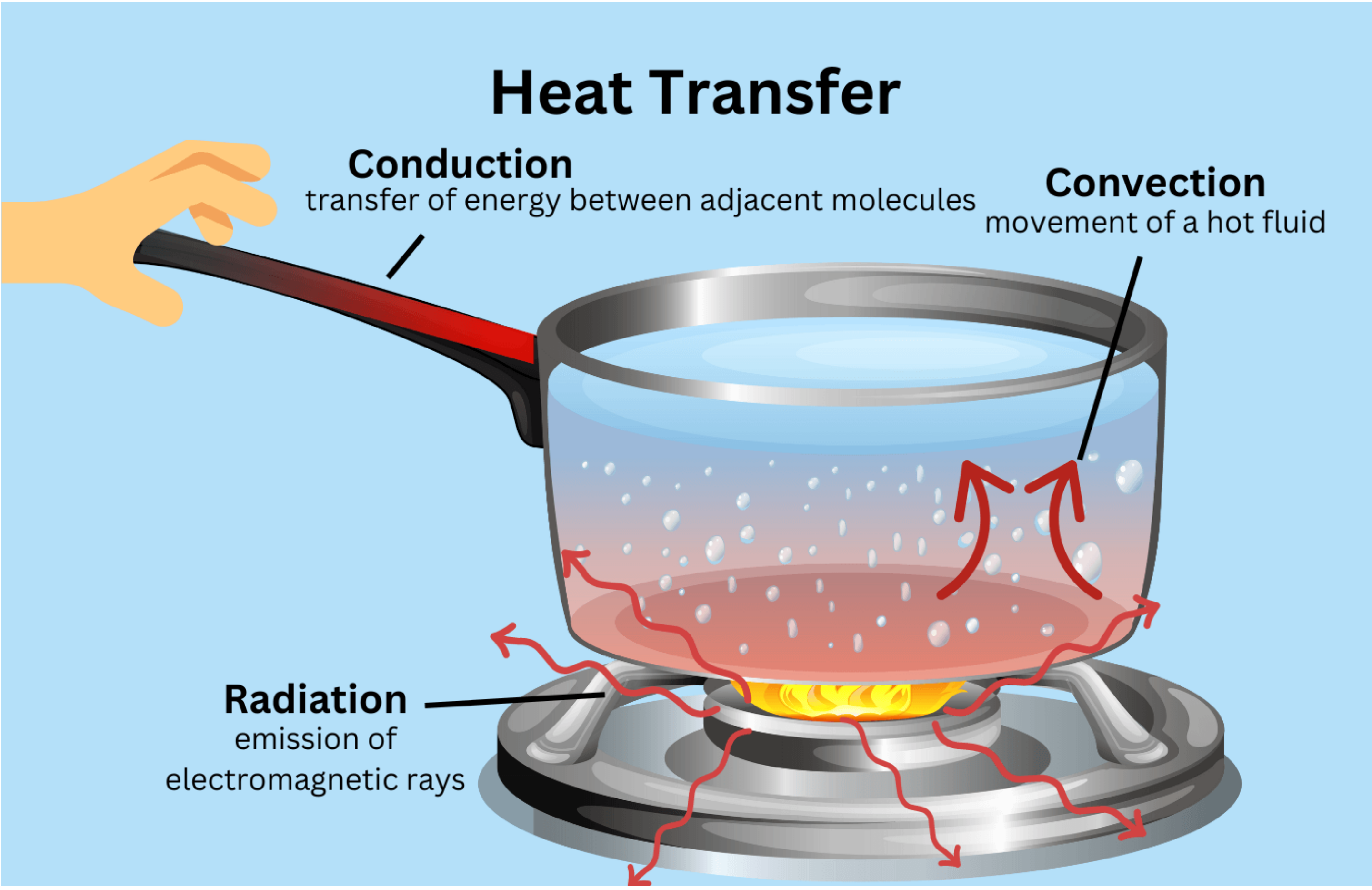
[2]Representative Concentration Pathway.

Source: Woods Hole Research Center

McKinsey & Company

- https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts

BUILDING PHYSICS AFFECTING THERMAL COMFORT



Modes Of Heat Transfer In Building Envelop

- ✓ Conduction
- ✓ Convection
- ✓ Radiation

Impact of design strategies on heat transfer through building envelope in various climates. Conduction Convection Radiation

	Conduction	Convection	Radiation
Geometry - Massing	HD	WH	All Climates
Orientation		WH	All Climates
External Surface to Building Volume Ratio	HD	WH	HD
Extent of Fenestration and Thermal Characteristics	HD	WH	All Climates
Internal Volume – Stack Ventilation	X	HD	X
Location of Fenestration – Pressure Driven Ventilation	X	WH	X

V. Low | Low | Neutral | High | V. High

WH: Warm Humid HD: Hot-Dry TE: Temperate CM: Composite CO: Cold

BUILDING PHYSICS AFFECTING THERMAL COMFORT

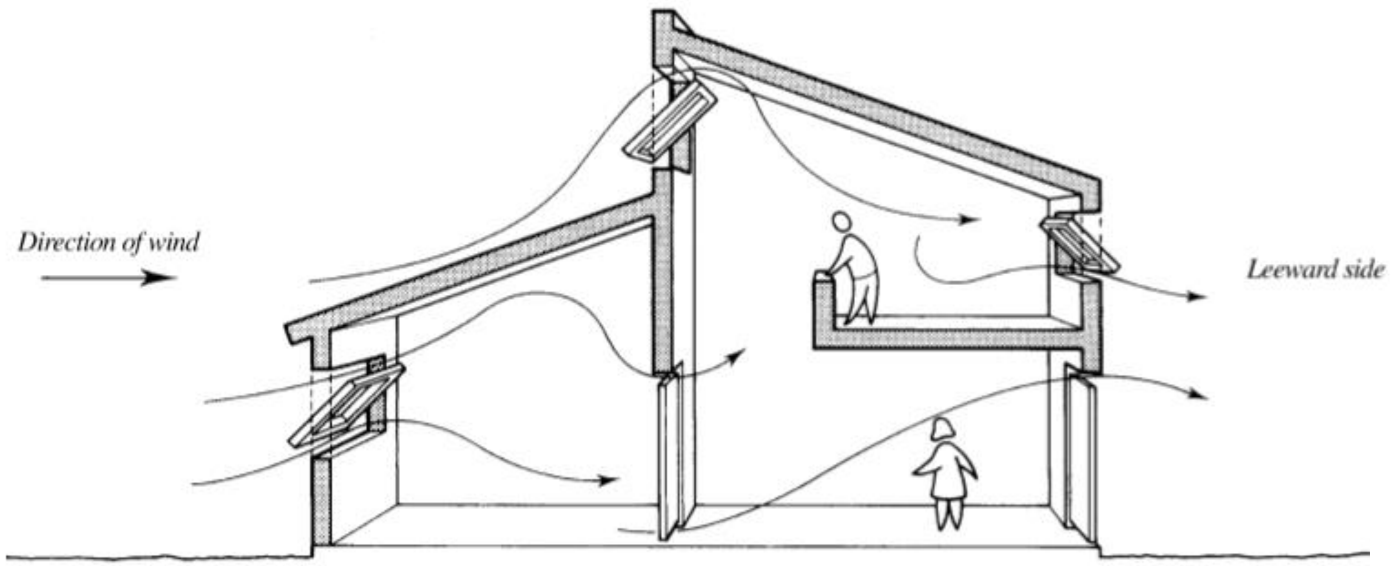
Building Envelope Relevant Metrices In Terms Of Heat Transfer

<table>
<tr><th>Parameter</th><th>Metric</th><th>Building envelope element</th></tr>
<tr><td>Thermal Conductivity</td><td>R value – U value</td><td rowspan="2">Walls
• Internal
• External</td></tr>
<tr><td>Thermal Mass</td><td>Specific heat capacity</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Thermal Conductivity (Frames and Glass)</td><td>R value – U value</td><td rowspan="3">Fenestration
• Windows
• Skylights
• Doors</td></tr>
<tr><td>Solar Gains</td><td>Solar Heat Gain Coefficient</td></tr>
<tr><td>Visible Light Transmittance</td><td>VLT</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Thermal Conductivity</td><td>R value – U value</td><td rowspan="2">Roofs
Floors
Foundations</td></tr>
<tr><td>Thermal Emissivity</td><td>Solar Reflectance</td></tr>
</table>

FUNDAMENTALS OF THERMAL COMFORT

Building operation modes

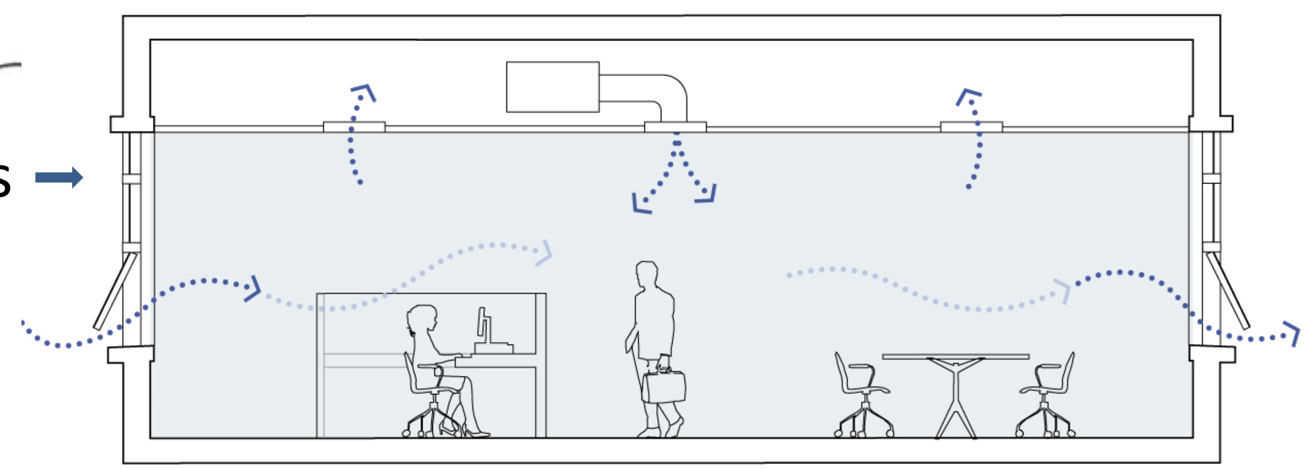
- ✓ Naturally Ventilated Buildings
- ✓ Mixed Mode Buildings
- ✓ Air-Conditioned Buildings

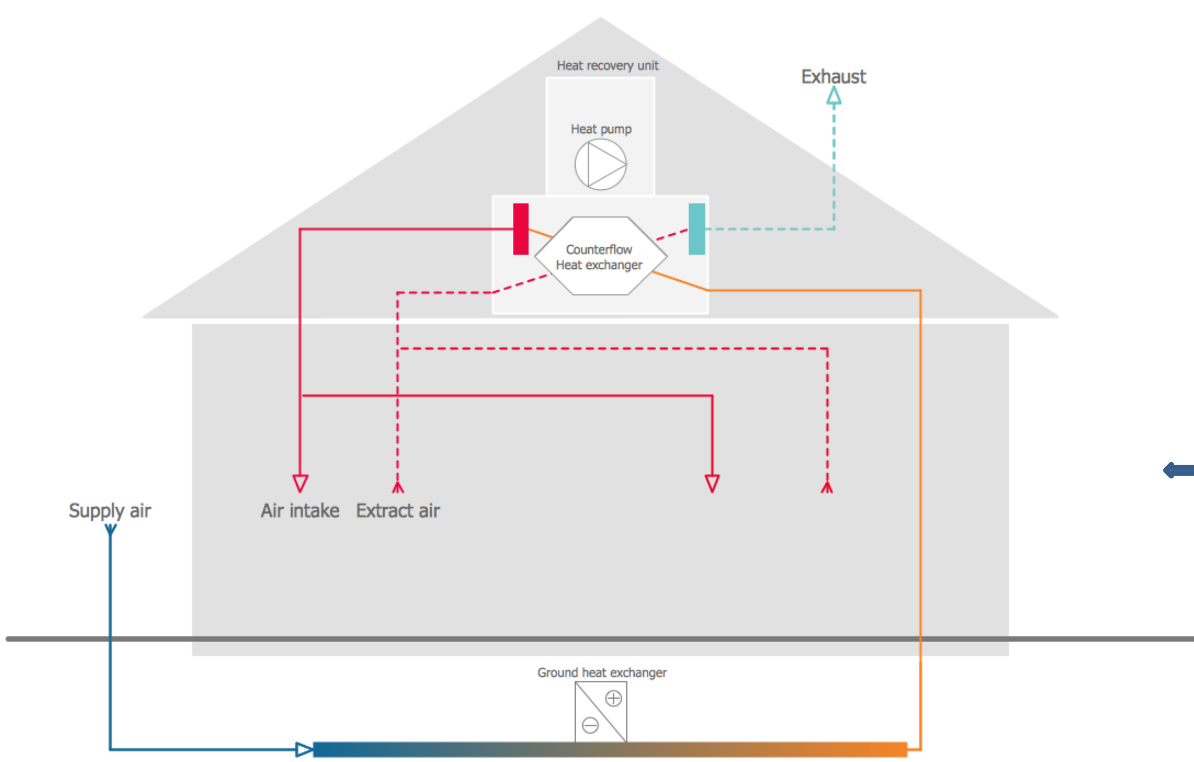


Natural ventilation.

← Naturally Ventilated Buildings

Mixed Mode Buildings →

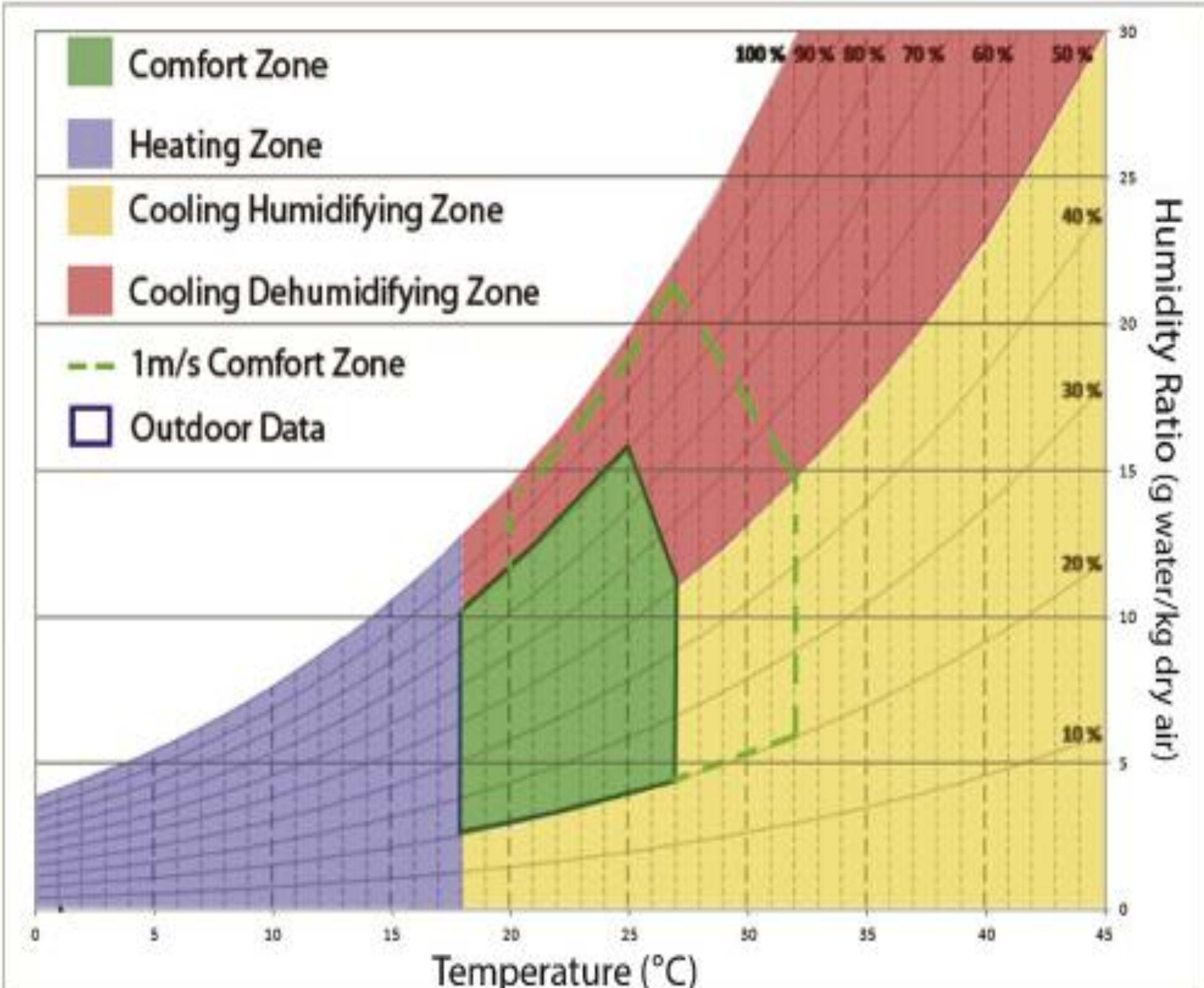




← Air-Conditioned Buildings

THERMAL COMFORT METRICS

Thermal comfort indices describe how the human body experiences atmospheric conditions, specifically air temperature, humidity, wind and radiation.



Direct Indices

- ✓ Dry Bulb Temperature
- ✓ Dew Point Temperature
- ✓ Wet Bulb Temperature
- ✓ Relative Humidity
- ✓ Air Movement

Rationally Derived Indices

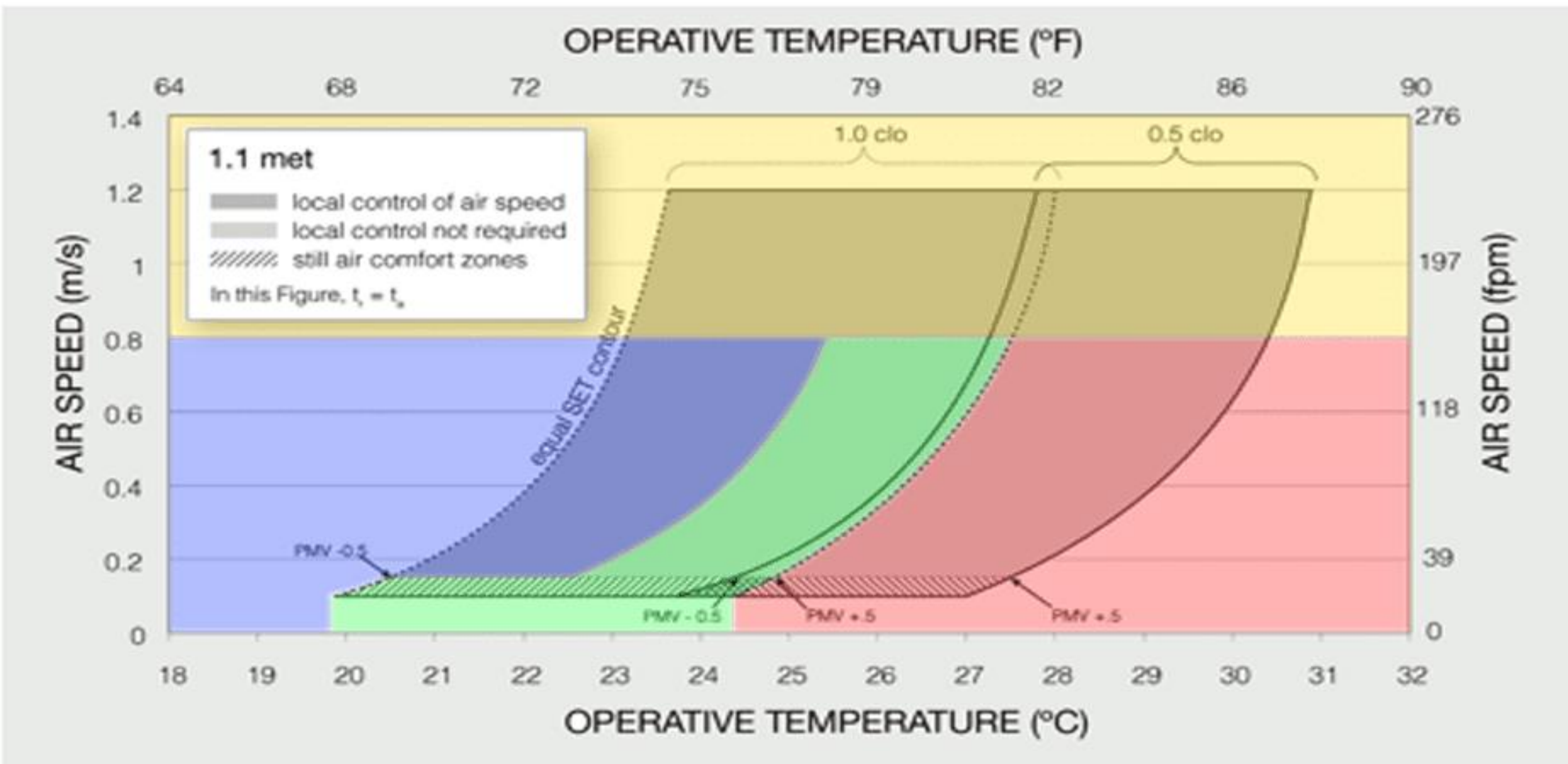
- ✓ Mean Radiant temp
- ✓ Operative Temperature
- ✓ Heat Stress
- ✓ Thermal Stress

THERMAL COMFORT METRICS

Operative temperature is defined as a uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non uniform environment

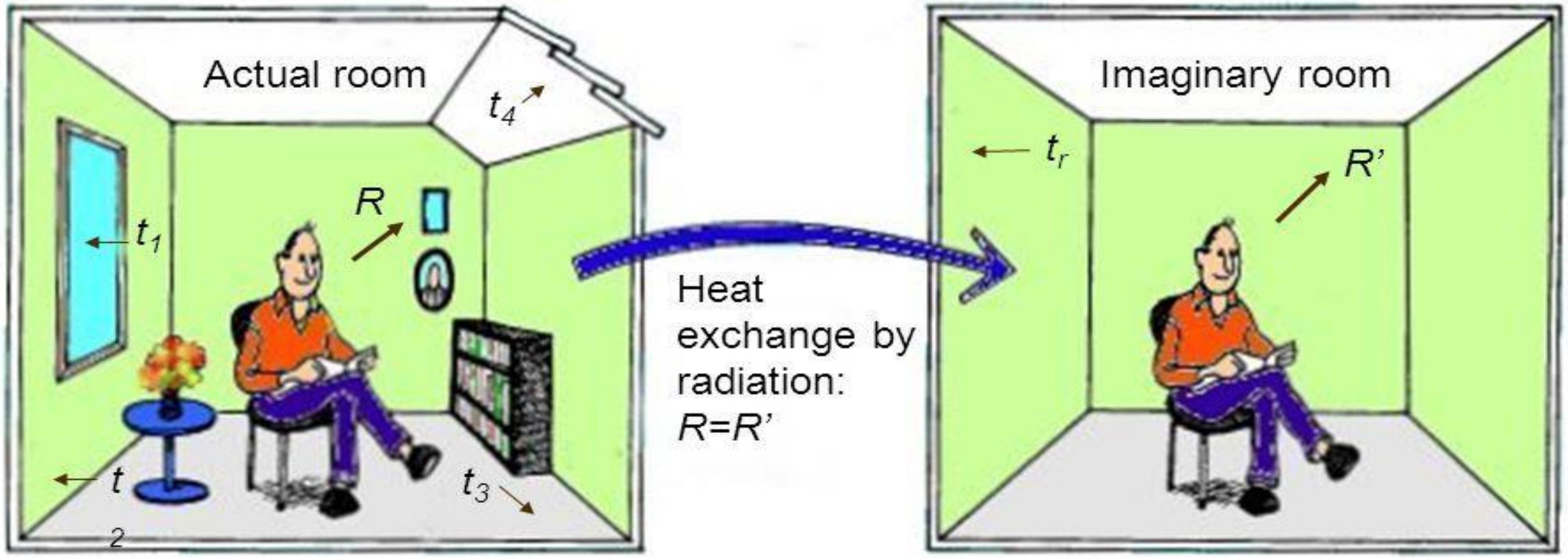
Naturally Ventilated Buildings

Indoor Operative Temperature = (0.54 x outdoor temperature) + 12.83



Comfortable | Too Hot | Too Cold | Too Drafty

Mean Radiant Temperature



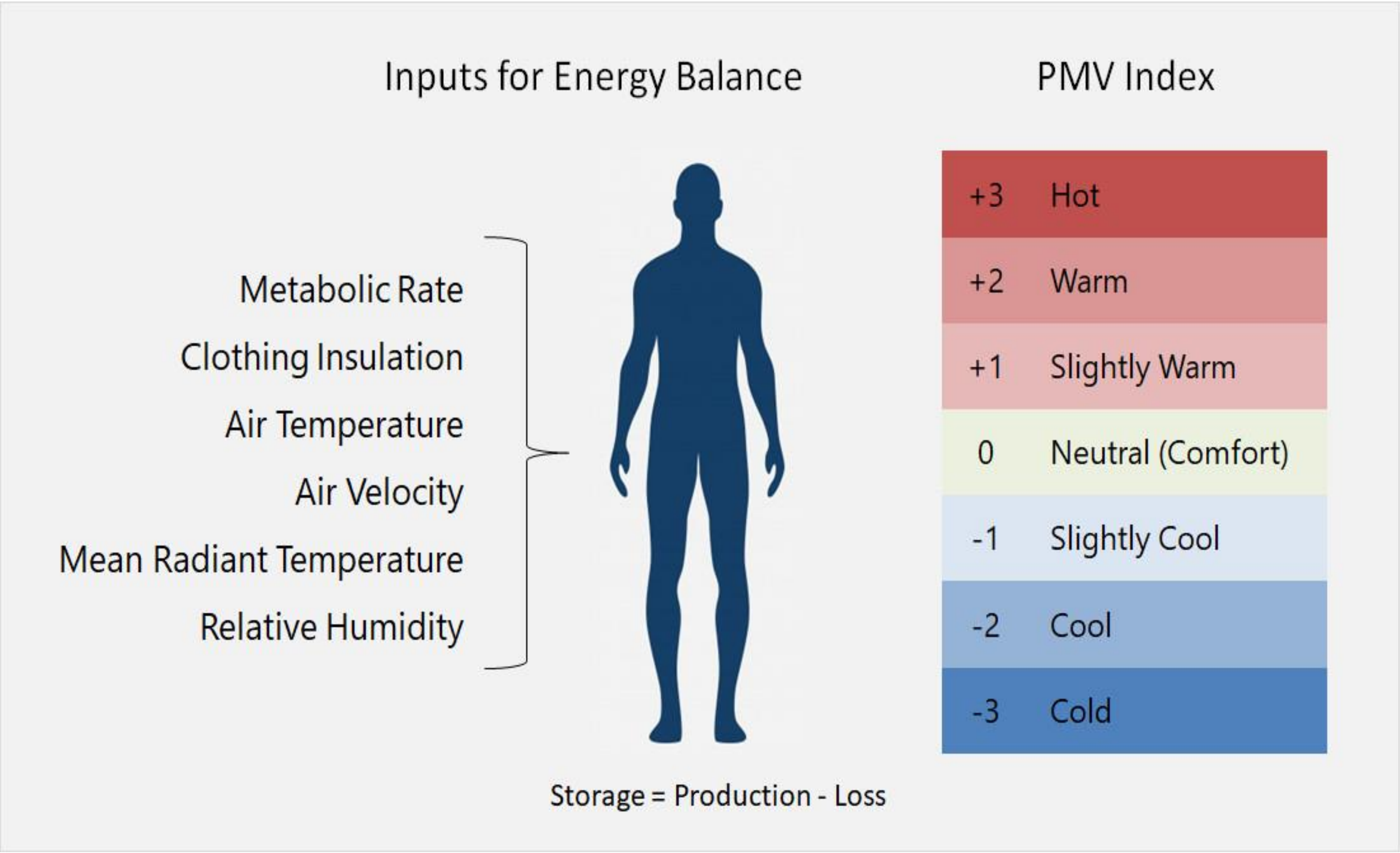
- The Mean Radiant Temperature is that uniform temperature of an imaginary black enclosure resulting in same heat loss by radiation from the person, as the actual enclosure.
- Measuring all surface temperatures and calculation of angle factors is time consuming. Therefore use of Mean Radiant Temperature is avoided when possible.

$$MRT = T_1 F_{p-1} + T_2 F_{p-2} + \ldots + T_n F_{p-n}$$

THERMAL COMFORT METRICS

THE PREDICTED MEAN VOTE (PMV)

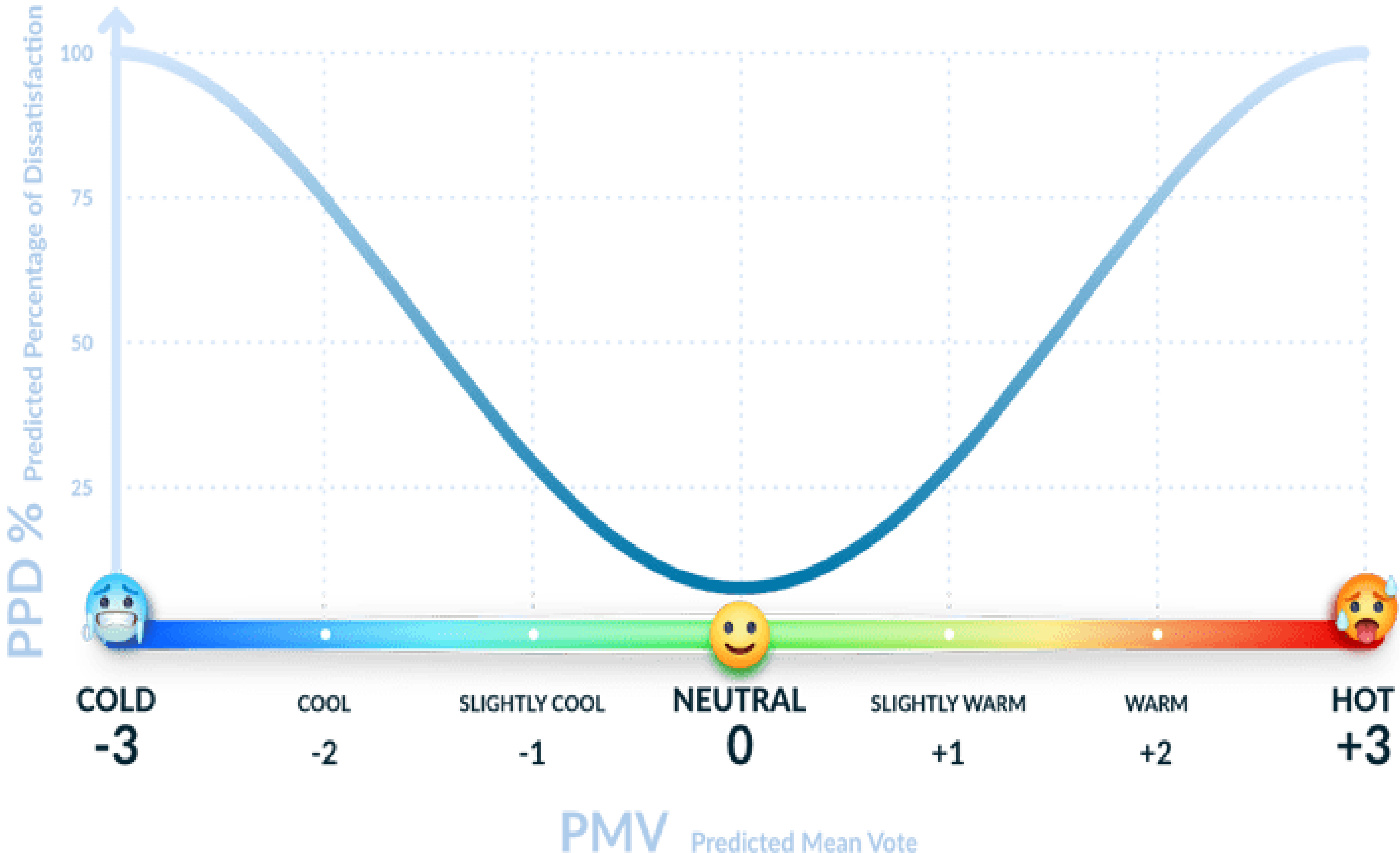
- ✓ PMV refers to a thermal scale that runs from Cold (-3) to Hot (+3).
- ✓ PMV range for thermal comfort = **-0.5 and +0.5** for an interior space.**(ASHARE 55)**



THERMAL COMFORT METRICS

PREDICTED PERCENTAGE OF DISCOMFORT

PPD, or index that establishes a quantitative prediction of the percentage of thermally dissatisfied occupants (i.e. too warm or too cold)



THERMAL COMFORT & AFFORDABLE HOUSING

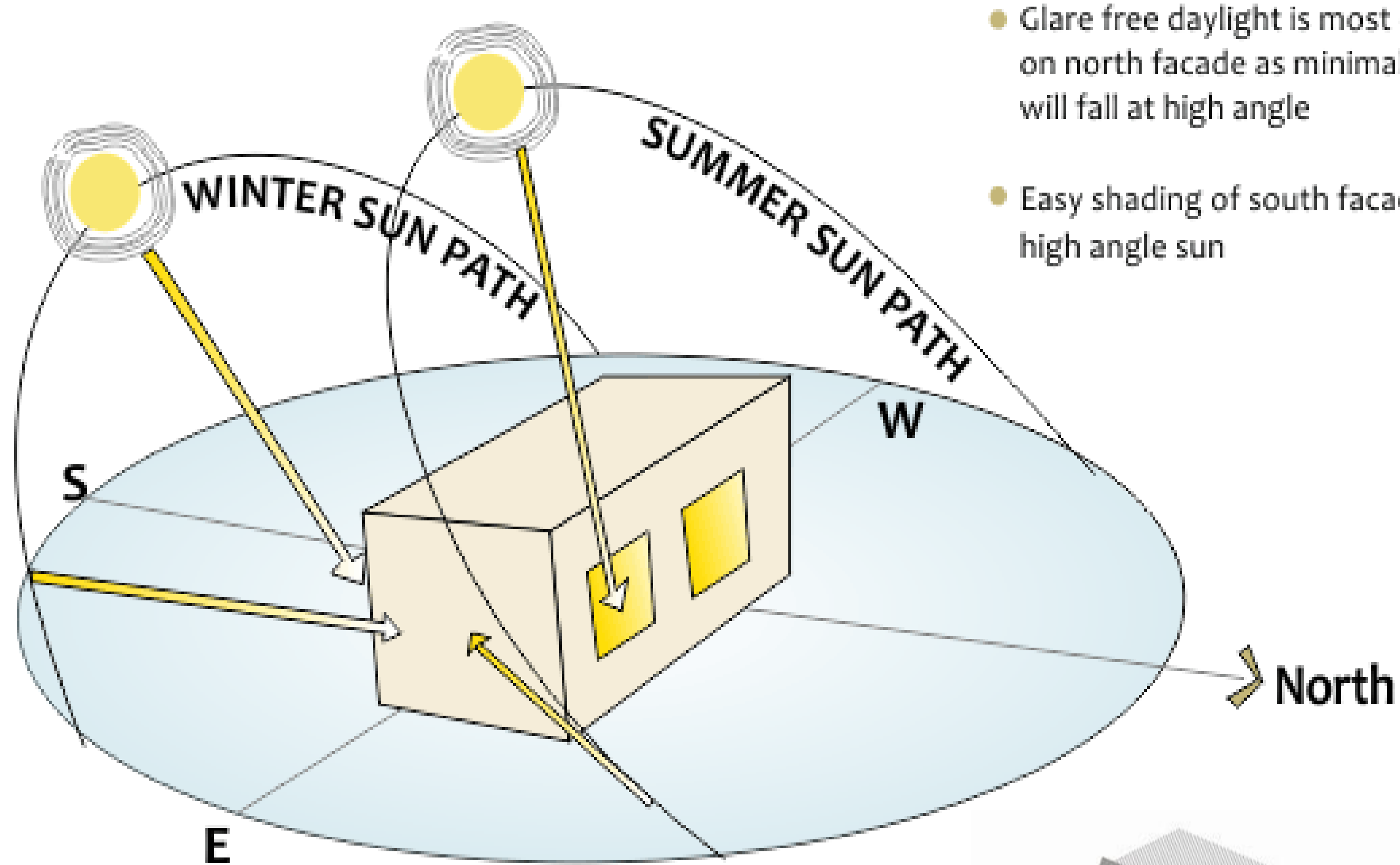
Details mentioned under this section is taken from Handbook –
"Innovative Construction Technologies & Thermal Comfort in Affordable Housing"
More details about the topics can be taken from the document. It is freely available at
https://ghtc-india.gov.in/Content/pdf/rachna/Rachna_Handbook.pdf

AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

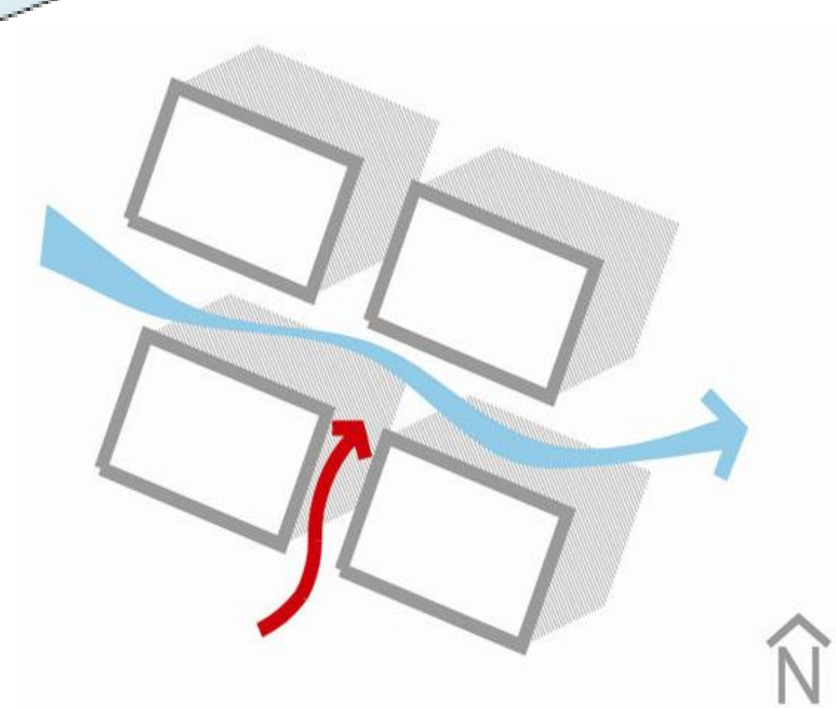
ORIENTATION OF BUILDING BLOCKS:

SUMMER SUN
- Sun path at a high angle sun, north to E-W axis
- Glare free daylight is most easily available on north facade as minimal solar radiation will fall at high angle
- Easy shading of south facade from high angle sun

WINTER SUN
- Sun path at a low angle , south to E-W axis
- Solar radiation will penetrate south facing facades at a low angle during winter



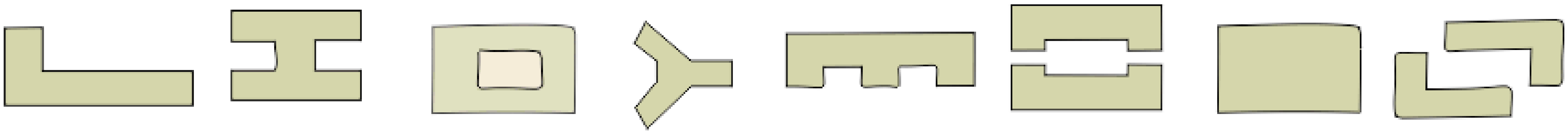
East and west facades continue to receive uniform, strong solar radiation at a low angle through the year.



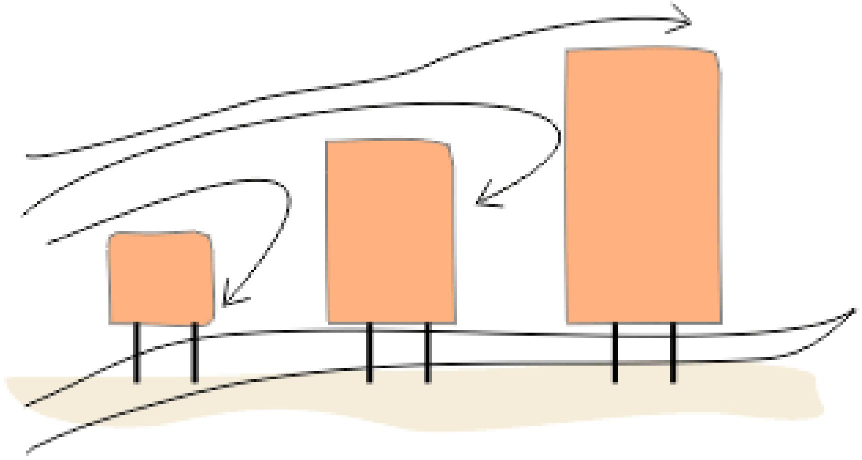
Source: NZEB

AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

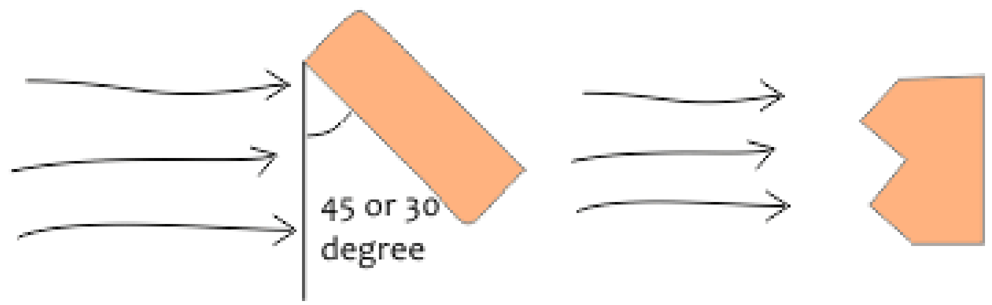
ORIENTATION OF BUILDING BLOCKS



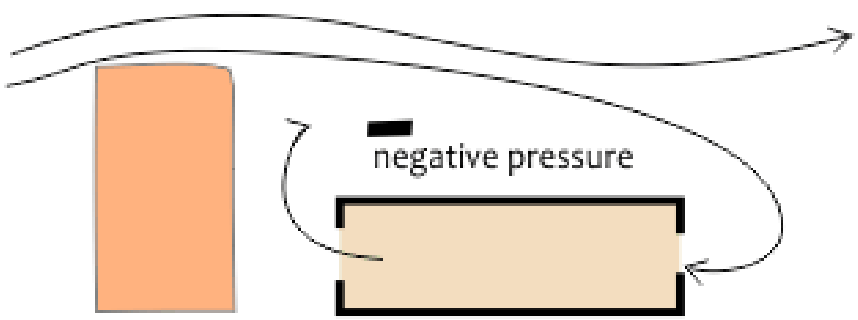
Orient longer facades along the north. This will provide glare free light in summer from north without shading and winter sun penetration from the south.



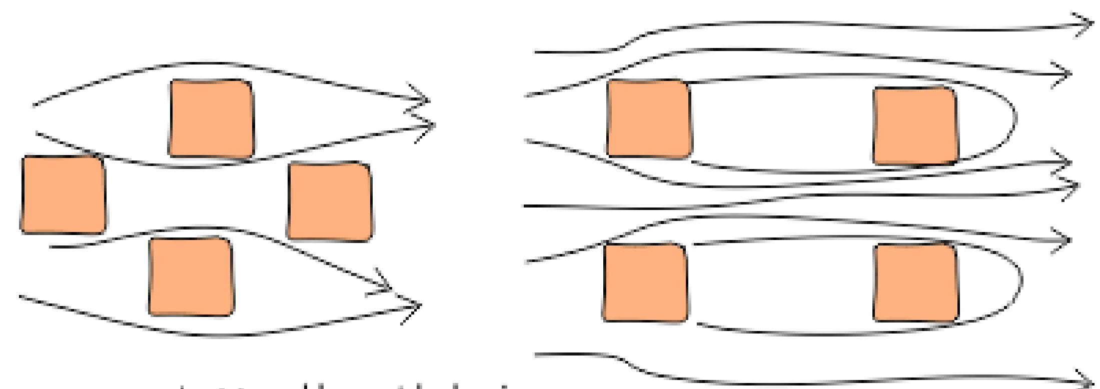
if a site has multiple buildings, they should be arranged in ascending order of their heights and be built on stilts to allow ventilation



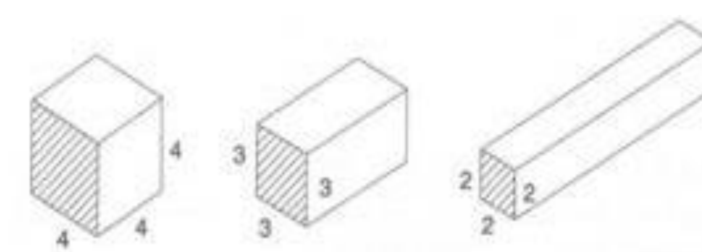
Place buildings at a 30 or 45 degree angle to the direction of wind for enhanced ventilation. Form can be staggered in the wind facing direction also to achieve the same result.



Taller forms in the wind direction of prevailing wind can alter the wind movement pattern for low lying buildings behind them



staggered layout helps in accentuating wind move



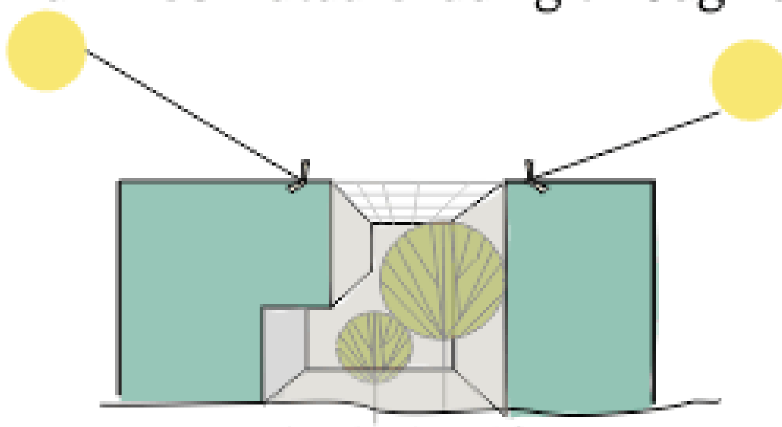
Solid shape type	Surface area (S)	Volume (V)	Ratio (S/V)
a	96	64	1.5
b	103.2	64	1.61
c	136	64	2.13

Source: NZEB

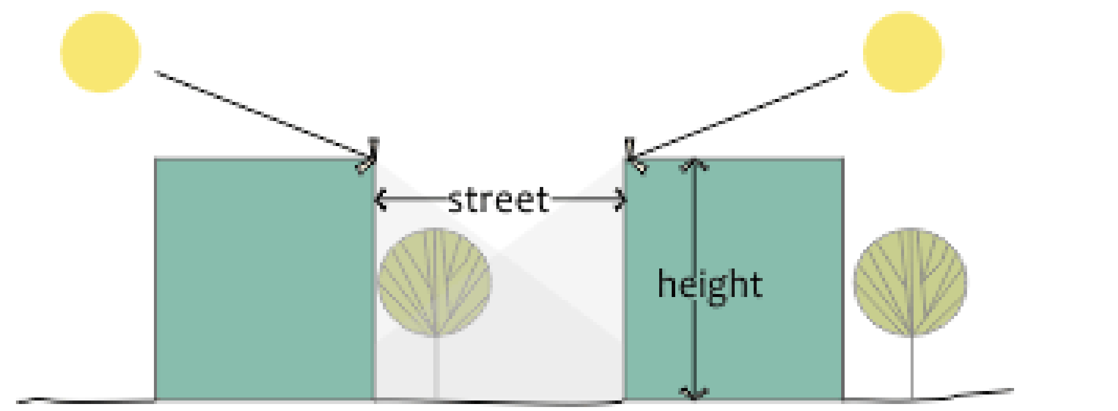
AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

FORM OF BUILDING BLOCKS:

1 Maximise mutual shading through built forms

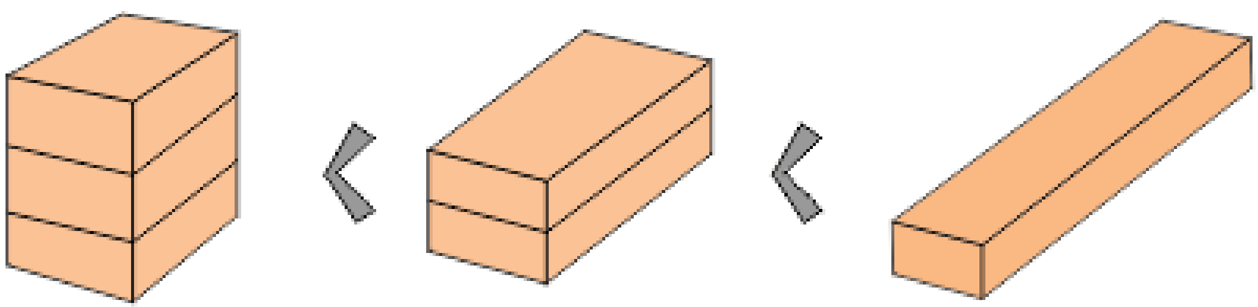


closely placed forms



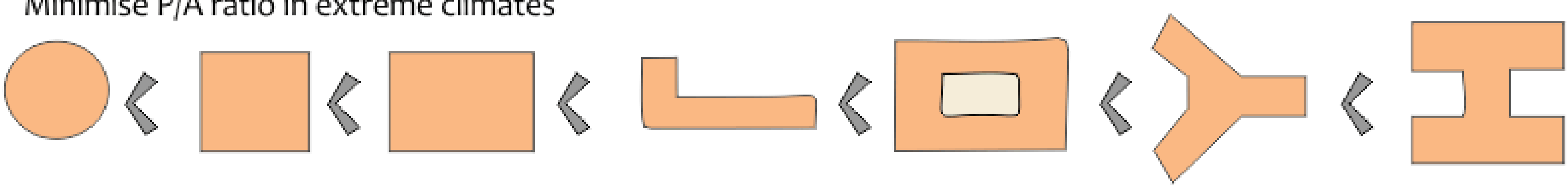
narrow streets - keep building height to street width ratio minimal

2 Minimise S/V ratio in extreme climates



increase compactness by reducing surface area for the same volume

3 Minimise P/A ratio in extreme climates



AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

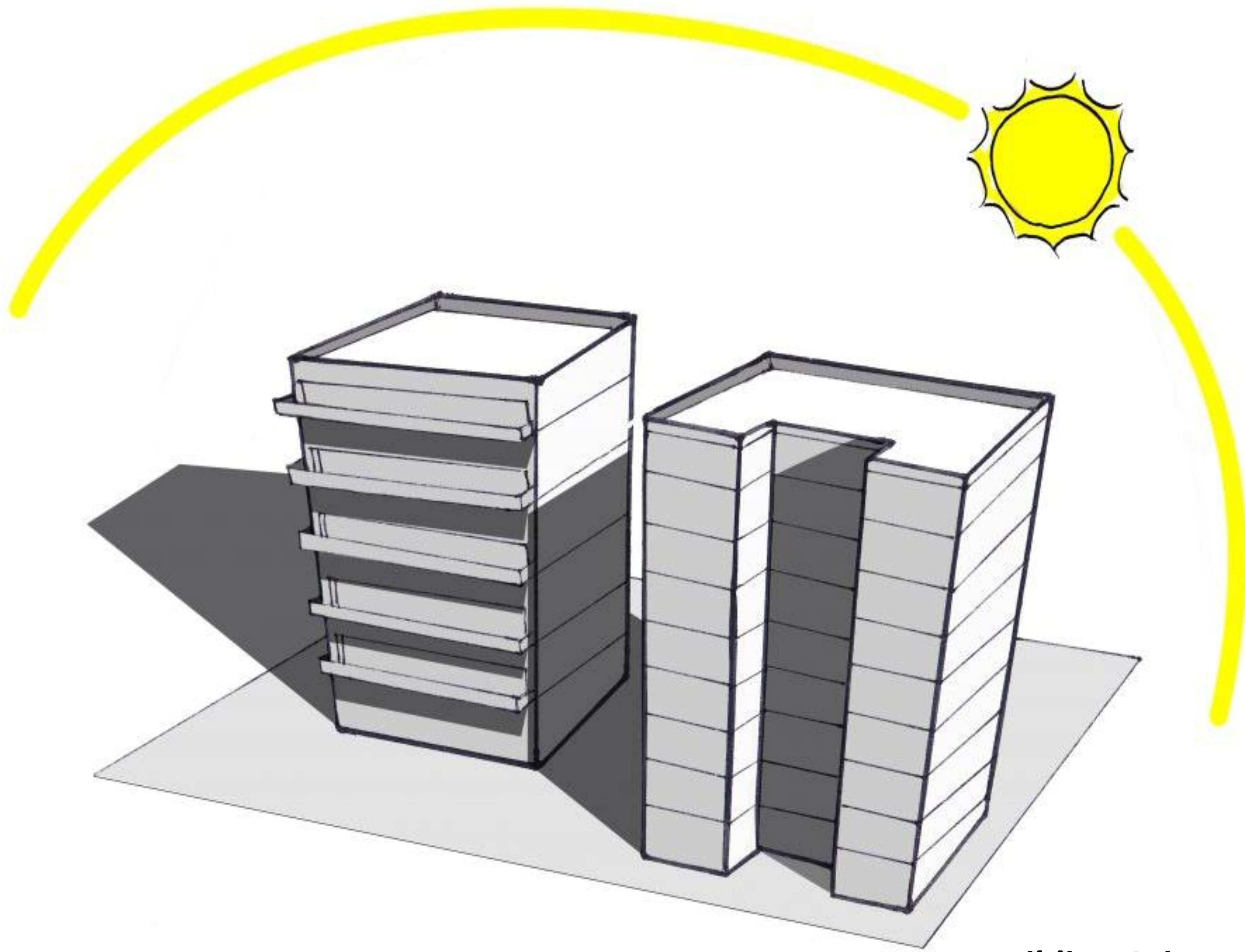
UDAAN, low cost mass housing project at Mumbai

- Maximum daylight
- Proper ventilation

The Orientation can alter the thermal comfort up to – 9 % as the area of the wind facing wall varies with the orientation

Source: NZEB

AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES



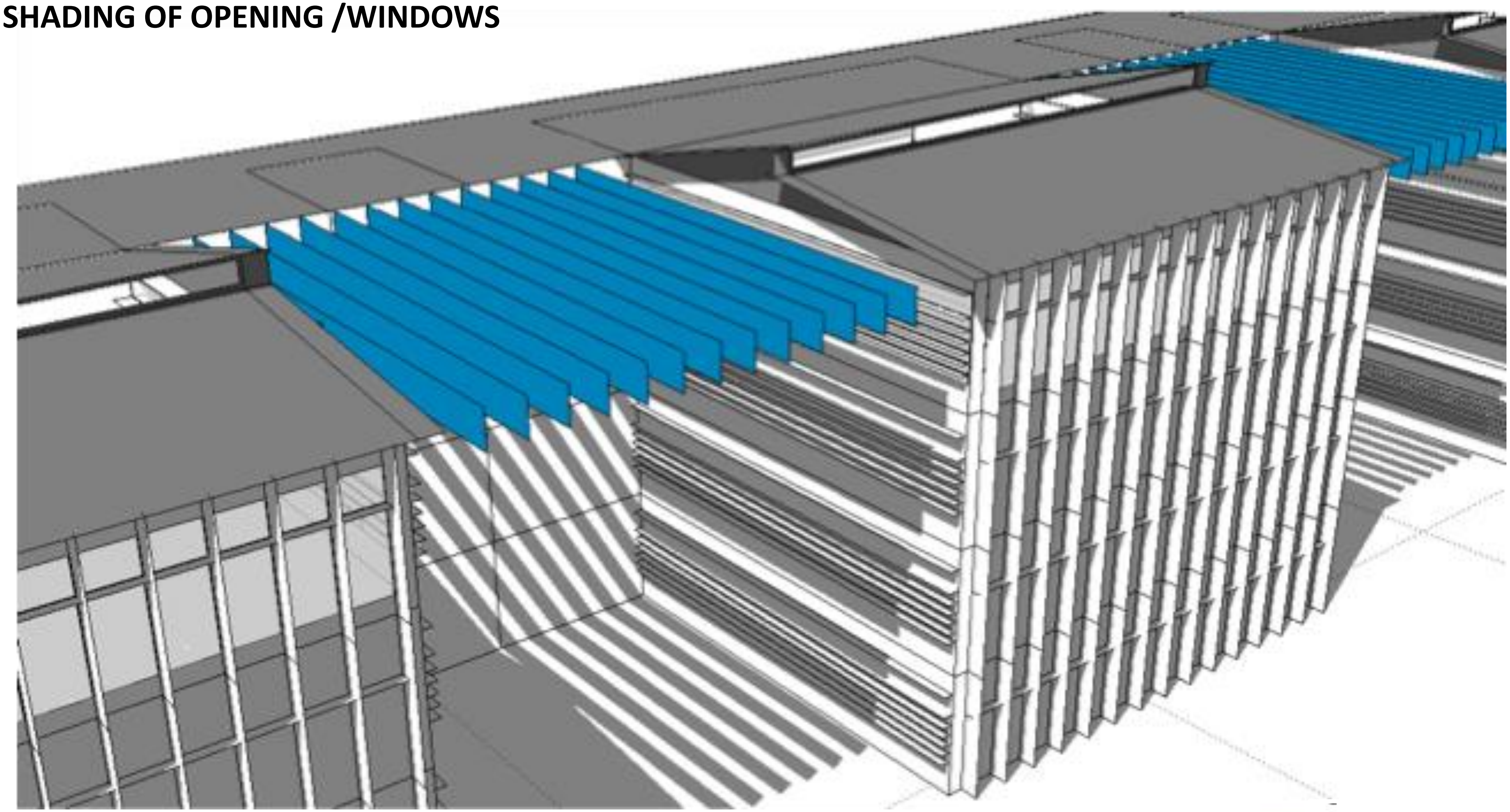
Building Orientation and Form

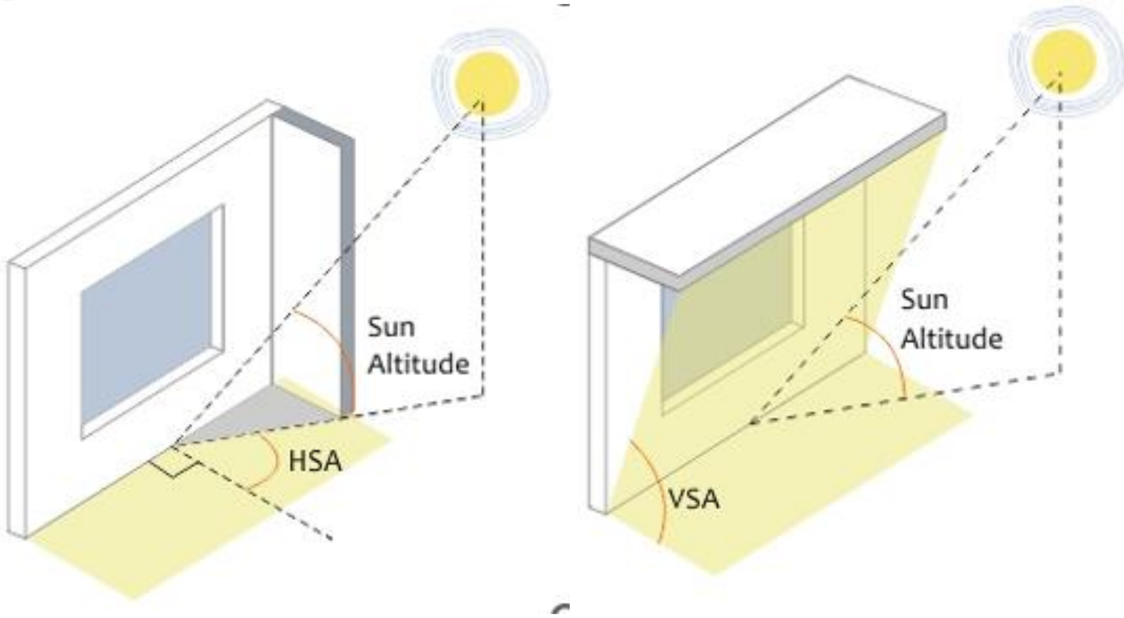
•In extreme climatic condition *compact planning* is more preferable
•Minimising the perimeter to area ratio of building form, building performs better in terms of thermal comfort
•*Compact forms* gain less heat at day time and loss heat during night time

Minimizing the surface area to volume ratio minimizes heat transfer.

AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

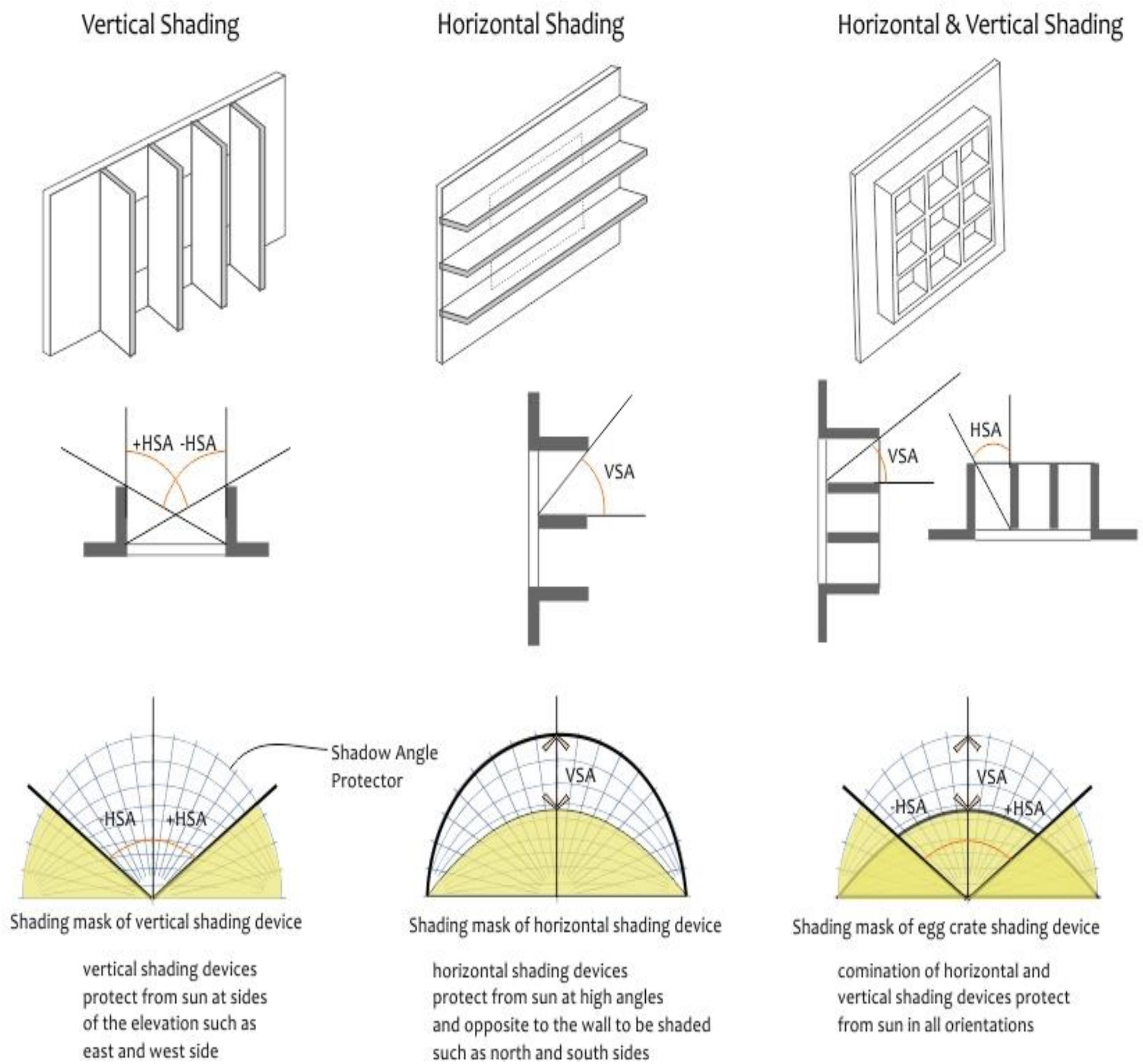
SHADING OF OPENING /WINDOWS





AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

SHADING OF OPENING /WINDOWS

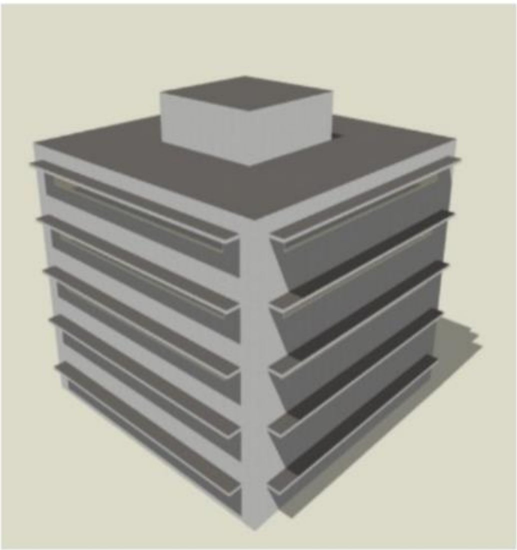


Solar shading devices helps

- Diffusing light
- Control heat
- Improving daylight

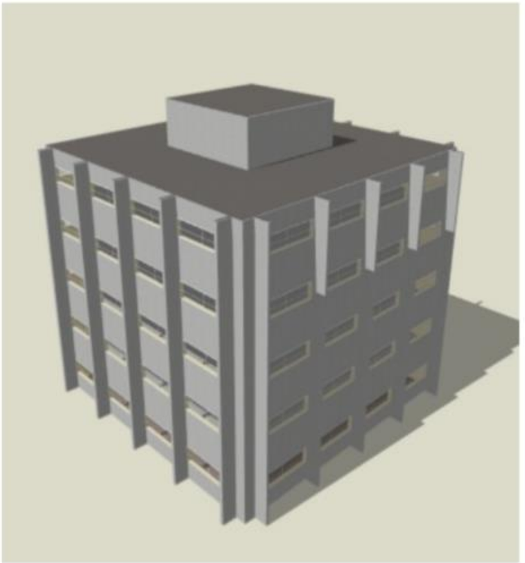
Comfortable living

Horizontal BIPV Shading Devices Cases



H-SD-0 (no inclination)
H-SD-30 (inclined at 30°)
H-SD-45 (inclined at 45°)
H-SD-60 (inclined at 60°)

Vertical BIPV Shading Devices Cases



V-SD-0 (no inclination)
V-SD-30 (inclined at 30°)
V-SD-45 (inclined at 45°)
V-SD-60 (inclined at 60°)

Use of shading device at Palace of Assembly, Chandigarh

Source: NZEB

WWR (Window-to-wall ratio)

Visible Light Transmittance (VLT)

VLT of non-opaque building envelope indicates the potential of using daylight. Ensuring minimum VLT helps in improving day lighting, thereby reducing the energy required for artificial lighting

WWR = $A_{(Non - Opaque)} / A_{(envelope)}$

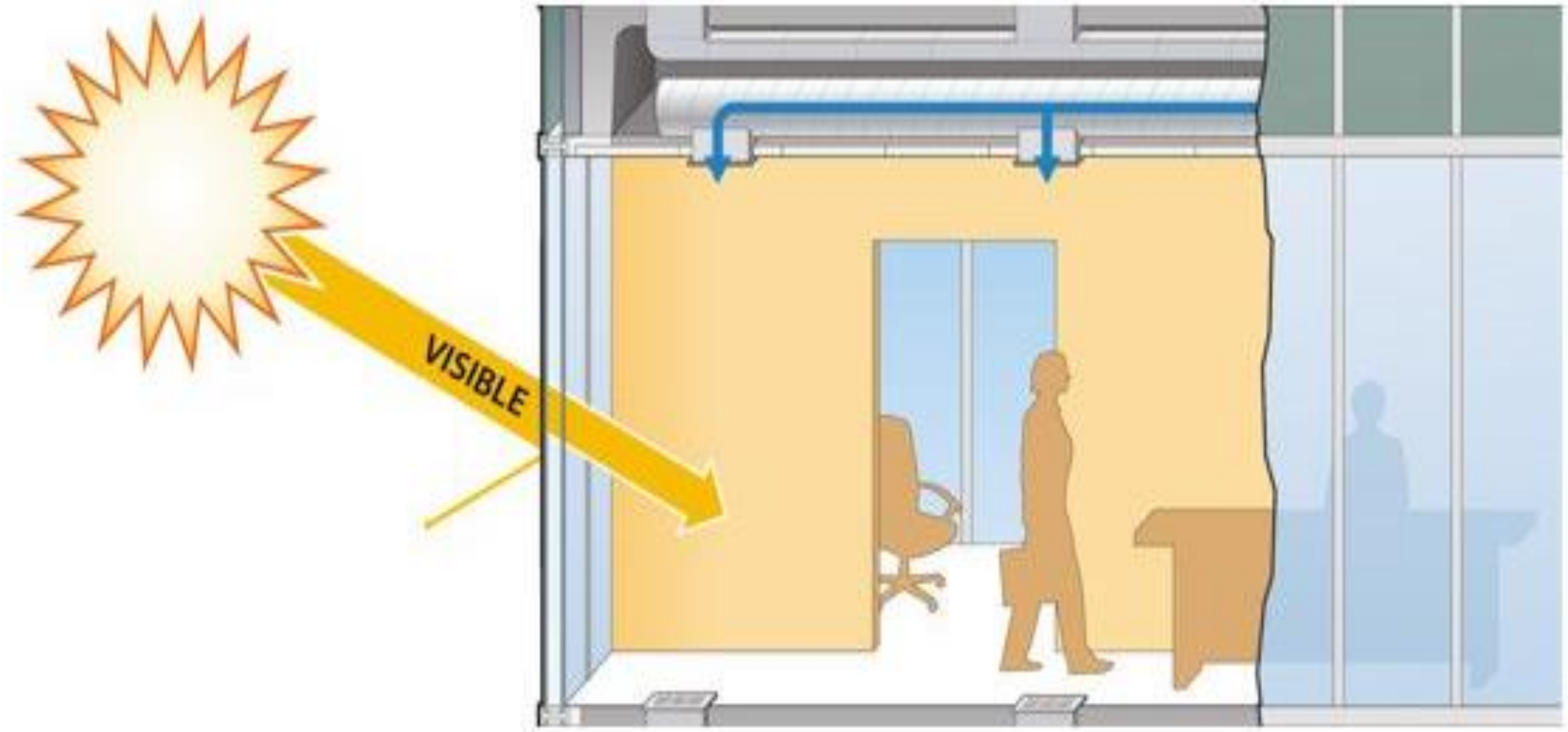


TABLE 2 Minimum visible light tra

Window-to-wall ratio (WWR)[16]	Minimum VLT [17]
0–0.30	0.27
0.31–0.40	0.20
0.41–0.50	0.16
0.51–0.60	0.13
0.61–0.70	0.11

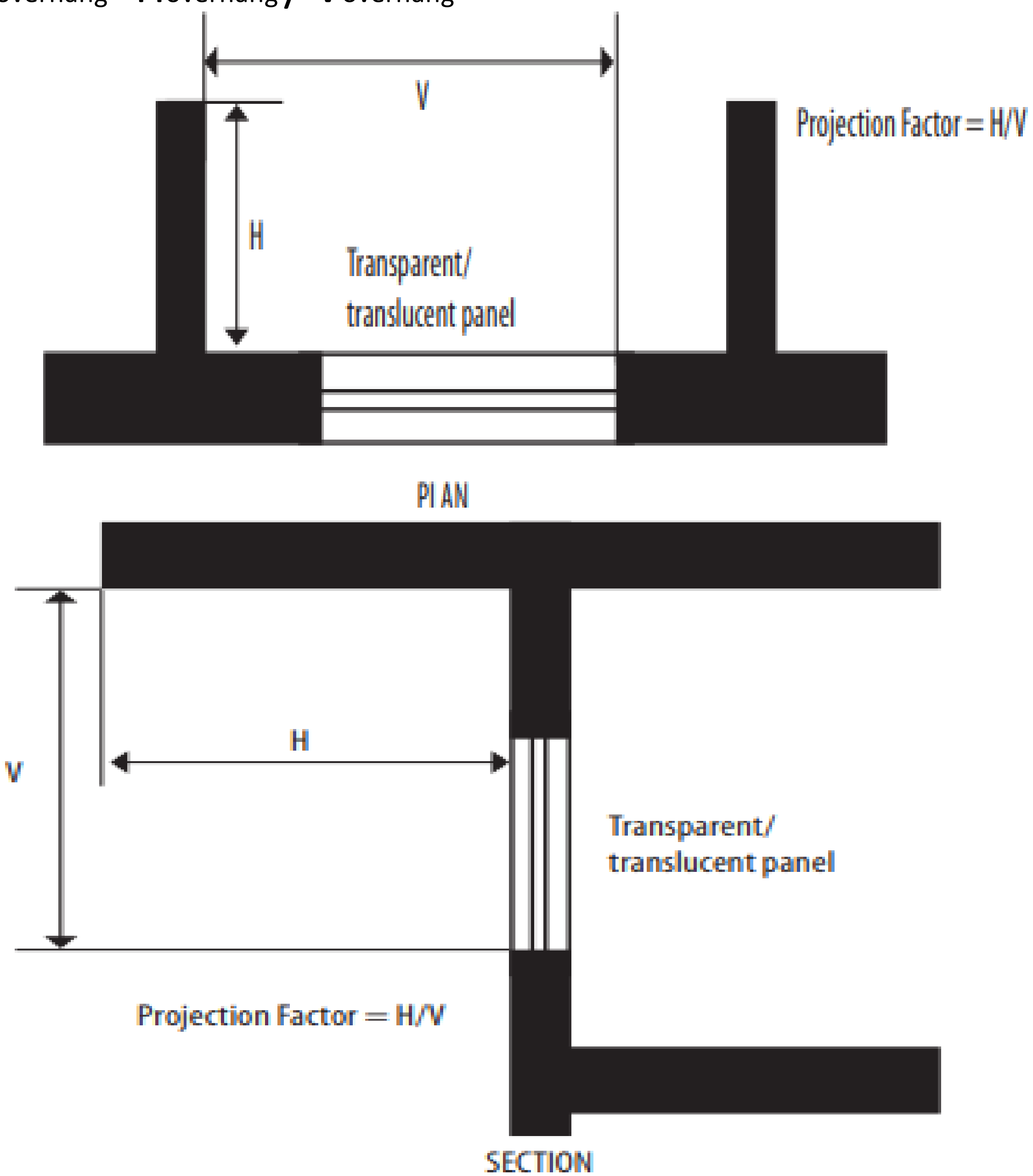
SOURCE Bureau of Indian Standards (BIS). 2016. National Building Code of India 2016. New Delhi: BIS.

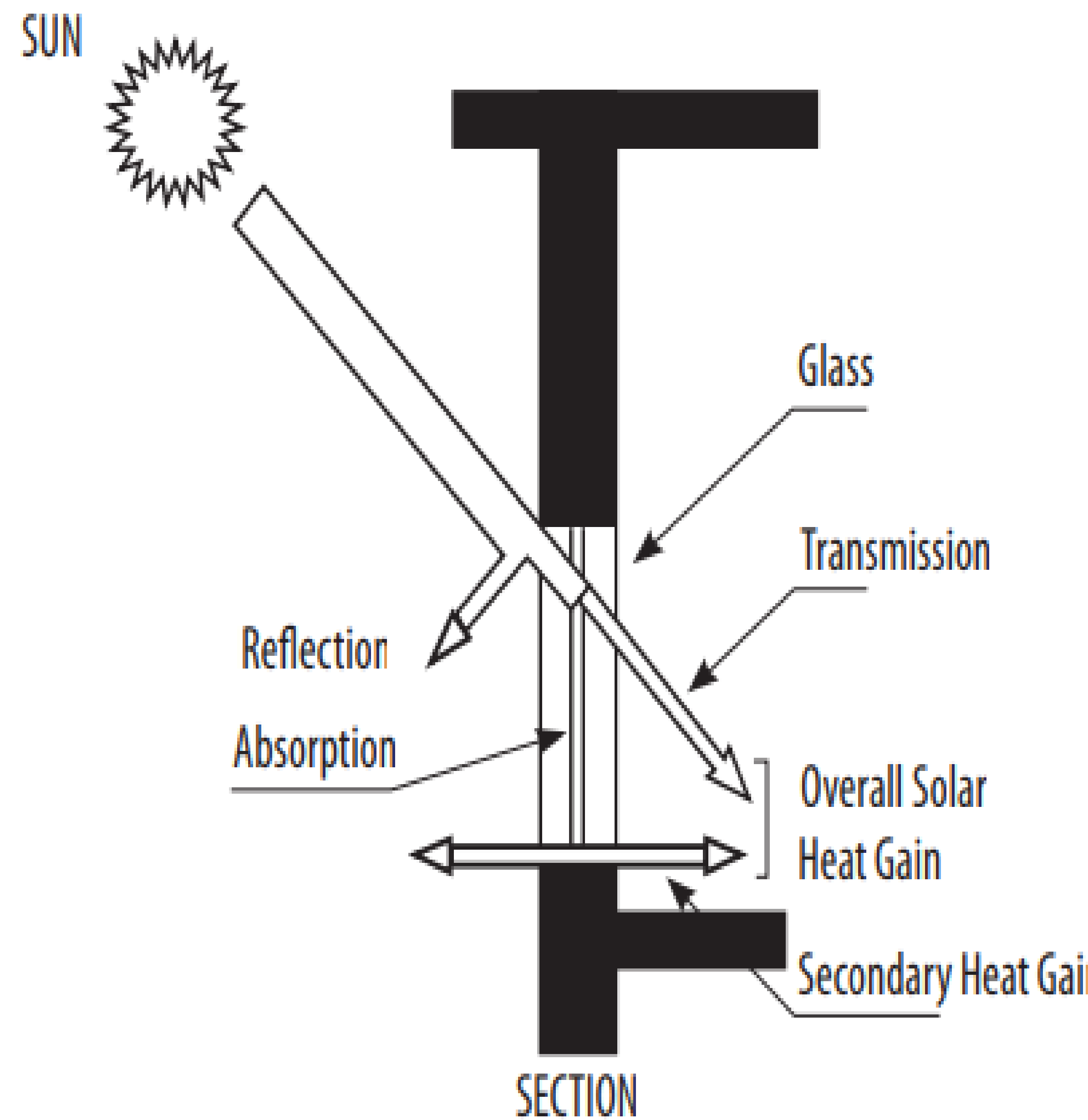
AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

Solar Heat Gain Coefficient (SHGC): SHGC is the fraction of incident solar radiation admitted through non-opaque components, both directly transmitted, and absorbed and subsequently released inward through conduction, convection, and radiation

Projection factor, overhang: the ratio of the horizontal depth of the external shading projection (Hoverhang) to the sum of the height of a non-opaque component and the distance from the top of the same component to the bottom of the farthest point of the external shading projection (Voverhang), in consistent units.

$PF_{overhang} = H_{overhang} / V_{overhang}$





AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

Residential Envelope Transmittance Value

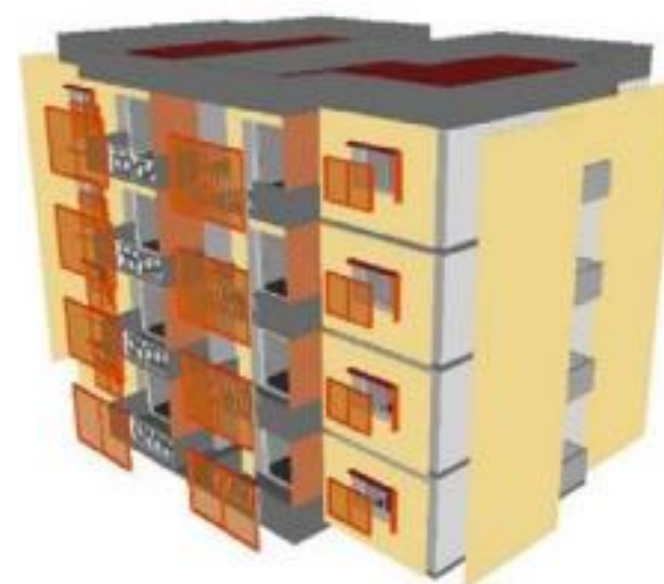
RETV characterizes the thermal performance of the building envelope ***(except roof).***

Limiting the RETV value helps in reducing heat gains from the building envelope, thereby improving the thermal comfort and reducing the electricity required for cooling. Its unit is W/m2 .

$$RETV = \frac{1}{A_{envelope}} \times \left[\begin{array}{ll} \left\{ 6.06 \times \sum_{i=1}^{n} \left(A_{opaque_i} \times U_{opaque_i} \times \omega_i \right) \right\} & \textit{Term-I} \\ + \left\{ 1.85 \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times U_{non-opaque_i} \times \omega_i \right) \right\} & \textit{Term-II} \\ + \left\{ 68.99 \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times SHGC_{eq_i} \times \omega_i \right) \right\} & \textit{Term-III} \end{array} \right]$$

RETV- 21.0 W/m²
Business-As-Usual
Building Envelope

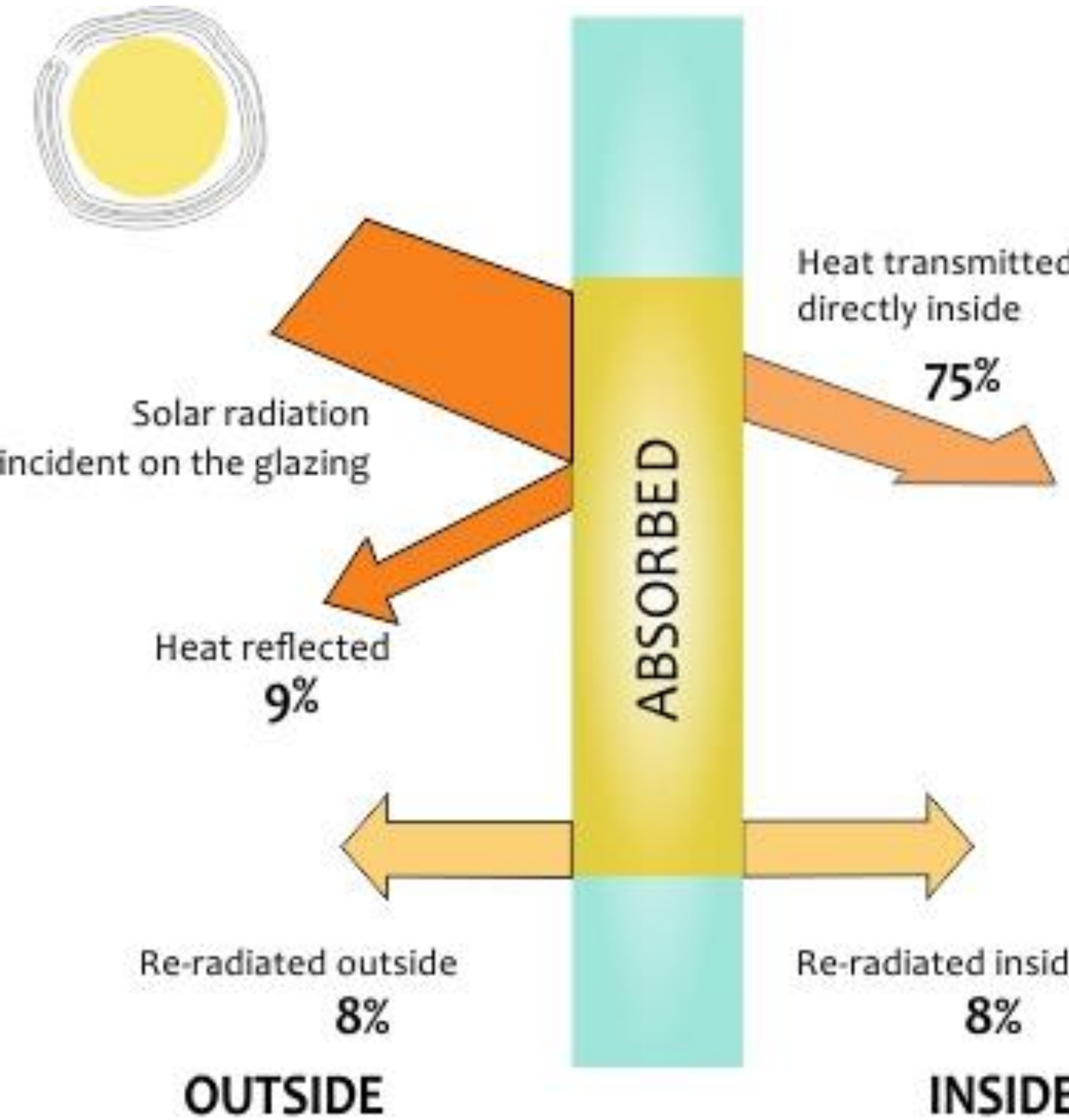
RETV- 18.0 W/m2
Building Envelope Details:
Better insulation in walls and roof (U-value)
High solar reflectance on roof (SRI)



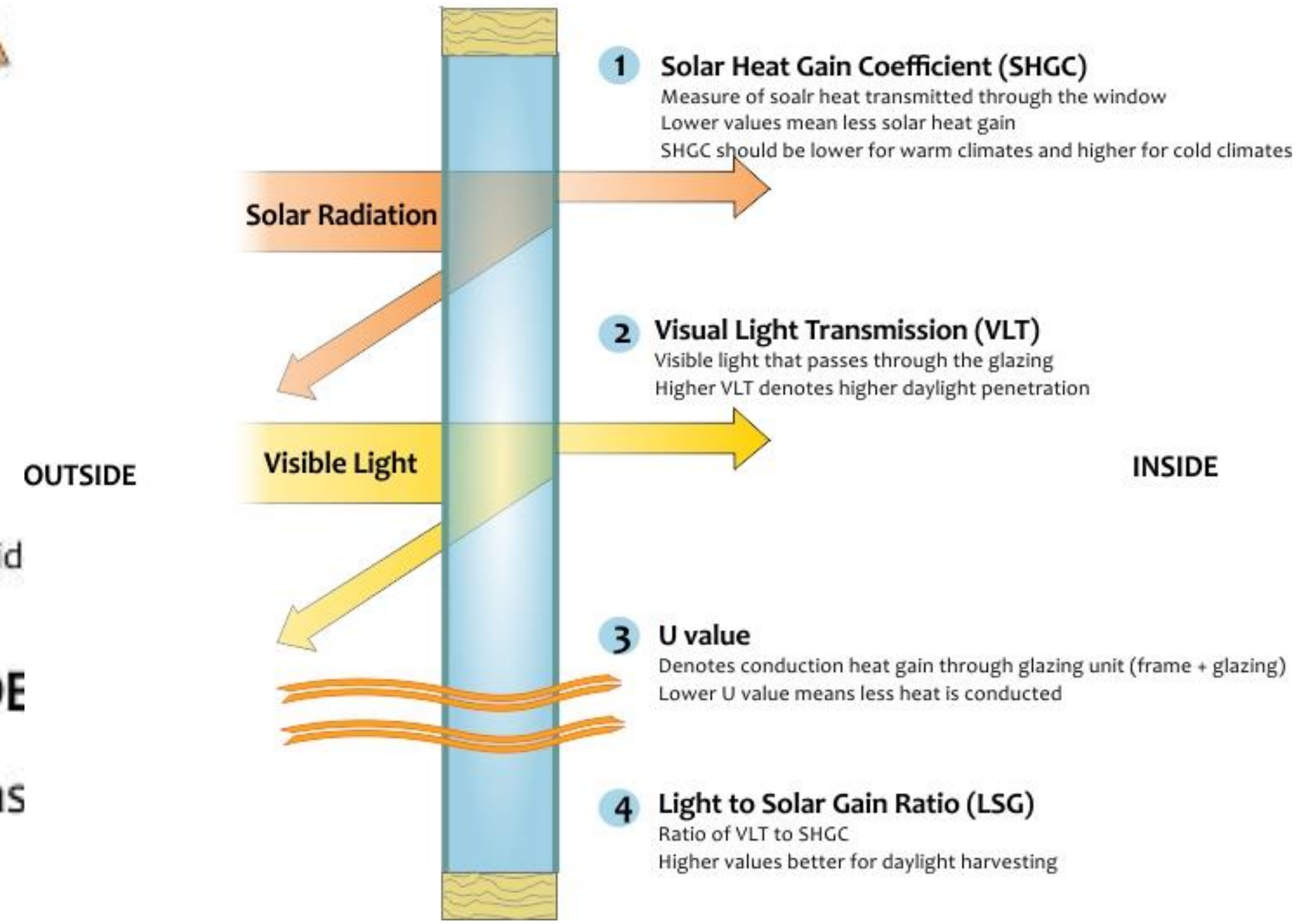
RETV- 15.0 W/m2
Better Windows (U Value, SHGC, VLT, Building Envelope Optimization)

Fenestration

A fenestration system with low U-value and low effective SHGC can result in ***reduction of heating and cooling demand*** by 6-11% in moderate climate and between 8-16% in hot humid, hot dry, and composite climates.



Heat transmission in a single glazing clear glas

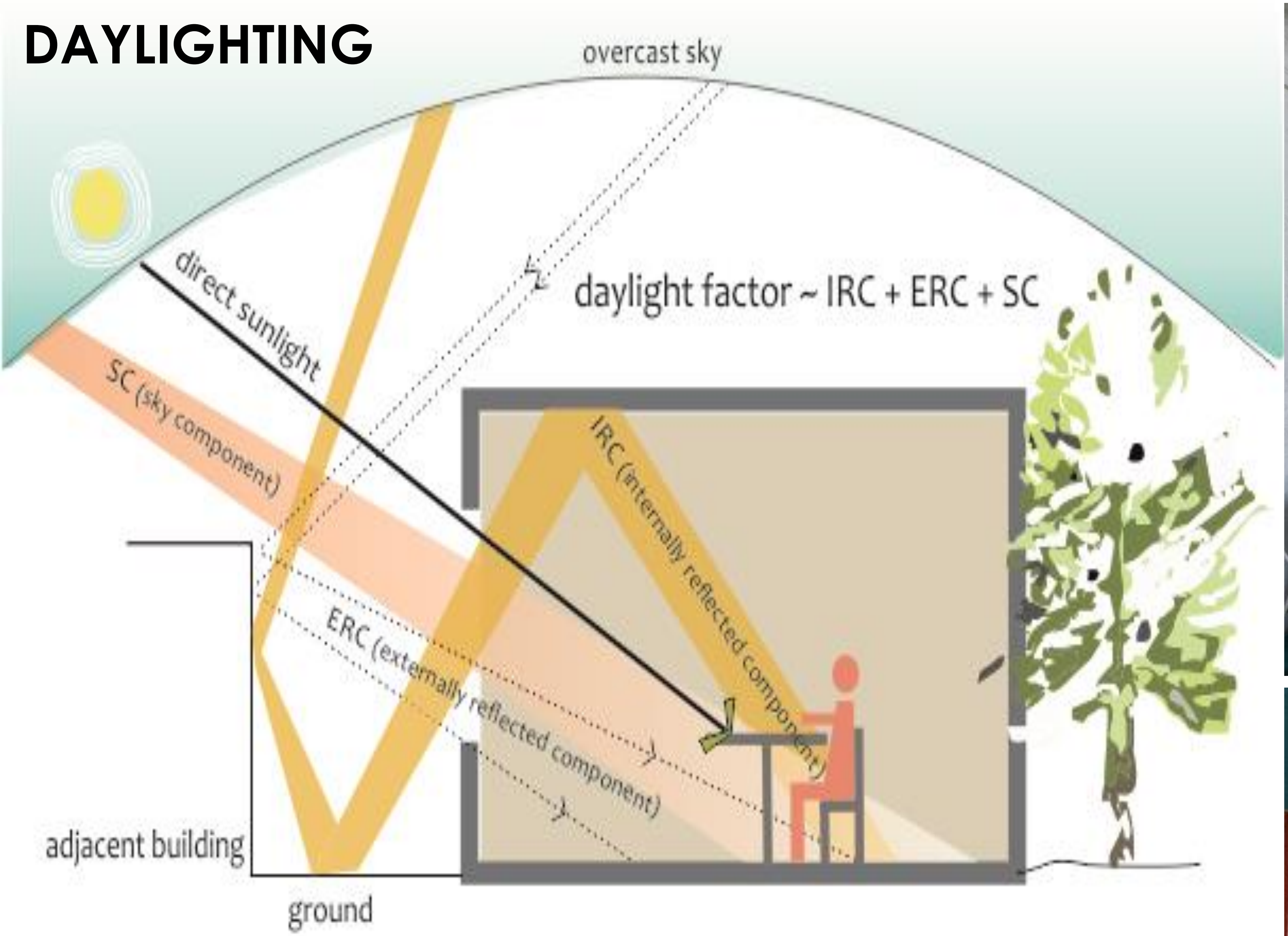


Fenestration type

Source: NZEB

AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

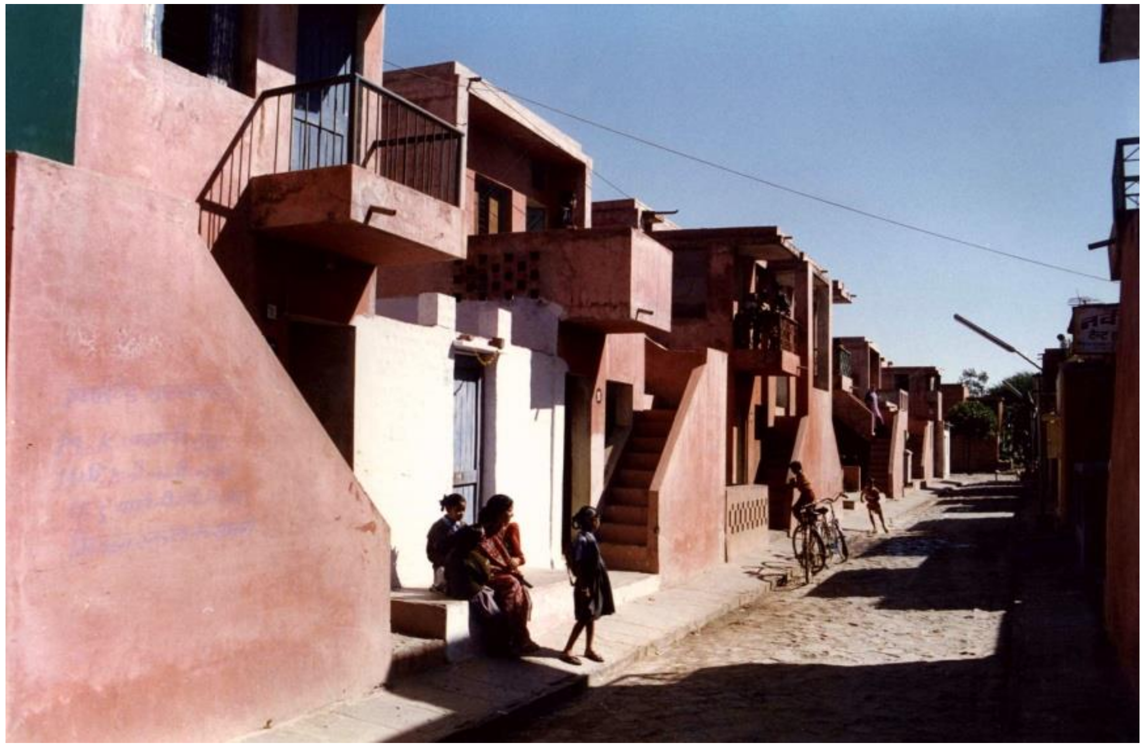
DAYLIGHTING



- Designed daylighting features enhance

1. Indoor environmental quality,
2. Building occupant performance

Daylighting can impact the energy use by **reducing** the lighting energy demand up to **20-30%.**



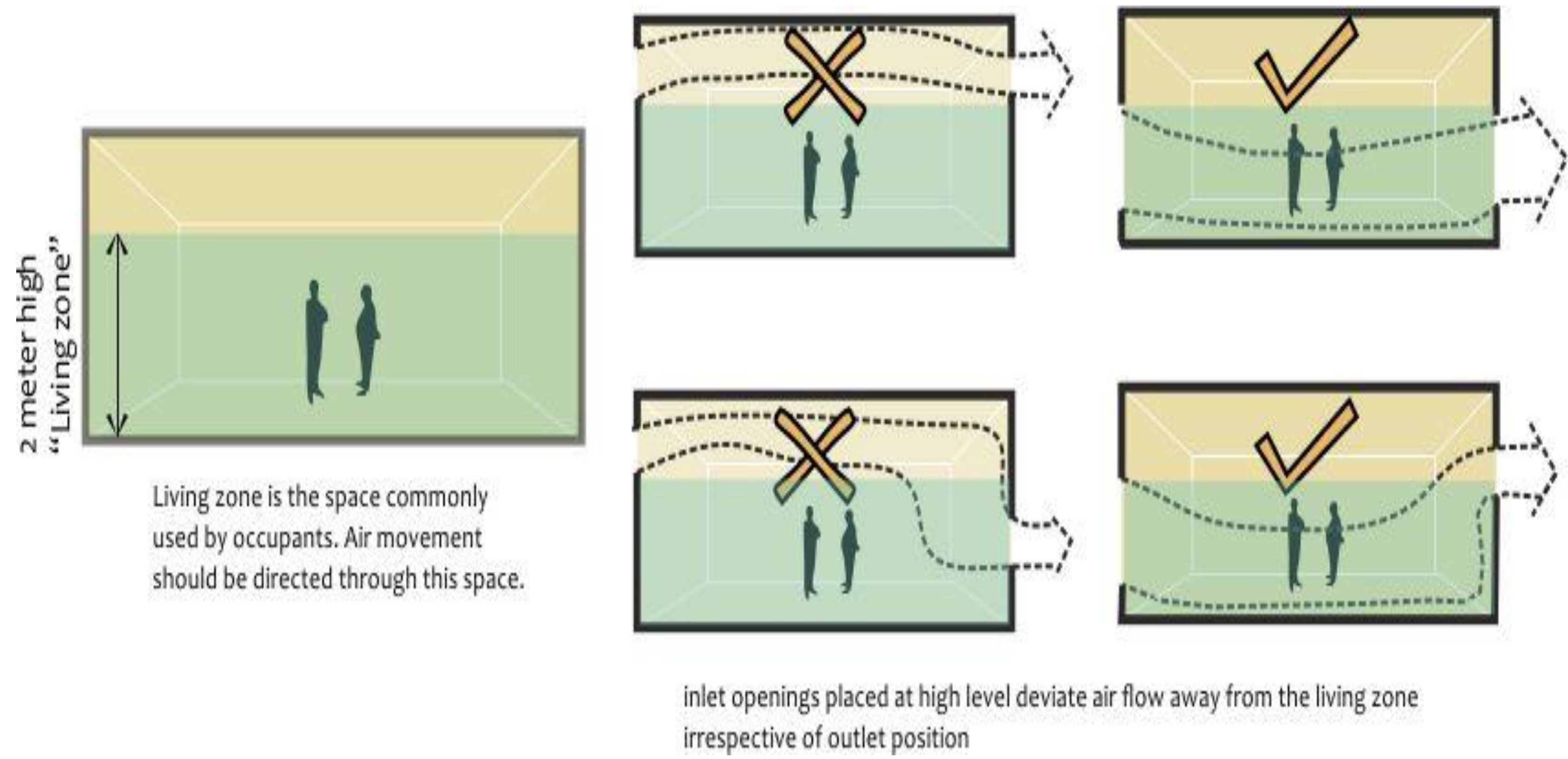
Day lighting and Shading at Aranya Housing, Indore

Source: NZEB

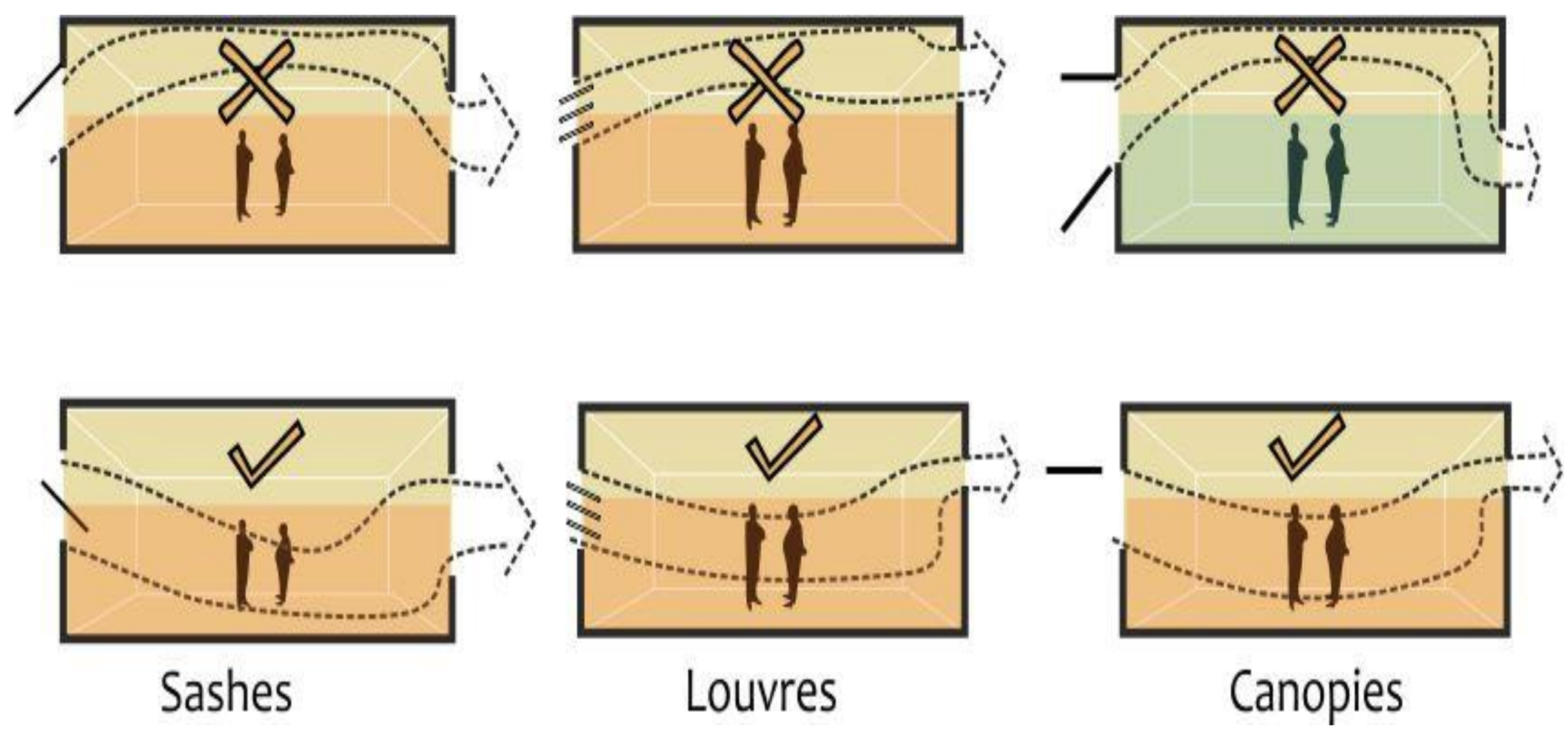
AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

NATURAL VENTILATION

Cross ventilation
to allow ***maximum air flow*** inside the space



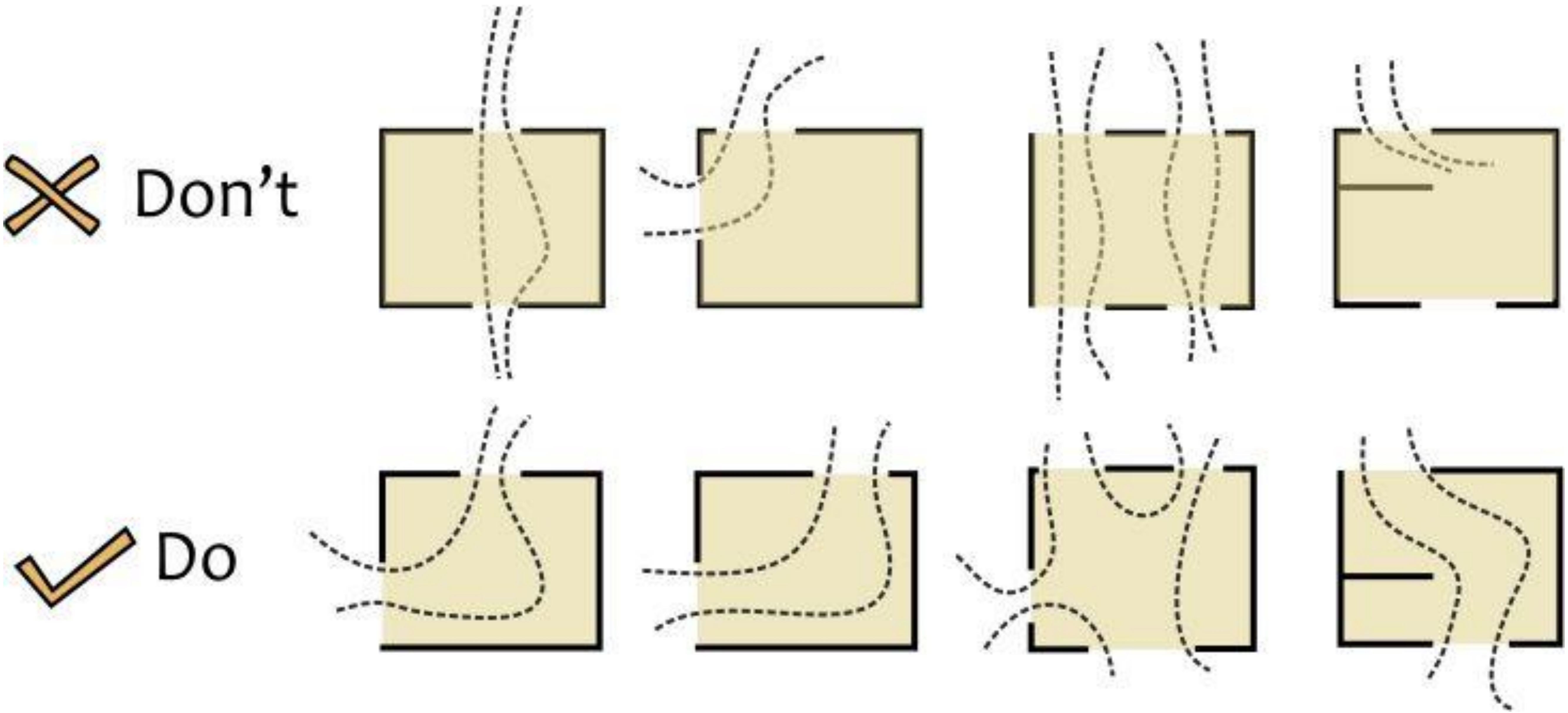
Types of opening and their location



Natural ventilation helps in reducing mechanical cooling load of the building

AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

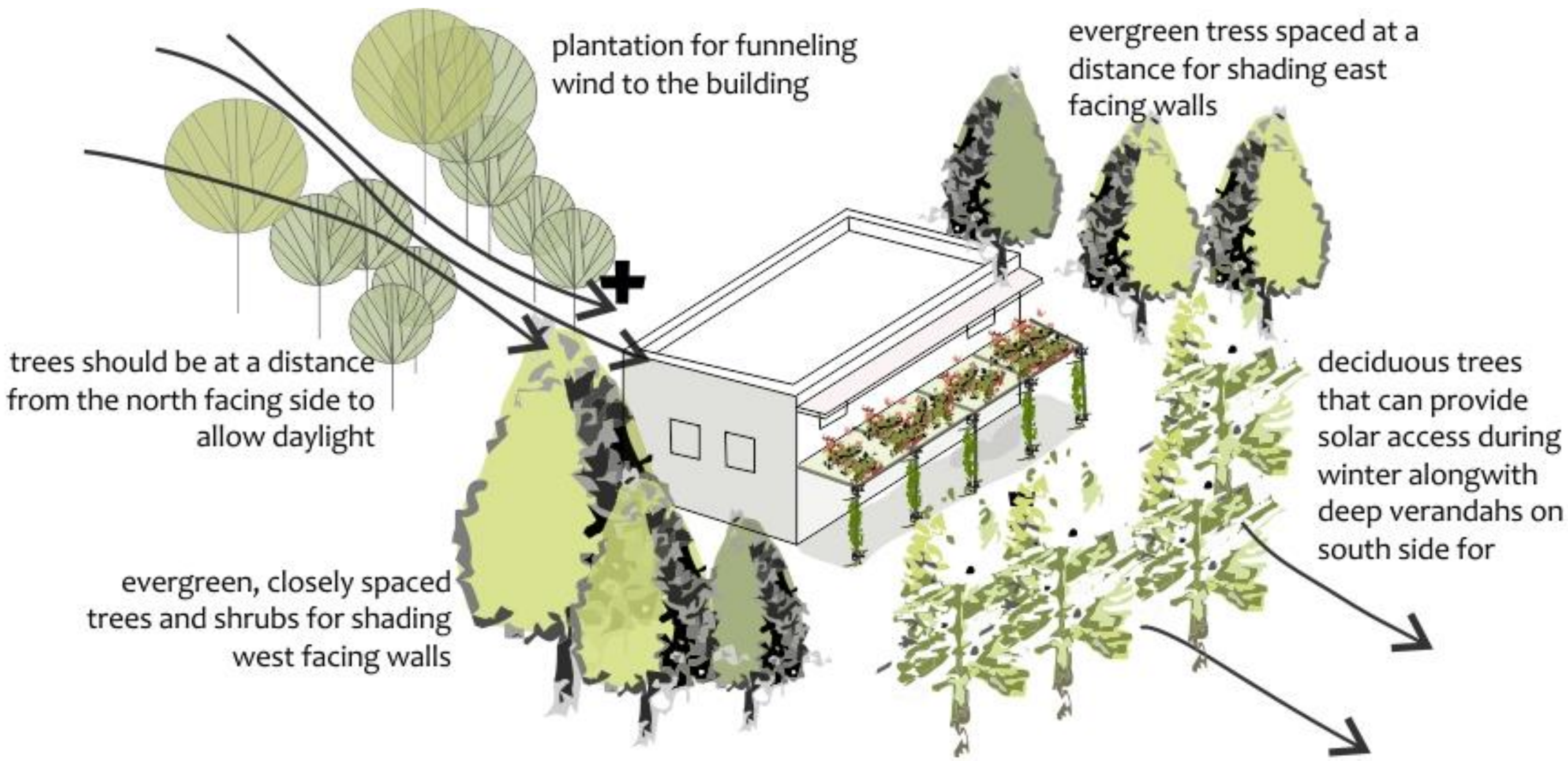
NATURAL VENTILATION



Horizontal placing of openings and internal partitions can alter the direction and spread of air stream

AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

VEGETATION



An increase in urban **vegetation** to reduce urban heat and improve outdoor **thermal comfort.**

Trees also reduce ambient air temperature due to evapo-transpiration.

Study shows that ambient air under a tree adjacent to the wall is about 2 – 2.5°C lower than that for unshaded areas.

Community, Gary Horton, Landscape Development

Source: NZEB

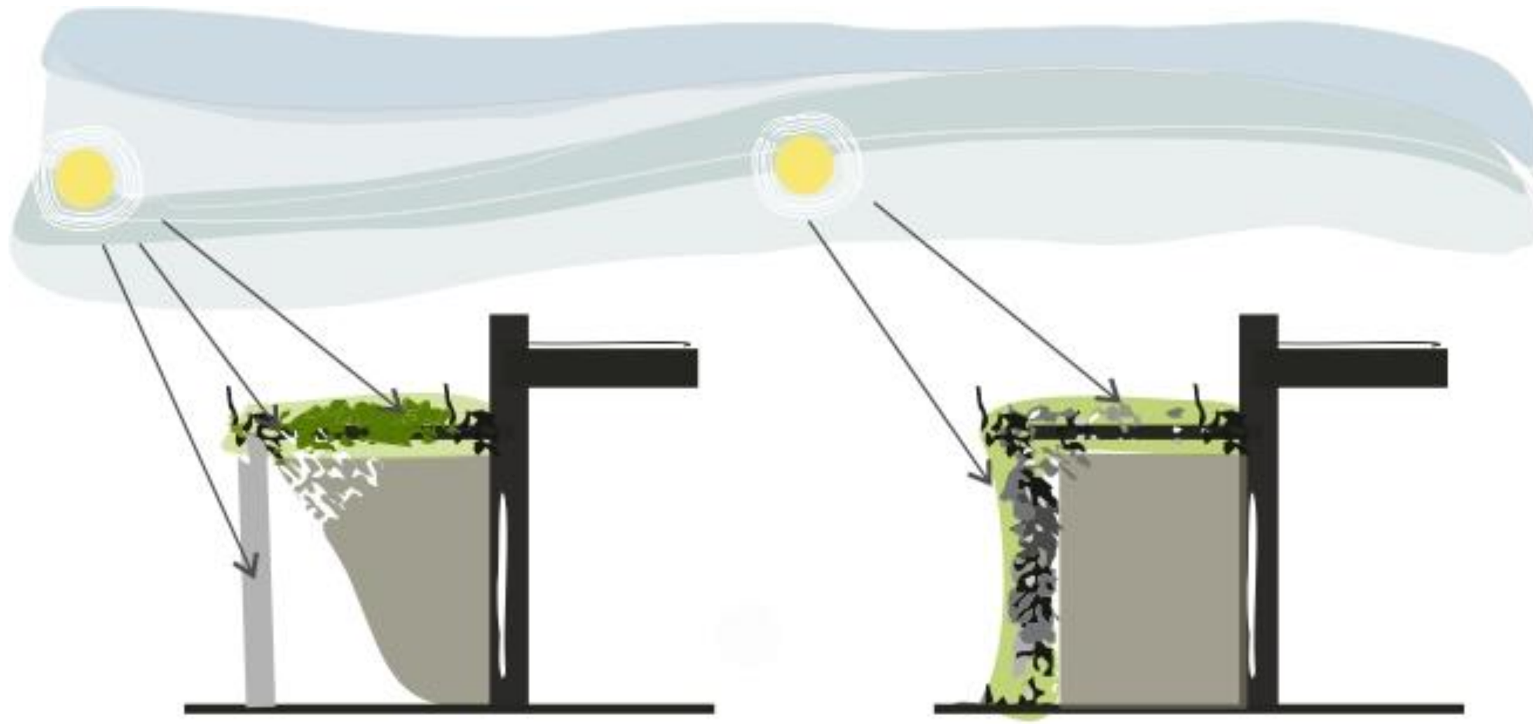
AFFORDABLE HOUSING PASSIVE DESIGN STRATEGIES

VEGETATION

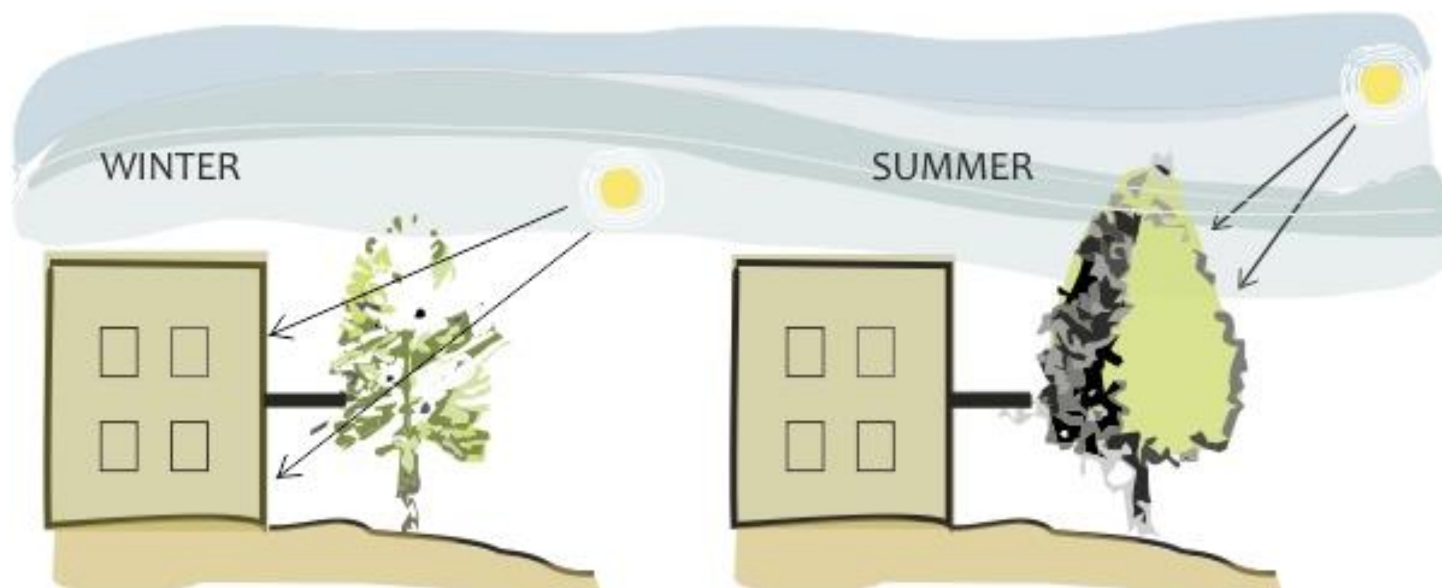
Trees and shrubs create different air flow patterns, provide shading and keep the surroundings cooler in warm weather.

Vegetation can be used for energy conservation in buildings in the following ways:

- ✓ Shading of buildings and open spaces through landscaping
- ✓ Roof gardens (or green roofs)
- ✓ Shading of vertical and horizontal surfaces (green walls)
- ✓ Buffer against cold and hot winds
- ✓ Changing direction of wind



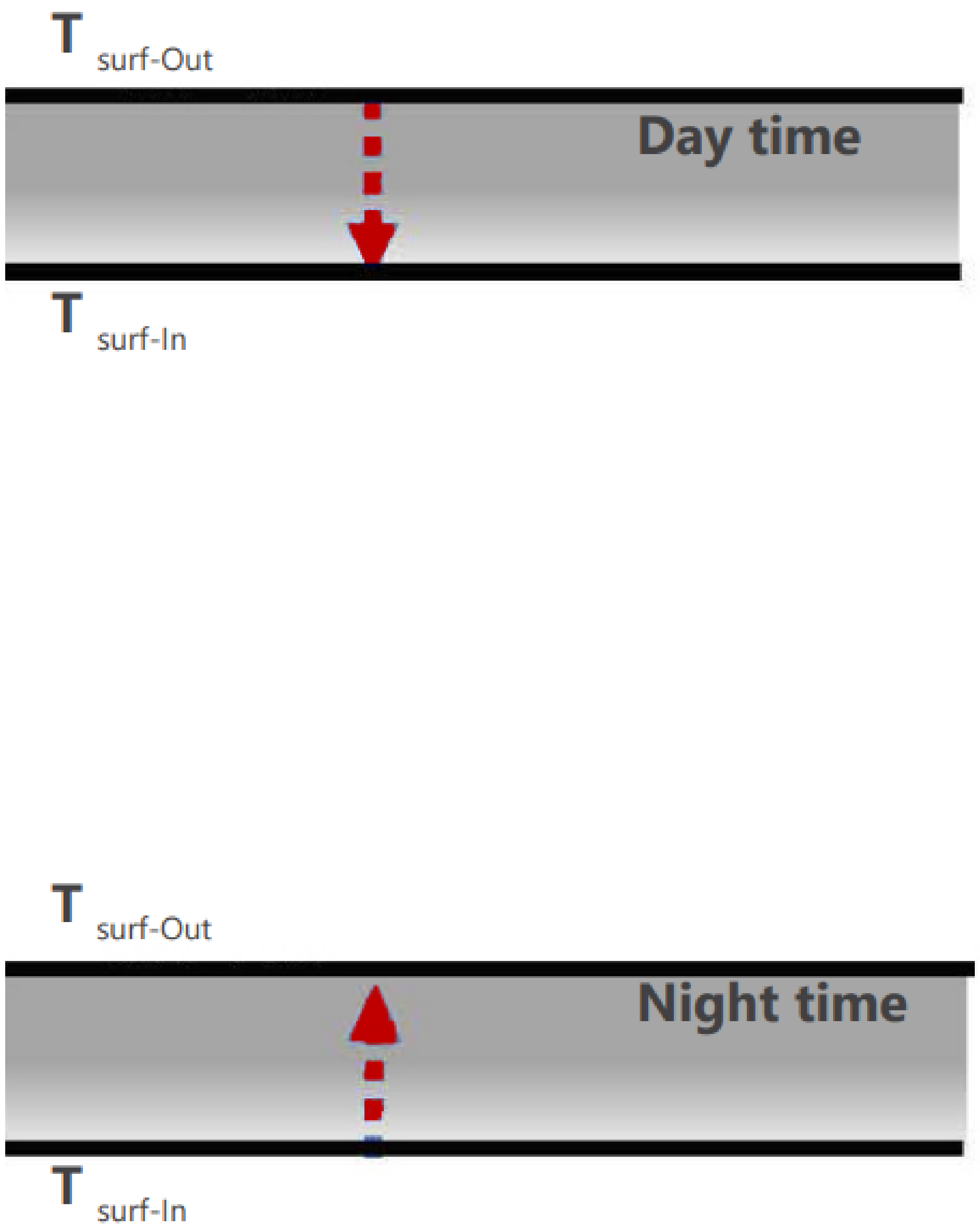
creepers are flexible shading devices for shading verandahs and interior spaces as per the season



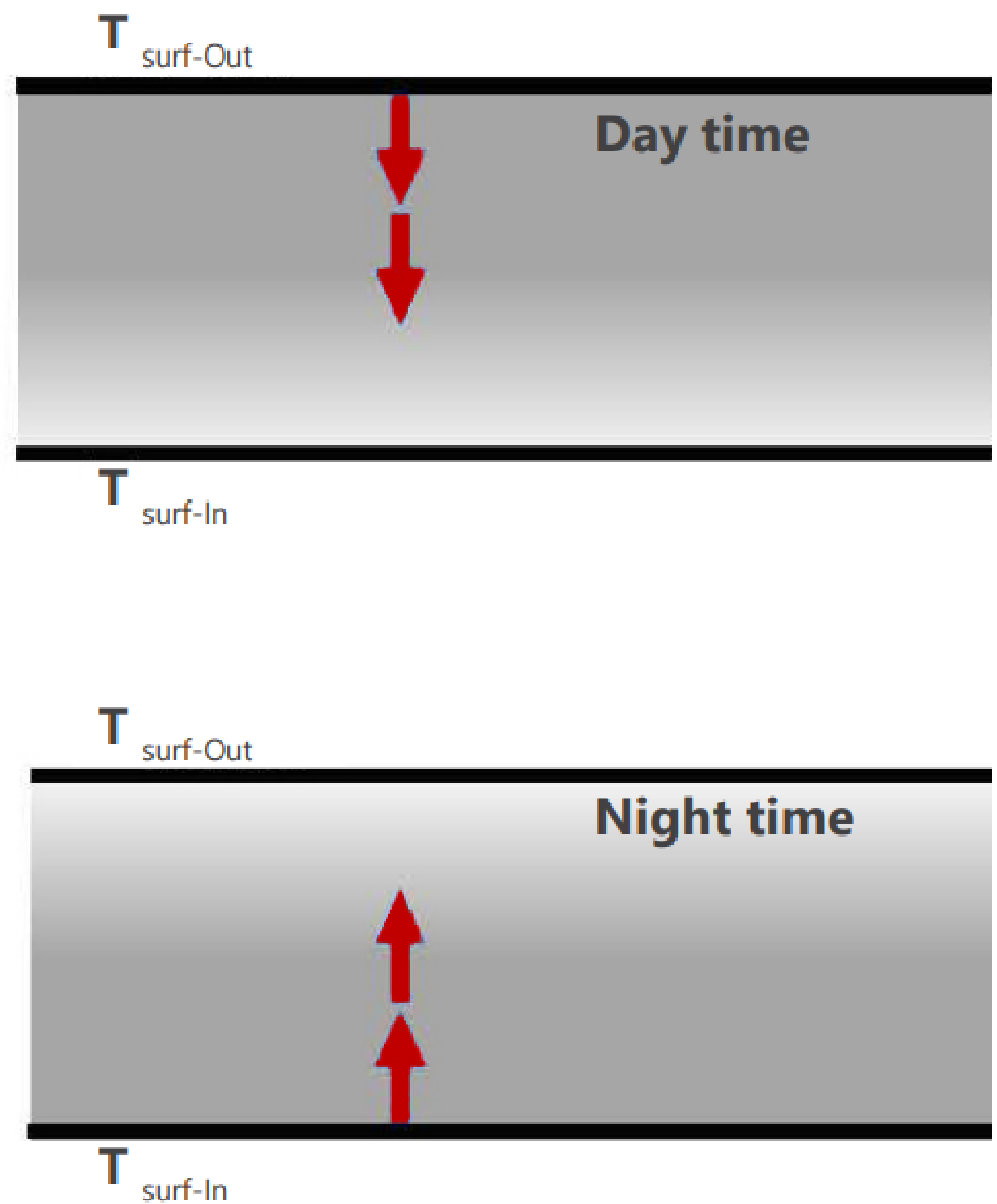
deciduous trees allow sun penetration in winter and block sun access during summer

INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

Thermal Insulation and Thermal Mass



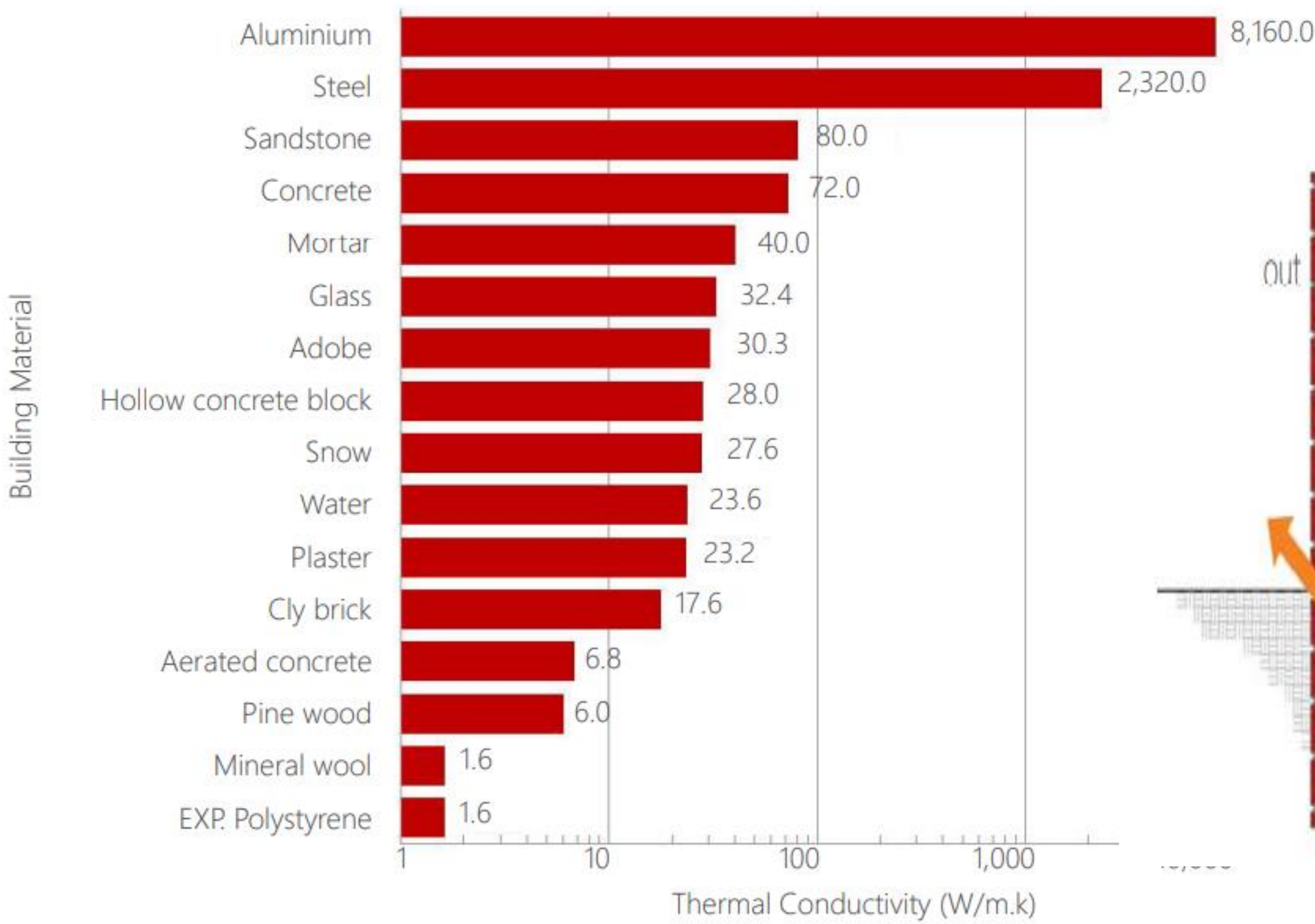
A- Thermal insulation through thermal conductivity



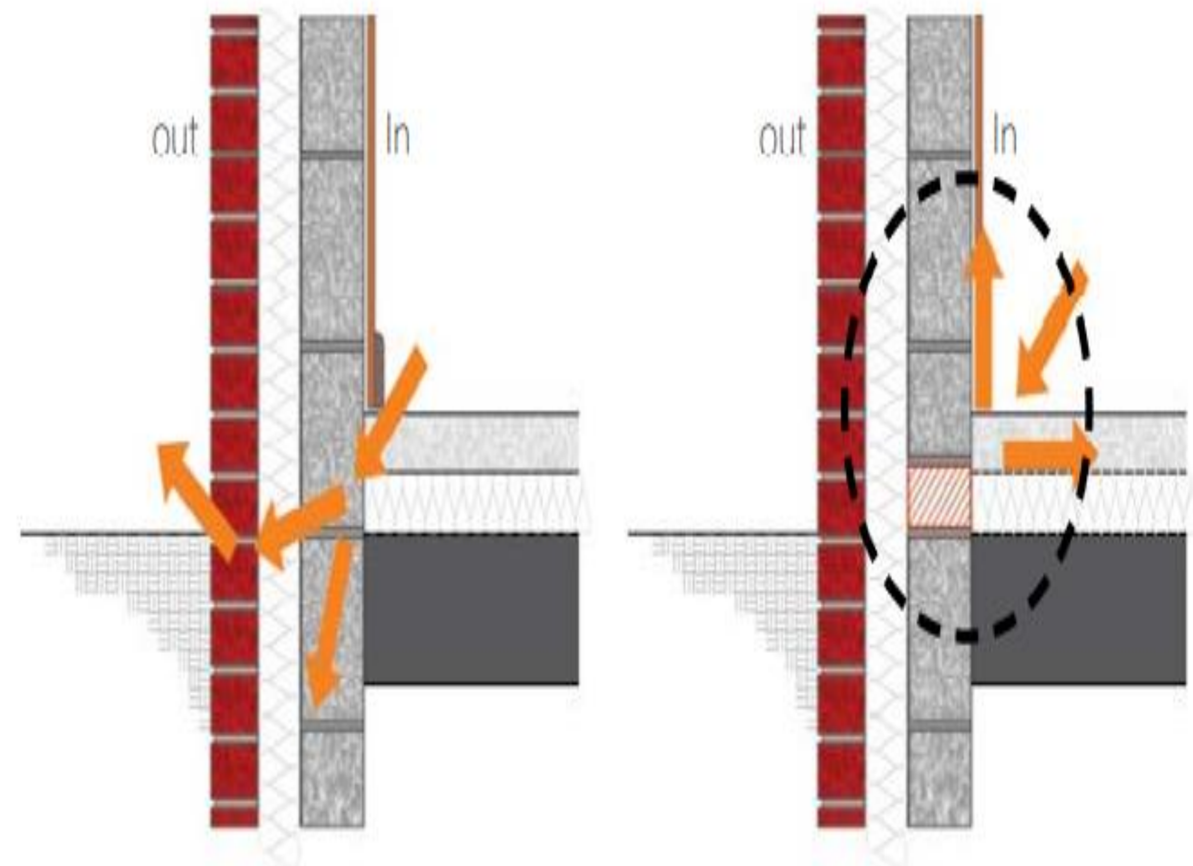
B- Thermal insulation through thermal mass

Thermal conductivity and Thermal Bridge

A thermal bridge is a part of the assembly (such as metal screws or nails) that allows direct heat transfer between indoors and outdoors due to interruptions in insulation.



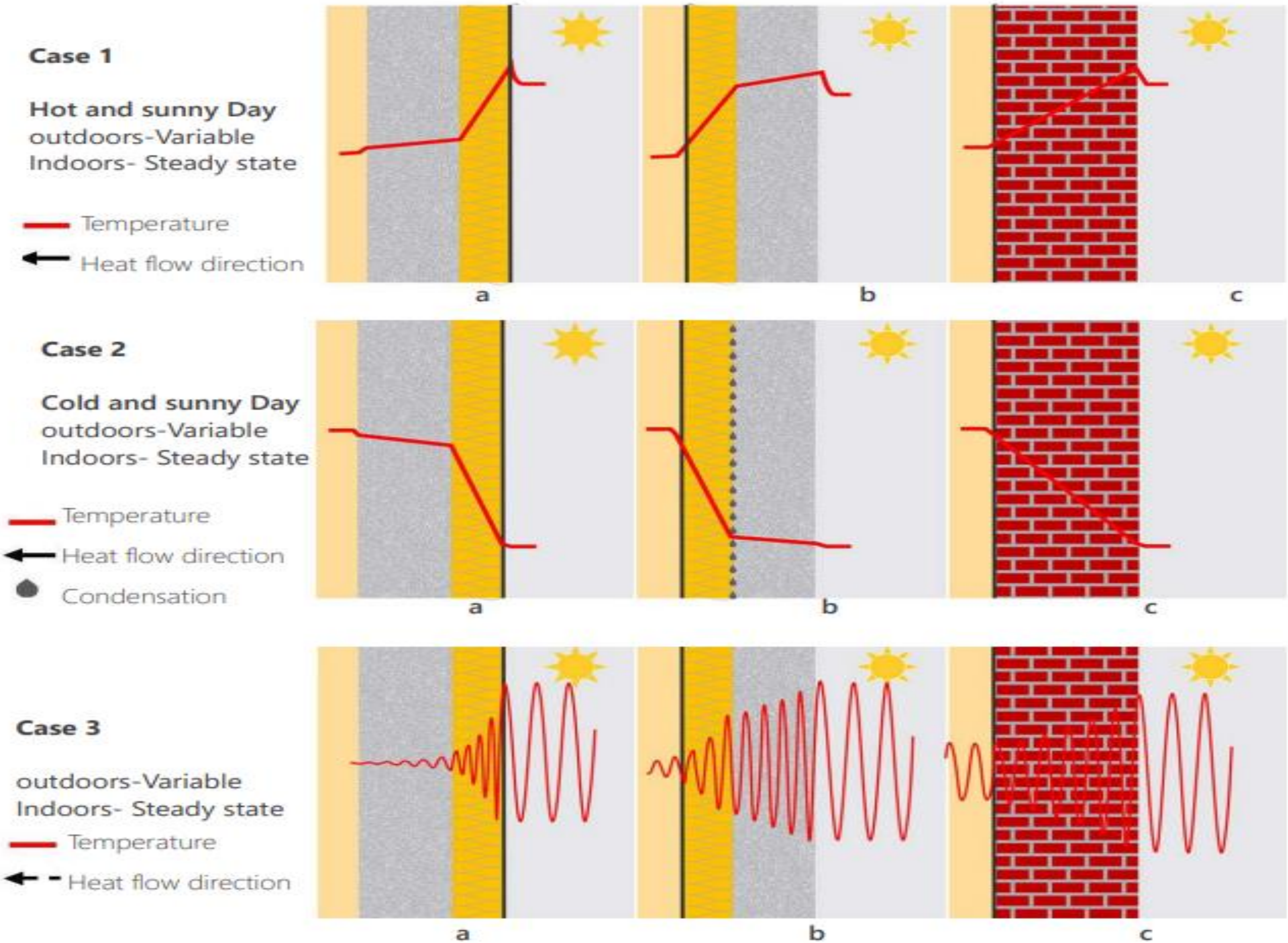
Thermal conductivities of common building materials



Walling assemblies and thermal bridging

INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

Temperature Profile Illustrations For Various Indoor And Outdoor Conditions

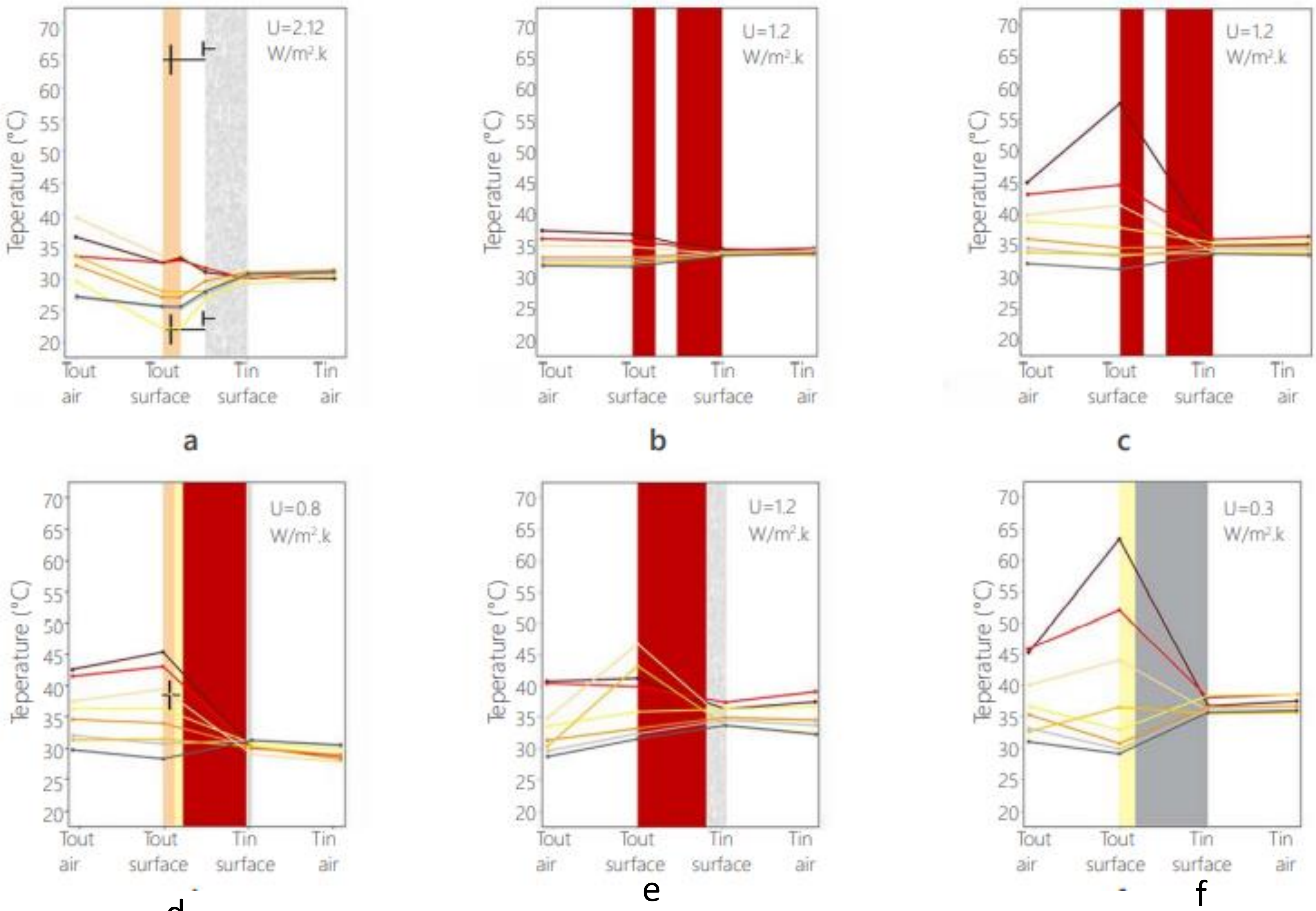


Example: -Steady state indoors and variable outdoors on cold-sunny day

INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

The Temperature Gradients Across Wall Sections Of Six Different Buildings Studied

U-value and surface temperature



Temperature gradients across wall sections for an extreme summer day

INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

U-value database of all selected walling assemblies and technologies

Walling Technologies

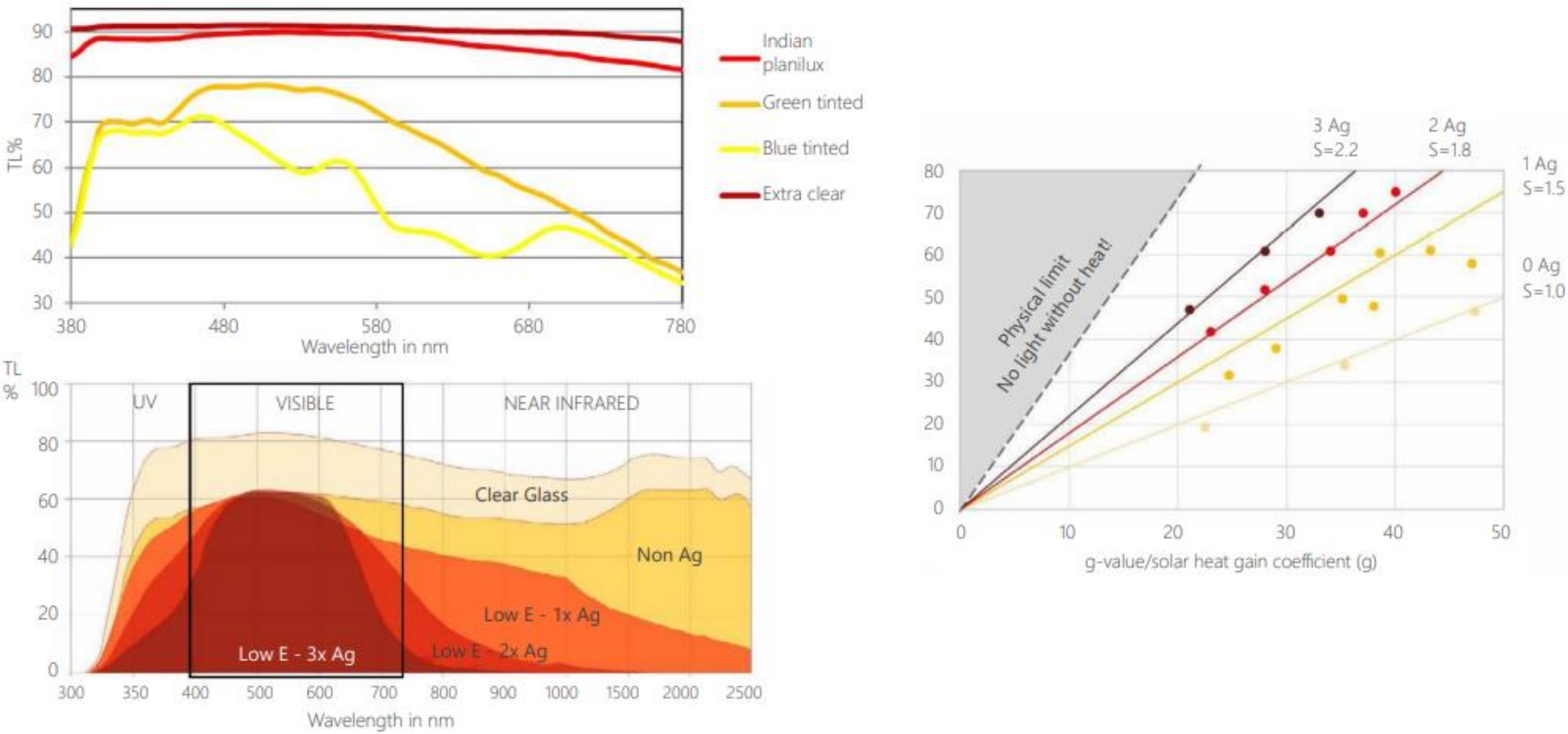
- ✓ The assemblies presented are a mix of commonly used traditional systems and emerging technologies in the Indian context.
- ✓ It can be observed from the figure that assemblies with insulation such as EPS, insulated panels have lower U-values and hence, can help in reducing heat gains through wall.

S/N	Test Phase	Wall types	Thickness (in mm)	U value ($W/m^2.K$)
1	1	Base case: Burnt Clay Brick Wall	250	2.41
2	1	Rattrap bond wall	250	2.11
3	1	Light Gauge framed steel structure with EPS	136	1.37
4	1	Light Gauge framed steel structure with PPGI Sheet	150	2.12
5	1	Reinforced EPS core Panel system	150	0.56
6	1	Glass fibre reinforced Gypsum Panel -Unfilled	124	2.06
7	1	Glass fibre reinforced Gypsum Panel -with RCC & non-structural filling	124	2.12
8	1	Glass fibre reinforced Gypsum Panel -with partial RCC filling	124	2.13
9	1	Structural stay-in-place formwork system (Coffor) – Insulated panel	230	0.44
10	2	Bamboo Crete	65	2.71
11	2	Wattle and Daub	45	3.61
12	2	Stabilized Adobe	230	2.11
13	2	Laterite Block Wall	205	2.17
14	2	Unstabilized Adobe	230	2.05
15	2	CSEB	230	2.79
16	2	Unstabilized CEB	230	2.74

S/N	Test Phase	Wall types	Thickness (in mm)	U value ($W/m^2.K$)
17	2	AAC Block Wall with Perlite based Cement Plaster	230	0.76
18	2	Unstabilized Rammed Earth	230	2.13
19	2	Stabilized Rammed Earth	230	2.09
20	2	AAC Block Wall with Cement Mortar and Cement Plaster	230	0.78
21	2	AAC Block Wall with Lime mortar and Lime Plaster	220	0.82
22	2	Burnt Clay Brick with Lime Mortar and Lime Plaster	250	2.31
23	2	Limestone with Lime Mortar and Lime Plaster	224	2.84
24	2	Limestone with Cement Mortar and Cement Plaster	230	2.82
25	3	Hollow Clay Brick (100 mm thick) with Cement Plaster	130	2.71
26	3	Hollow Clay Brick (100 mm thick) with Cement Plaster and XPS (25 mm)	158	0.89
27	3	Hollow Clay Brick (200 mm thick) with Rockwool and Cement Plaster	230	1.28
28	3	Hollow Clay Brick (200 mm thick) with Cement Plaster	230	1.83
29	3	Hollow Clay Brick (200 mm thick) with Cement Plaster and XPS (25 mm)	258	0.75
30	3	RCC Wall (100mm thick)	100	3.59
31	3	RCC Wall (100mm thick) + EPS (50 mm thick)	150	0.58
32	3	RCC Wall (100mm thick) + Styrofoam (24 mm thick) at both sides	154	0.65
33	3	RCC Wall (100mm thick) + PVC panel (6mm thick) at both sides	112	2.62
34	3	RCC Wall (100mm thick) + PVC panel (6mm thick) at both sides + EPS Board (50 mm thick) at one side	165	0.52

Visible Light Transmittance And Solar Heat Gains

Thermal Comfort in Affordable Housing 104 clear glass transmits nearly 90% of visible light, closely followed by Indian planilux or clear glass with 80-90% visible light transmissions while blue and green tinted glasses provide VLT levels in the range of 35% to 80%

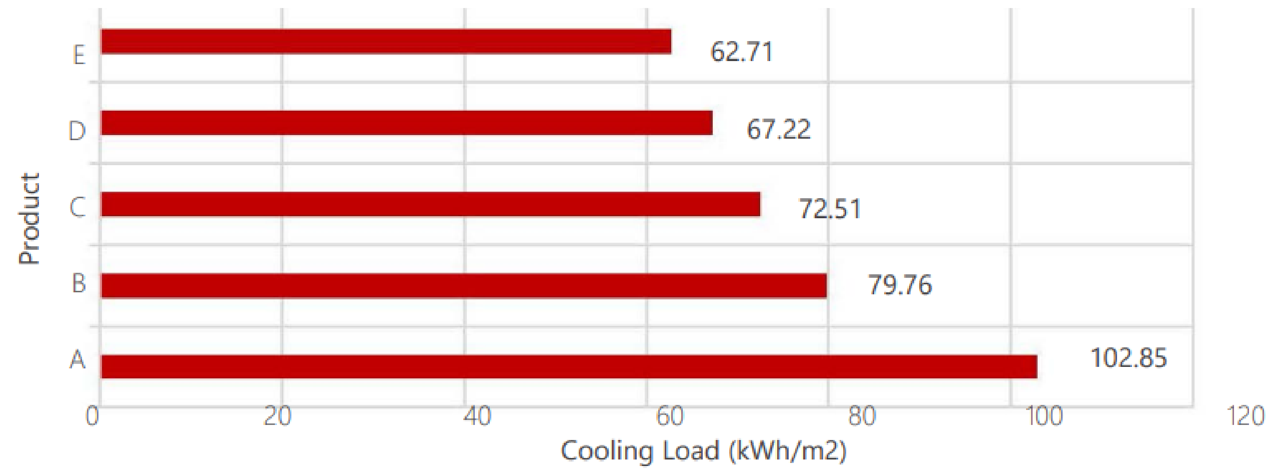


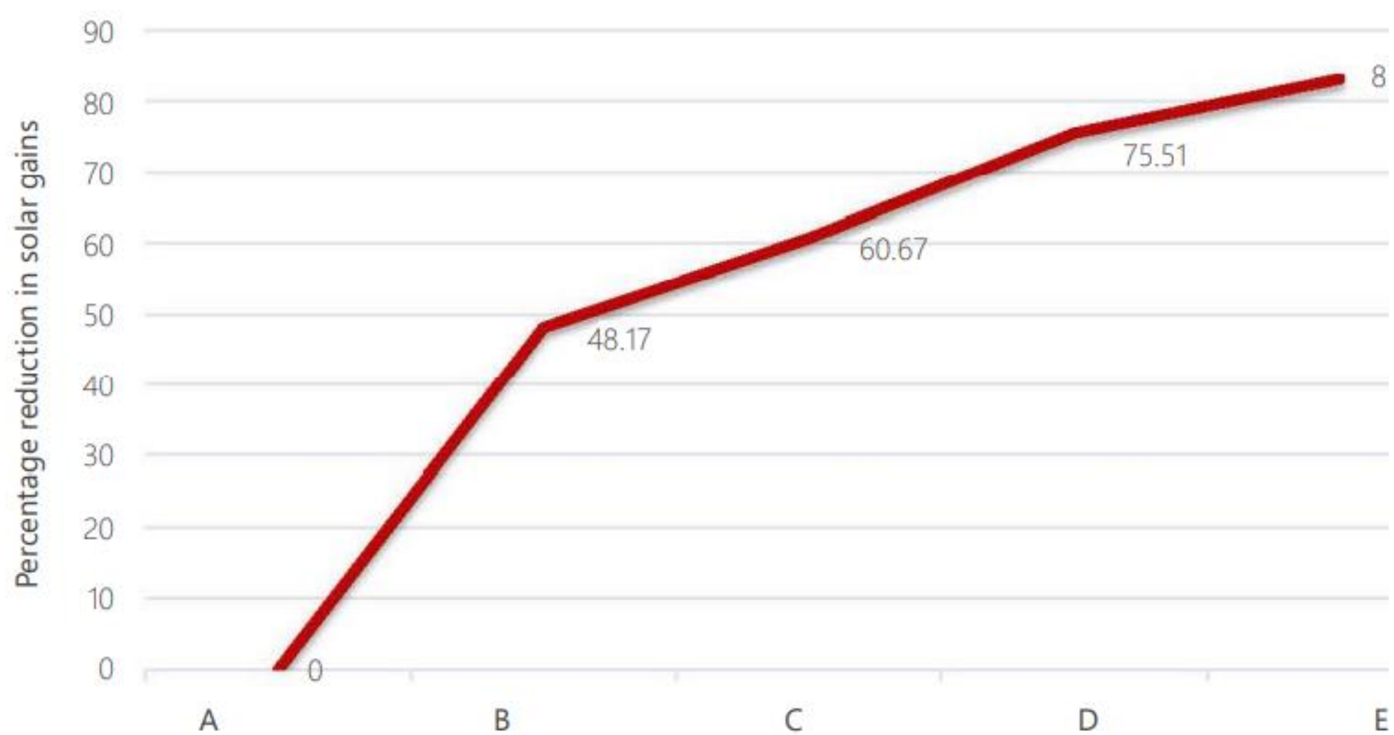
Top- VLT for different types of glasses; Middle- performance of different low-e coating combinations in UV, visible light, and IR spectrums. Bottom- selectivity, solar heat gain coefficient and visible light transmission of different low e-coating combinations

Properties of glazing assemblies

Table 25: Properties of glazing assemblies

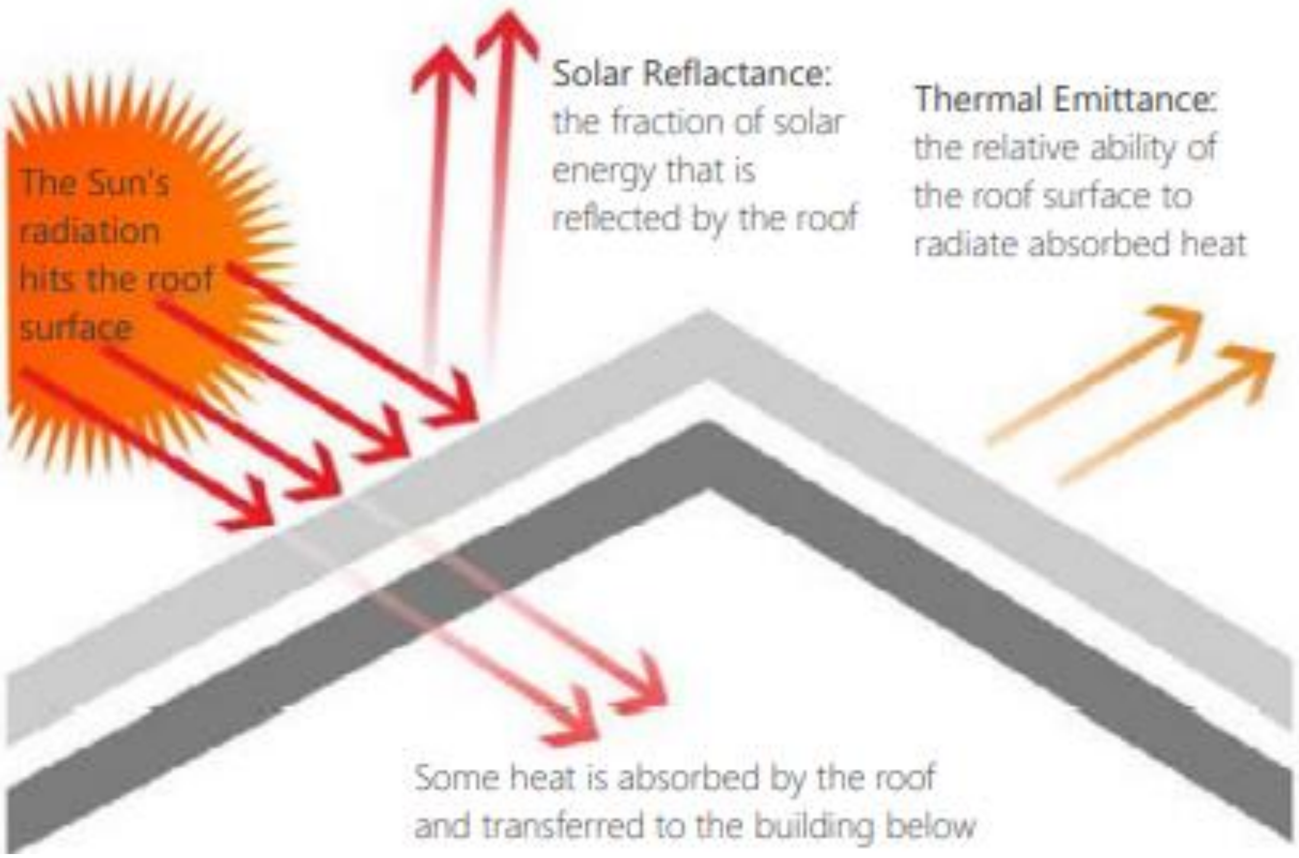
Product	VLT (%)	External Reflection (%)	Internal Reflection (%)	Solar Factor	Shading coefficient	U-value
A	80	15	15	0.76	0.87	2.6
B	46	16	18	0.22	0.25	1.5
C	46	20	22	0.47	0.54	2.8
D	51	18	22	0.28	0.33	1.5
E	47	17	11	0.38	0.43	1.9



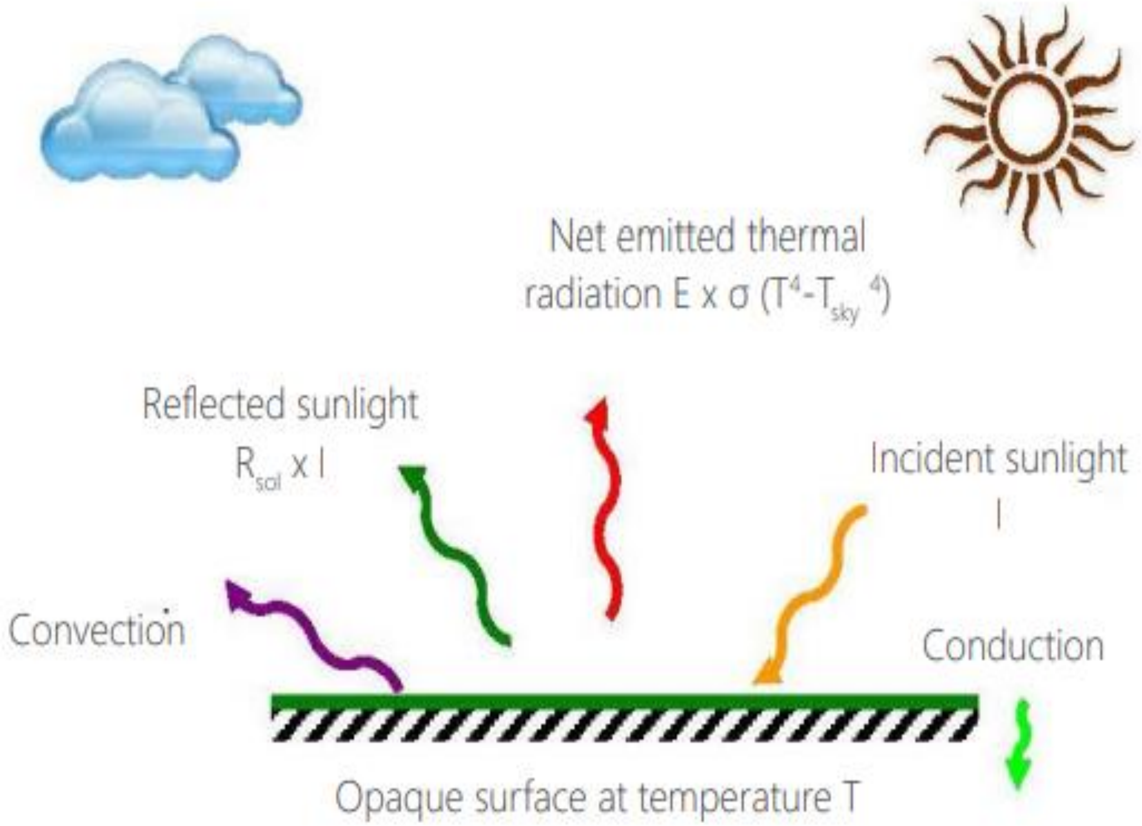


INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

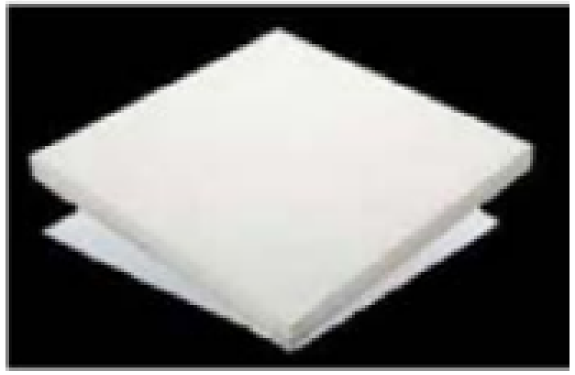
Roofing Coating Materials Reflectance, Emittance, Emissivity



surfaces with incident solar radiation



Factors affecting surface temperature of roof and/or roof coating materials



roofing materials

EFFECT OF MATERIALS ON THERMAL COMFORT

Before selecting insulation material for a building, the following factors need to be considered:

- ✓ The climatic conditions of the region
- ✓ The material flammability in case of an accident
- ✓ Material toxicity
- ✓ Ease of replacement of the material
- ✓ Material affordability
- ✓ Material durability
- ✓ Ease of installation

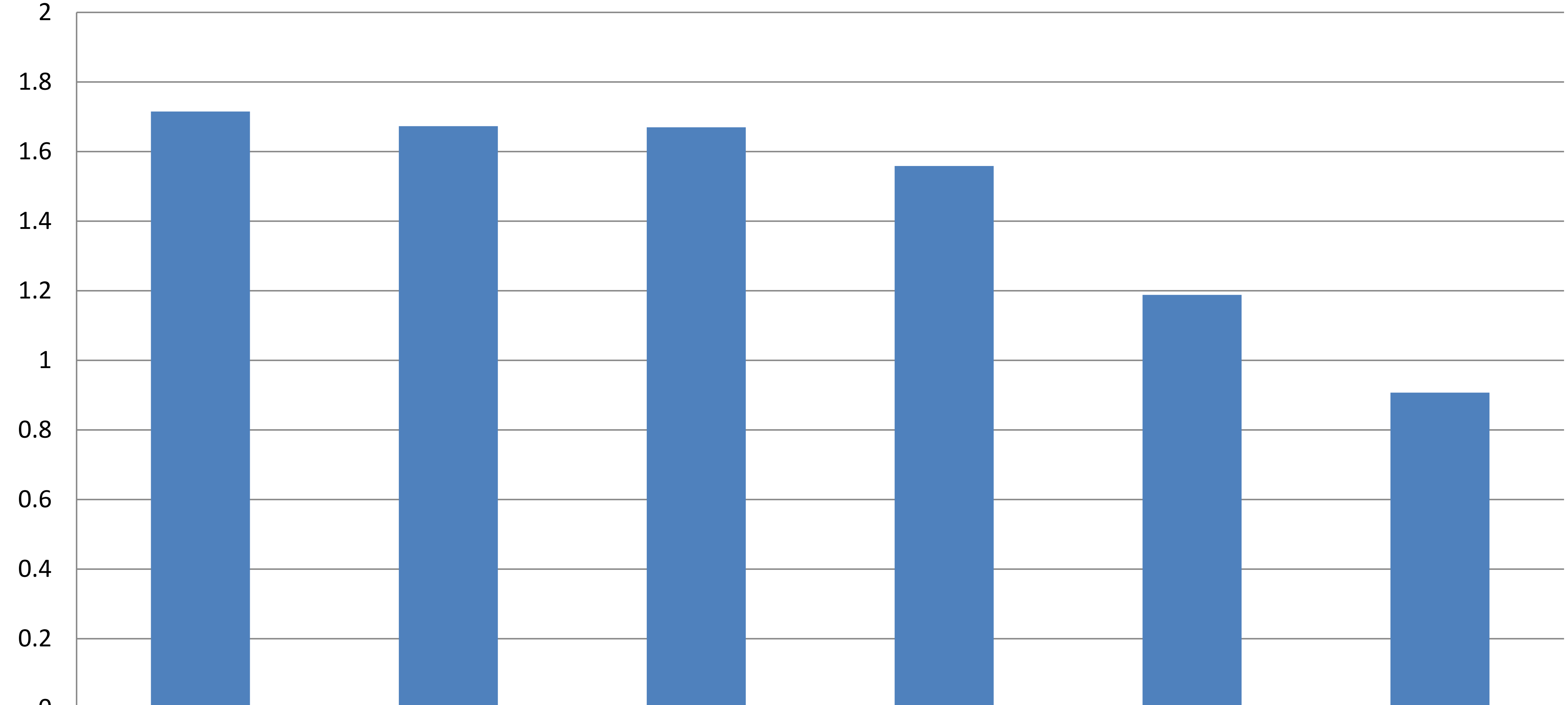
Characteristic of insulating materials	Insulating Power	Density	Fire Resistance	Water vapor diffusion	Resistance to water	Compression Strength	Traction Strength	Heat Resistance	Absorption of vibrations	Absorption of aerial noise	Cost at given insulation	Embodied Energy
Light mineral Wool	+	_._	++	-	O	_._	_._	+		++	+	_._
Dense Mineral Wool	++	+	++	_._	O	O	_	++	++	+	+	O
Glass foam	+	+	++	++	++	++	++	++	_._	_	+++	O
PUR	++	-	O	-	O	+	+	++	_	_._	+	++
EPS	++	_._	+	+	O	+	+	O	_	_._	+++	_
XPS	++	O	+	++	+	+	++	O	-	_._	+	+

++ Very high; + High; O Average; - Low; _._ Very low

Comparison of commonly used insulation material

MATERIAL CHARACTERISTICS FOR BETTER THERMAL COMFORT

Thus, the lower the U-value, the lower the rate of heat transfer, and the better the insulating property of the element



	Glass fibre reinforced Gypsum panel with RCC & non..	Rattrap bond wall	Brick wall	Glass fibre reinforced Gypsum panel - Unfilled	Light Gauge framed steel structure with EPS	Reinforced EPS core Panel system
U-Value ($W/m^2K.$)	1.715	1.673	1.67	1.559	1.188	0.907

Decrease in U value

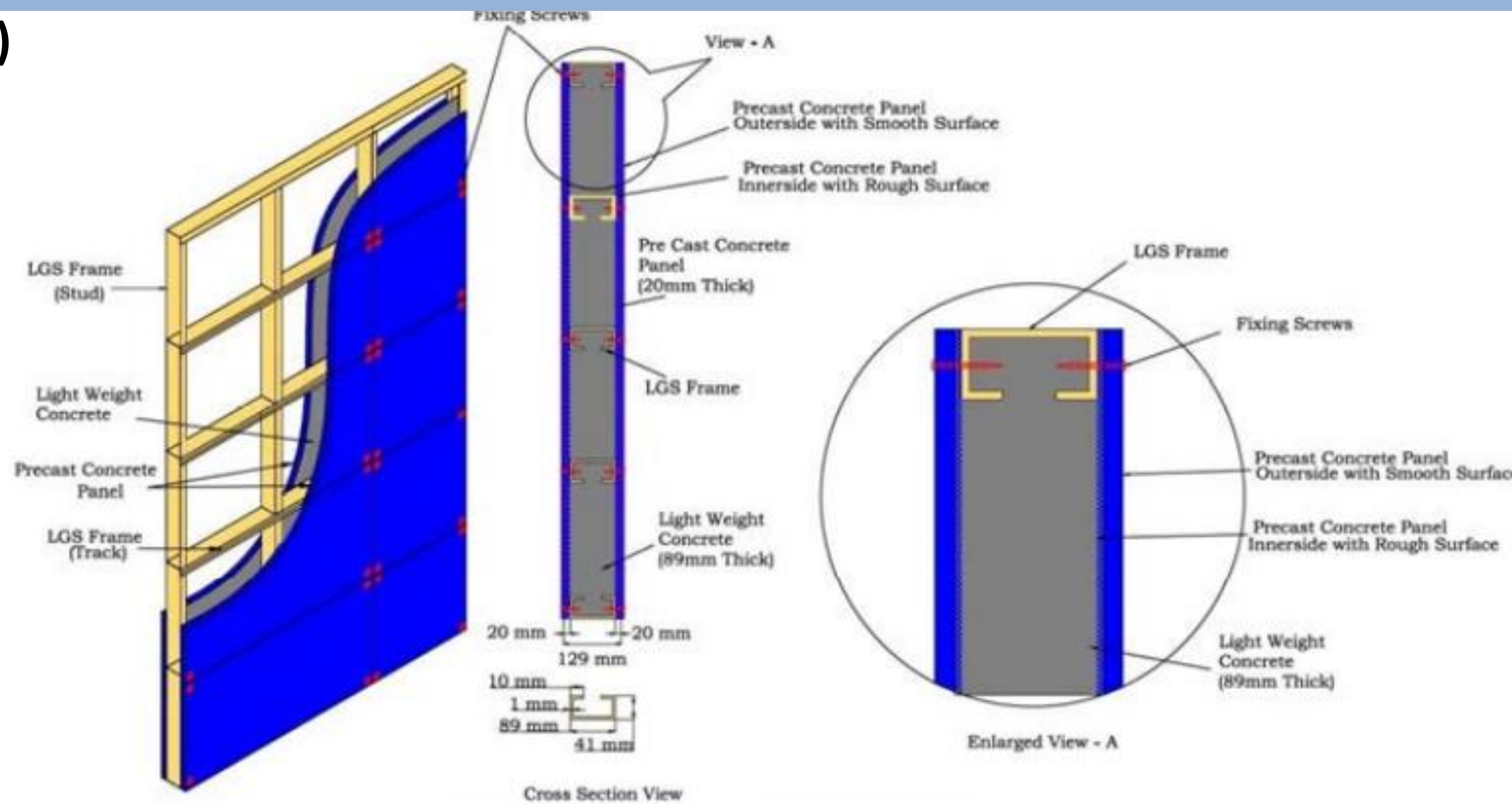
Enhance Thermal Comfort

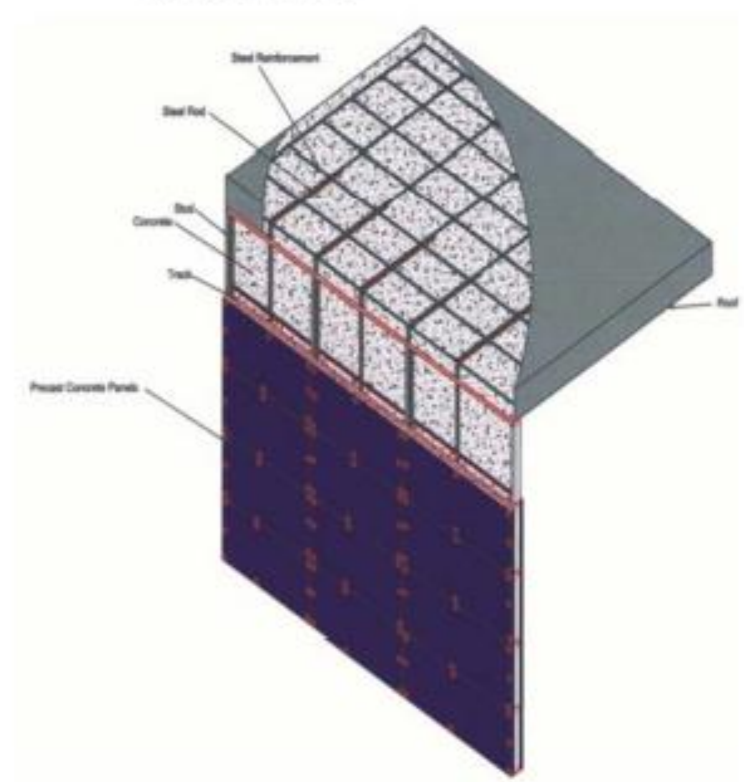
@source :CRDF Document of CEPT

INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

Light House Projects (LHP)

LHP – Agartala (Light Gauge Framed Steel Structure – Infill Concrete Panel)





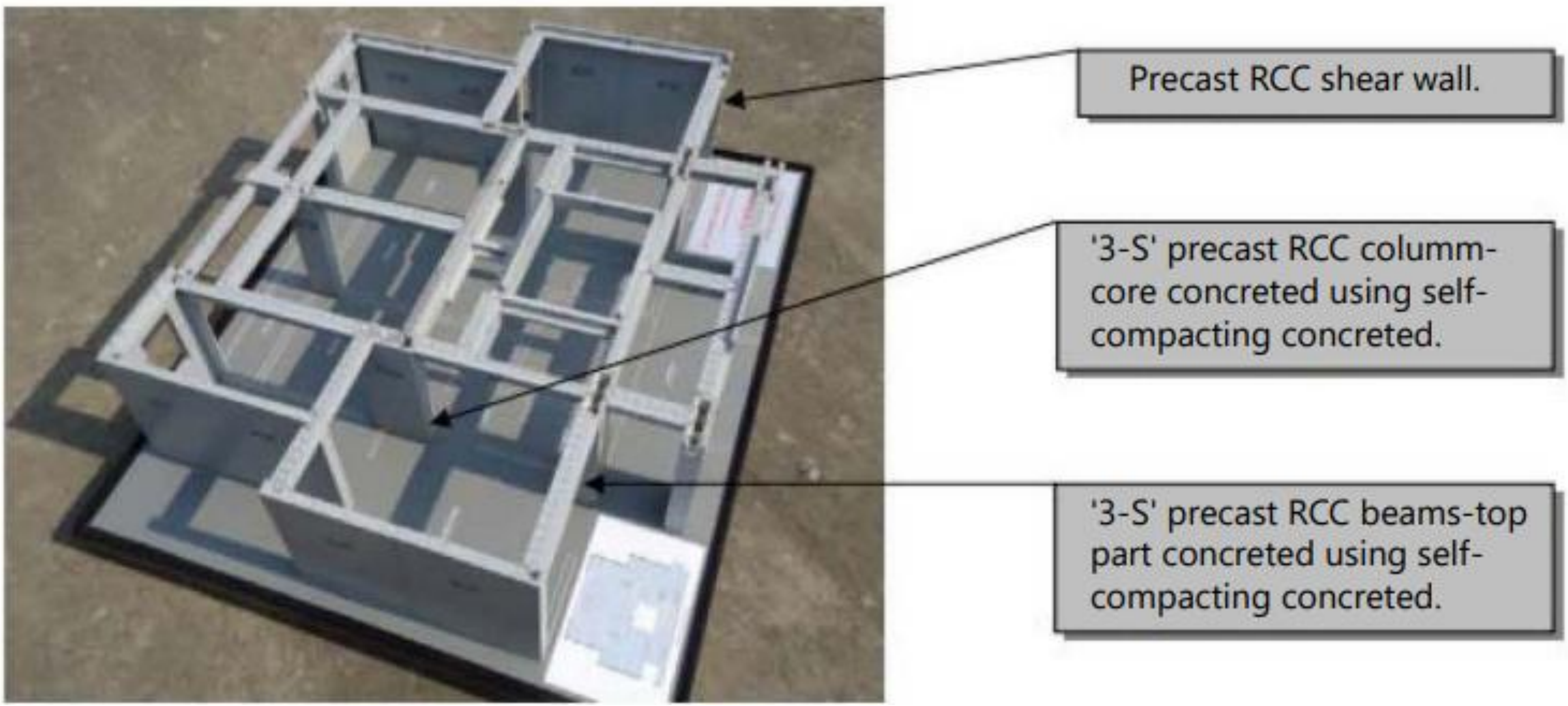
INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

LHP- Chennai (Precast Concrete Construction System)

3S system incorporates precast dense reinforced cement concrete hollow core columns, structural RCC shear walls (as per design demand), T/L/Rectangular shaped beams, stairs, solid precast RCC slabs for floor/ roof, lintels, parapets and chajjas.

Salient features

- ✓ Precast dense reinforced cement concrete hollow core columns, structural RCC shear walls, T/L/Rectangular shaped beams, stairs, floor/roof solid.
- ✓ AAC blocks are used for partition walls



INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

LHP- Indore (Prefabricated Sandwich Panel System)

- ✓ Prefabricated Sandwich Panels are lightweight composite wall, floor, and roof sandwich panels.
- ✓ They are made of thin fiber cement/calcium silicate board acting as face covered boards with the core material as a mix of EPS granule balls, adhesive, cement, sand, flyash, and other bonding materials in mortar form.
- ✓ The core material is pushed under pressure into preset molds in a slurry state.

Salient features

- ✓ Facilitate quick and cost-effective construction
- ✓ EPS granule balls used as core material make the board lightweight

Pole Holes

Solid Heart

Rod Holes

Block Holes

INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

LHP- Lucknow (PVC Stay-in-place formwork)

- ✓ Stay-in-place formwork refers to an innovative formwork system made of rigid polyvinyl chloride (PVC) that acts as durable finished formwork for concrete walls.
- ✓ It has slide and interlock technology for the extruded components to create continuous formwork.
- ✓ The two faces of the wall are connected by continuous web members to form hollow rectangular components

Salient features

- ✓ Rigid polyvinyl chloride (PVC) based formwork system serves as a permanent stay-in-place durable finished formwork for concrete walls
- ✓ The PVC extrusions consist of the substrate (inner) and modifier (outer). The two layers are co-extruded during the manufacturing process to create a solid profile.

INNOVATIVE BUILDING MATERIALS AND NEW METHODS OF CONSTRUCTION FOR AFFORDABLE HOUSING

LHP- Rajkot (Monolithic concrete construction with tunnel formwork

- ✓ LHP Rajkot utilized tunnel formwork as the innovative construction technology which uses customized engineering formwork replacing the conventional steel/plywood shuttering system.
- ✓ Tunnel formwork is used cellular structures. It is based on two half shells which are placed together to form a room or cell and several cells constitute an apartment.

Characteristics of the system

- Maximum span between walls shall be 5.60 m without accessory units and 7.00 m with accessory units.
- Height of the formwork – Typically, the forms are designed for a floor to ceiling height of at least 2.51 m.However, it can be increased by using the leg jacks or movable panels.
- Appearances of the faces after form removal – The joints connecting the units may have fins which should be sanded off and smoothed with paint filler. Remaining surfaces allow direct application of finishing paint or wallpaper.
- Working rhythm using the system – Under average temperature conditions, the normal rhythm is two days per cycle with one day and two nights for drying and setting the concrete, given ordinary cement is used.
- Time period required for execution of the process – The time required for execution varies according to the cell plan. For a cell consisting of two formed wall surfaces and a floor surface, the average time is less than 1-1.5 hours per square meter of building. This time includes the form removal, oiling, displacement of the units, formwork, and adjustment.

LHP-Ranchi (Pre-cast concrete construction- 3D Volumetric)

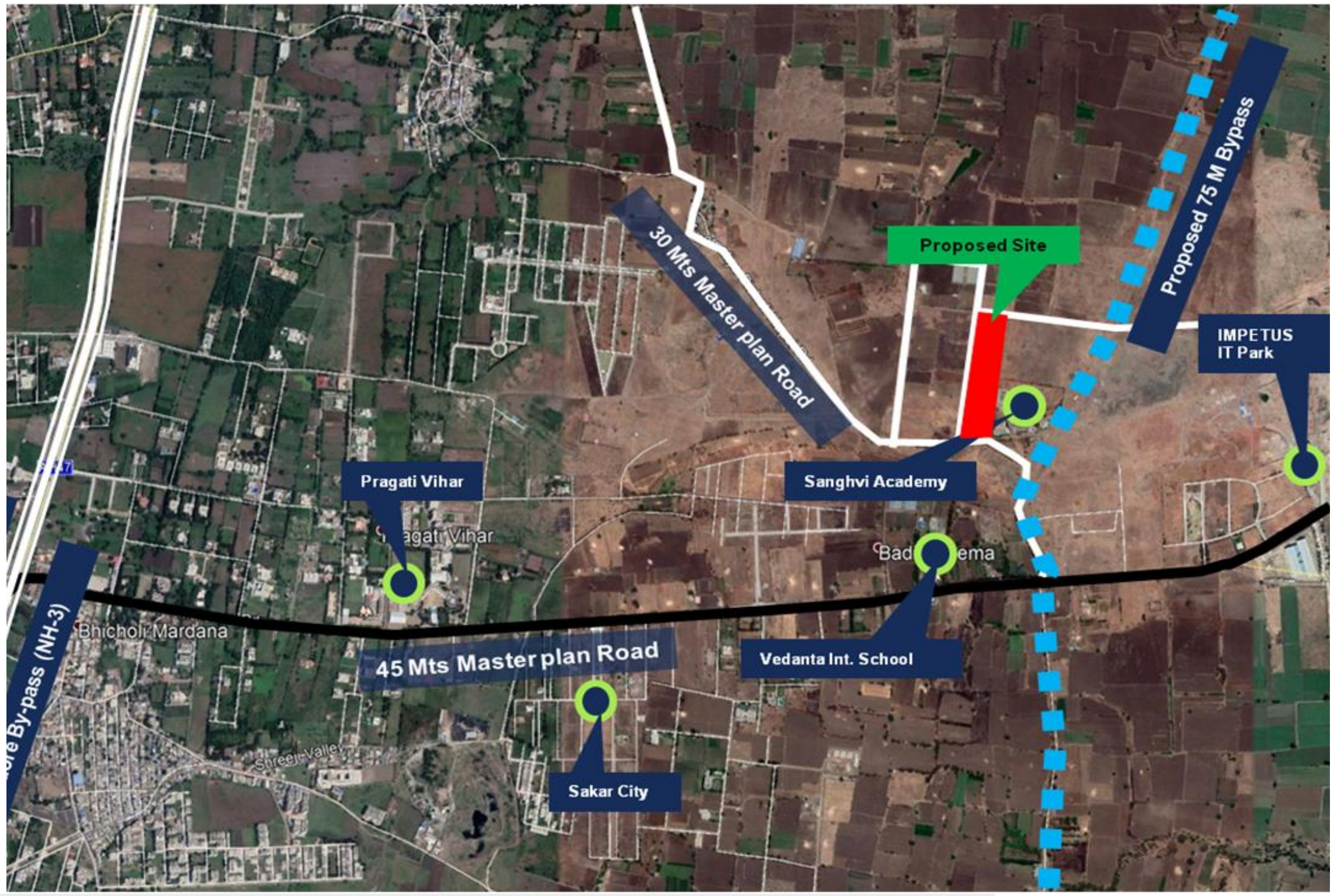
3D Volumetric concrete construction involves construction with solid precast concrete structural modules like room, toilet, kitchen, bathroom, stairs etc. & any combination of these. The modules are cast monolithically either at a plant or a casting yard in a controlled condition.

Salient features

- ✓ About 90 % of the building work including finishing is complete in the plant/ casting yard resulting in significant reduction in constructior and occupancy time
- ✓ The required concrete can be designed using industrial by-products such as Fly Ash, Ground granulated blast furnace slag (GGBS), Micro silica etc. resulting in improve(workability
- ✓ Minimal shutter and scaffolding

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

LIGHT HOUSE PROJECT, INDORE



Description	Unit	Length	Width	Area
Living Room	Sqmt	3.12	3.08	9.61
Bed Room	Sqmt	3.12	2.99	9.33
Kitchen	Sqmt	2.1	1.81	3.80
Toilet	Sqmt	2.1	1.2	2.52
Balcony	Sqmt	2.07	1.06	2.19
Circulation Area	Sqmt	2.19	0.9	1.97
Thresold Area	Sqmt			0.50
Total Carpet Area	Sqmt			29.92

LIGHT HOUSE PROJECT, INDORE

Project Details

Land Area – 41920 sqm
Net Plot Area – 34276 sqm
No's of Dwelling Unit – 1024
No's of Tower – 08
No's of Floor – *SF* + 08
No's of DU / Tower – 128
Community Hall – 169.5 sqm

Key Highlights

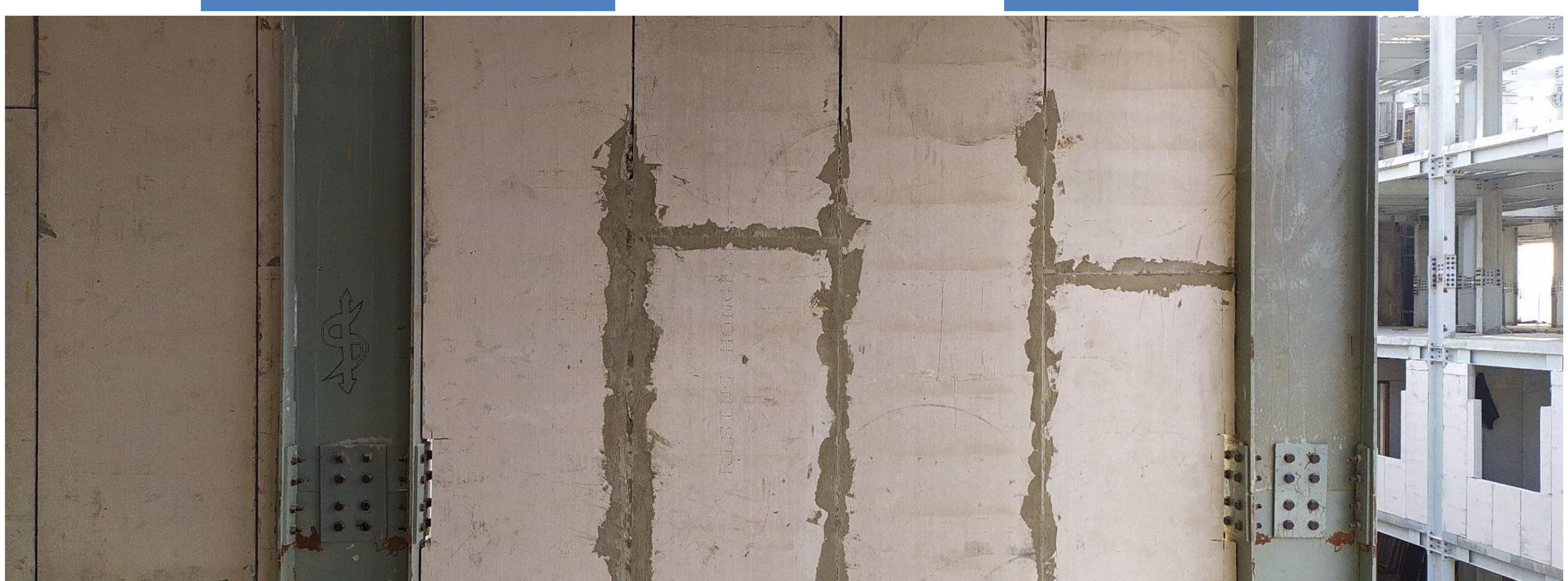
Technology – Pre-Fabricated Sandwich Panel & PEB Structure
Project Start Date – 01-01-2021
Project Expected End Date – 31-03-2022
Amenities –
Rain Water Harvesting
Rooftop Solar Power System
Fire Equipment (s)
Elevator / Lift
Emergency Power Back-up
Sewage Treatment Plant
Central Waste Collection Plant

LIGHT HOUSE PROJECT, INDORE- TECHNOLOGY

Structural System – *Pre Engineering Building*
Slab- *Deck Sheet Slab*
Walling System - *Pre fabricated sandwich panel system*

PEB STRUCTURE

DECK SHEET SLAB



PREFABRICATED SANDWICH PANEL WALLING

LIGHT HOUSE PROJECT, INDORE- TECHNOLOGY

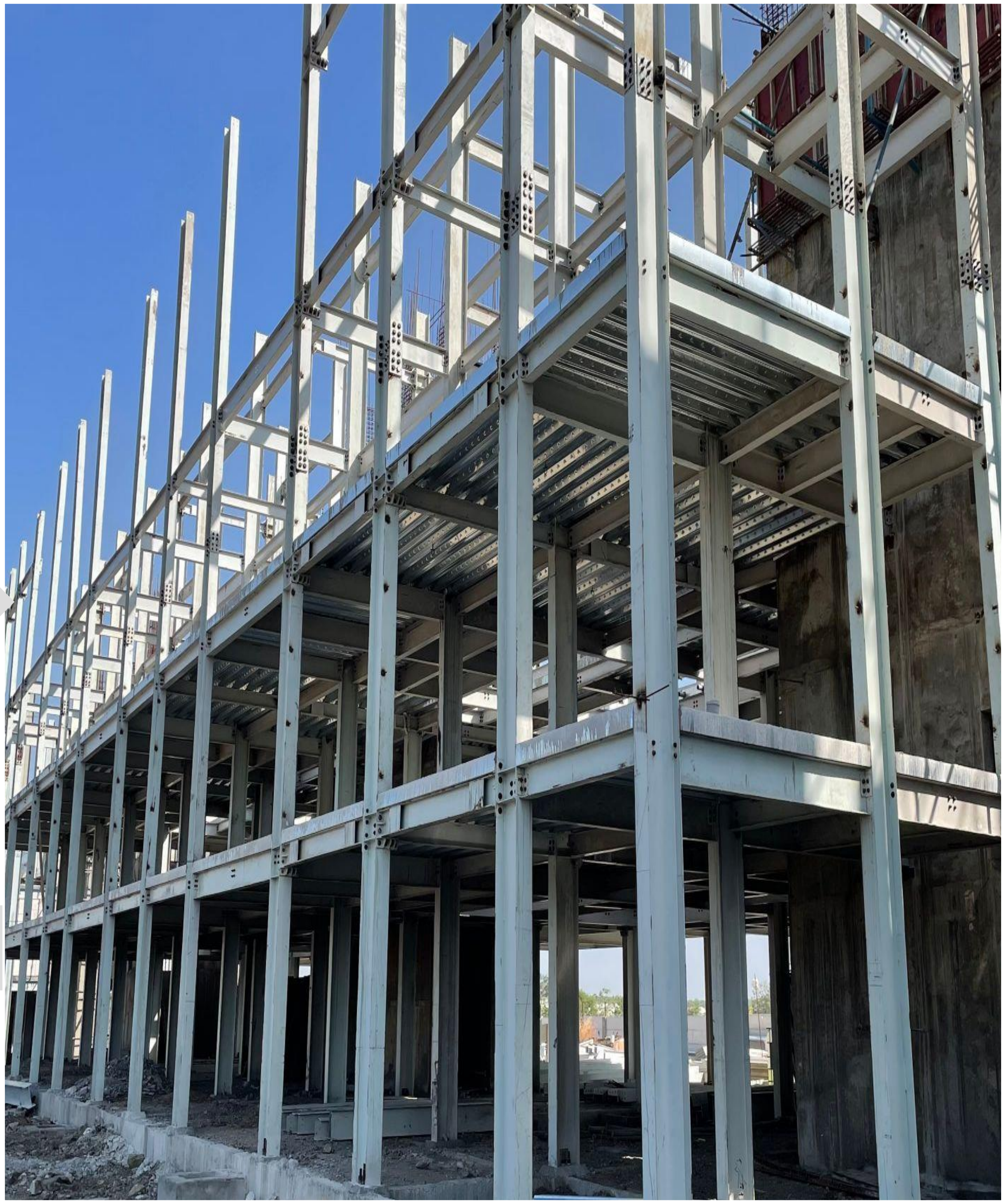
PEB STRUCTURE

- With **Pre-engineered steel building** systems, multi-stories can now be scripted in the shortest "set-up" time
- Speed in Construction

Lifting

Assembled Structure

Bolting



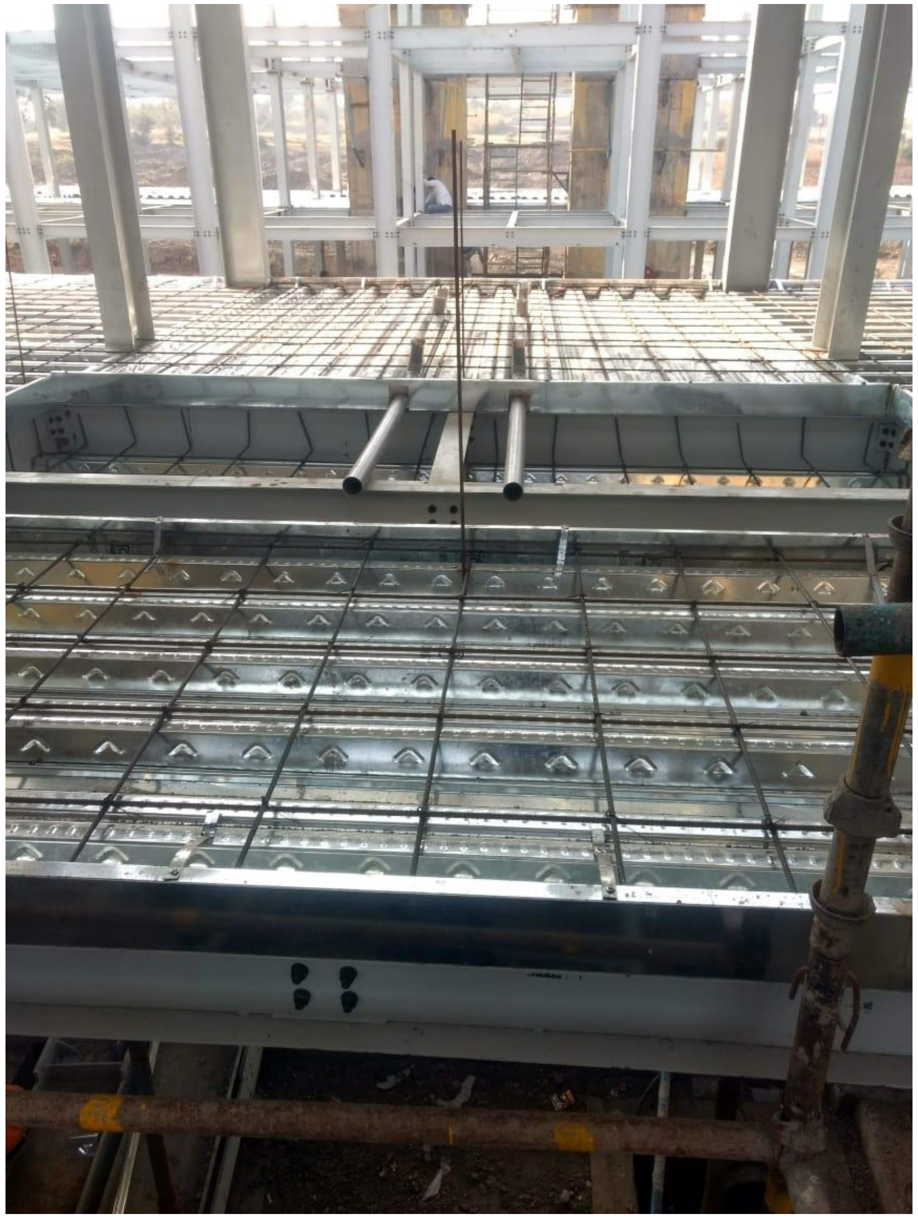
LIGHT HOUSE PROJECT, INDORE- TECHNOLOGY

DECK SLAB

Deck sheet laying

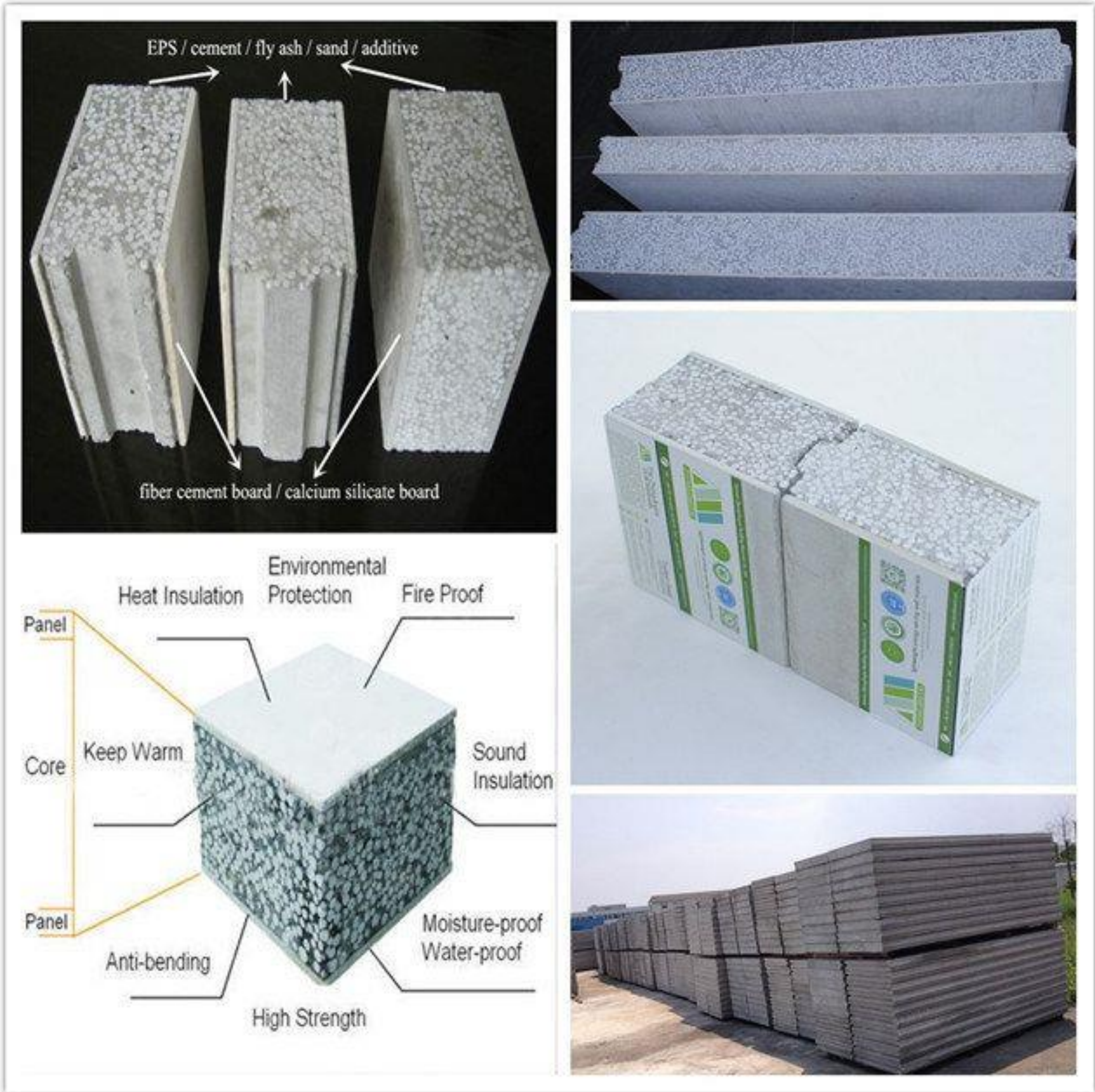
Services & reinforcement laying

Concreting



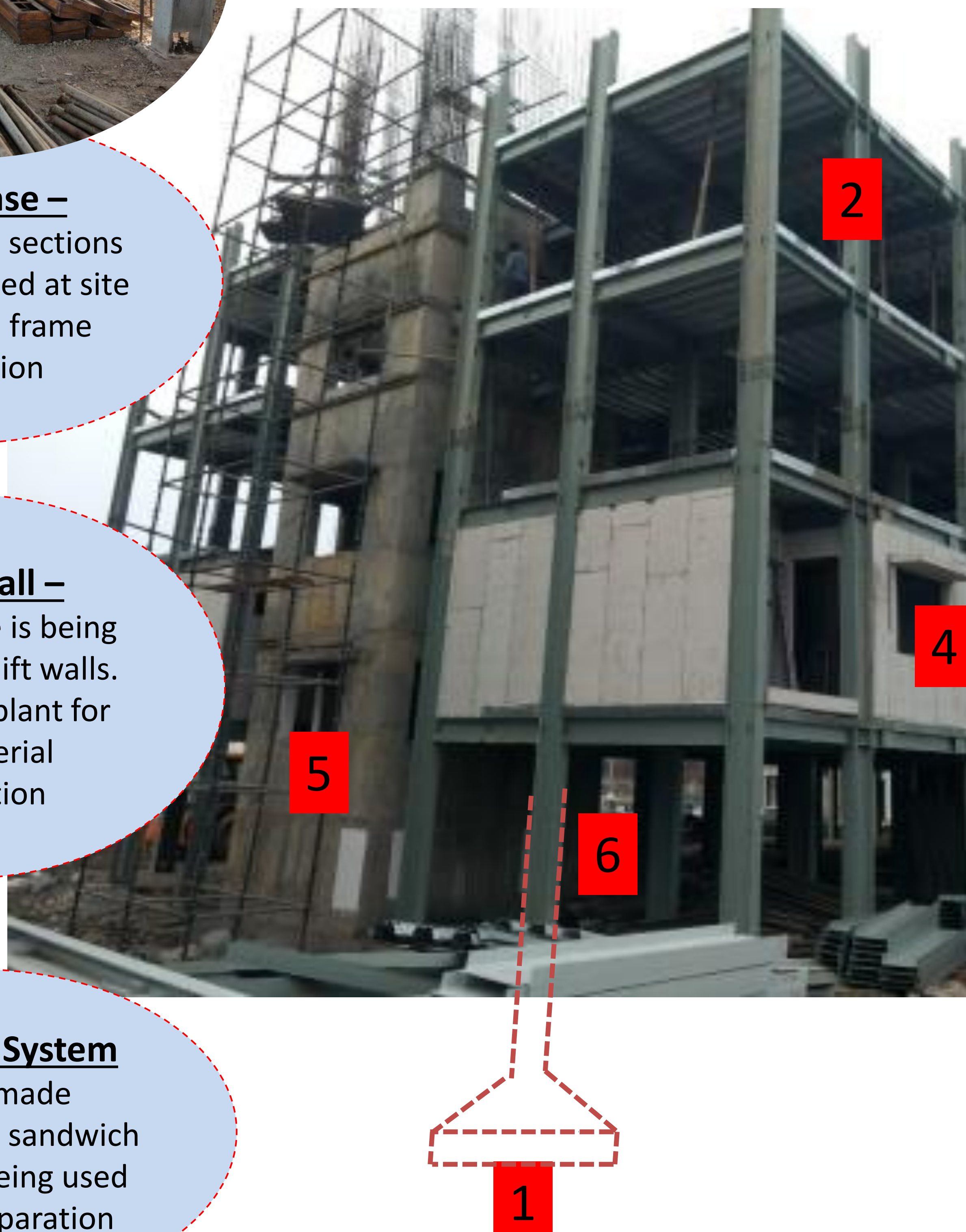
LIGHT HOUSE PROJECT, INDORE- TECHNOLOGY

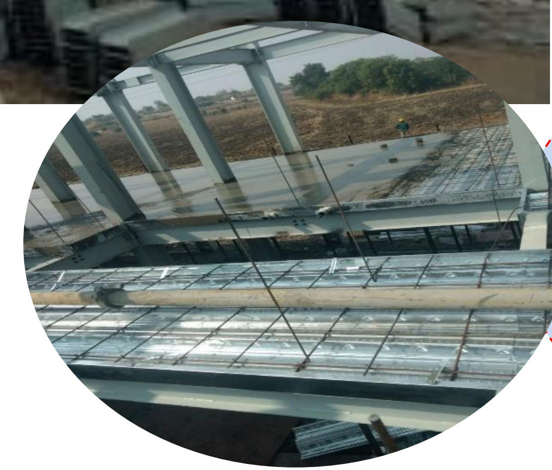
PRE FABRICATED SANDWICH PANEL SYSTEM



- Speed in Construction
- No use of water in curing
- Panels bring resource efficiency, better thermal insulation, acoustics & energy efficiency.

CONSTRUCTION METHDOLOGY





1.Substructure

RCC Isolated column footing

2.Structural System

Pre Engineered structure consists of factory manufactured steel column and beam erected on site.

3. Slab –

Deck sheet is placed on structure. over it, slab casting is done

4. Walling System

Factory made Prefabricated sandwich panels are being used for wall preparation

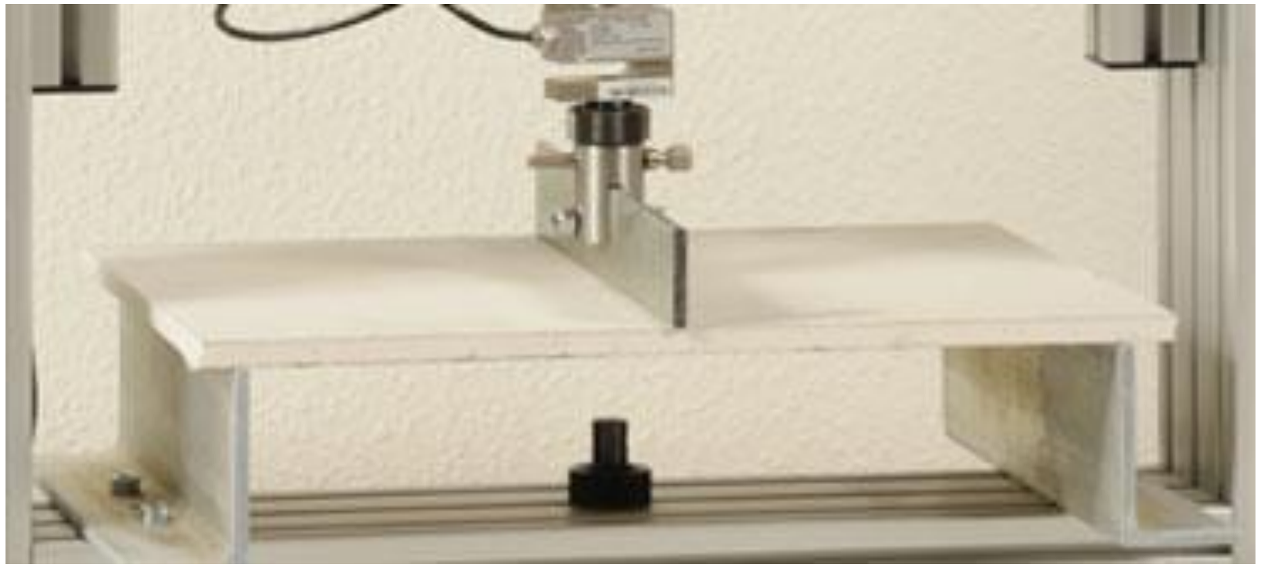
5. Lift Wall –

RCC structure is being prepared for lift walls. Onsite RMC plant for RCC material preparation

6. Staircase –

Fabricated MS sections are being welded at site for staircase frame preparation

LHP INDORE – TECHNOLOGY ADVANTAGES



Strength Test

Fast and Easy Construction

Fire Resistance Test

Energy saving by thermal resistance

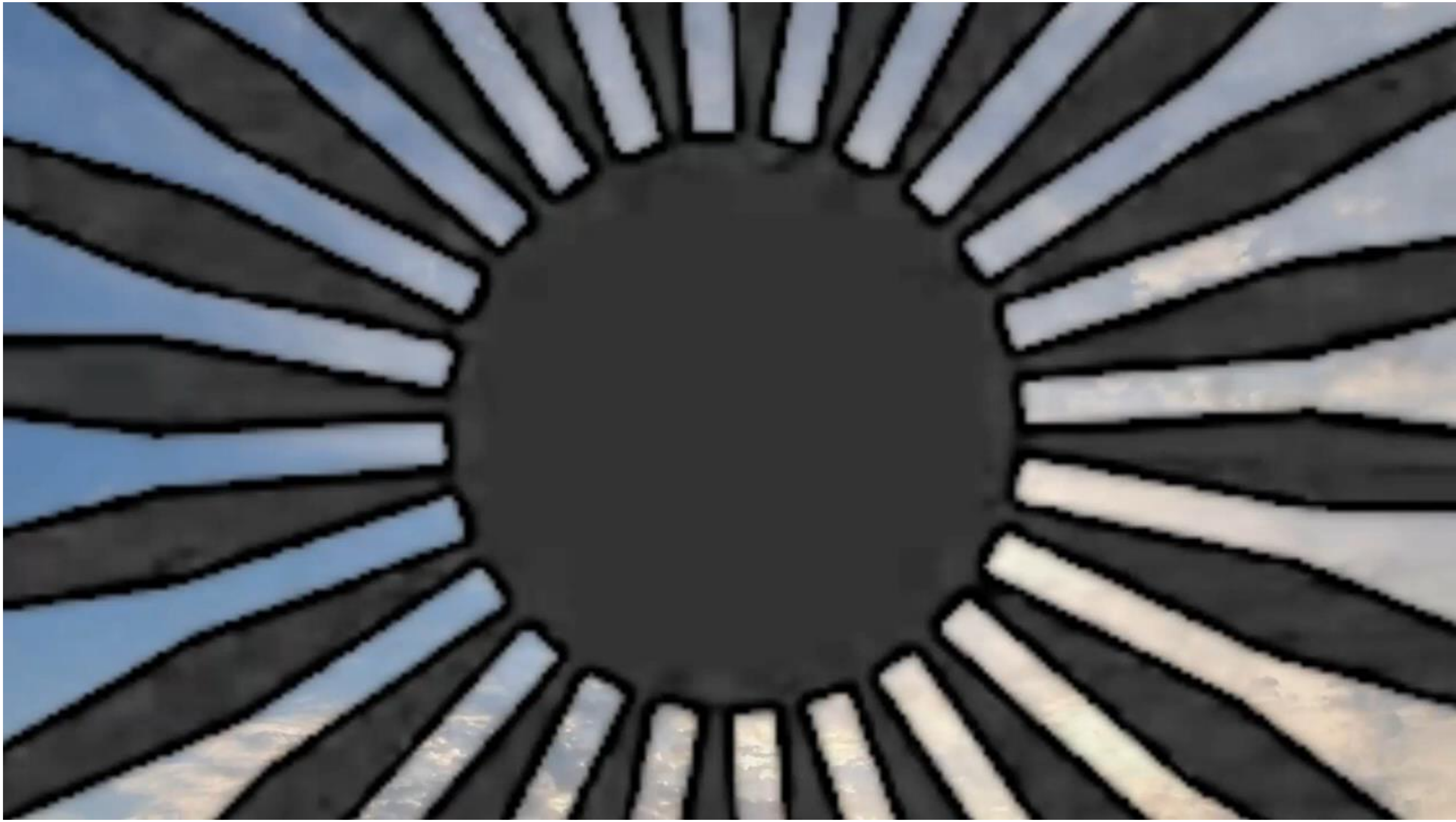
Recyclable

Eco friendly dry construction

1. Light weight and cost effective
2. Easy and faster construction
3. Fireproof
4. Water proof and damp proof
5. Non-toxic & environment-friendly
6. Energy saving & environment-friendly
7. Water saving due to dry construction
8. Smooth and flat surface, thus no plastering needed
9. High sound insulation
10. Cost effective
11. Ground staff optimization
12. Increase in carpet area up to 15% which saves money

https://youtu.be/3ENcie5HUqk

LHP INDORE – Via Video

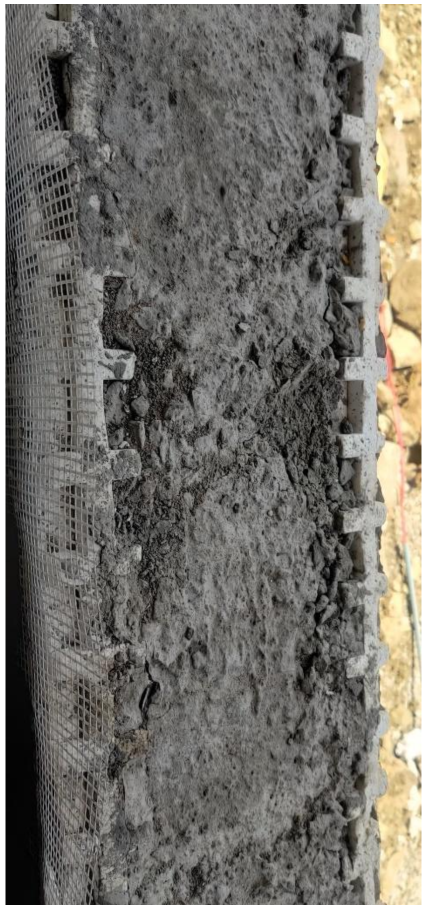


CASE STUDY – DEMONSTRATION HOUSING PROJECT BHOPAL

Insulating concrete forms (ICFs) cast-in-place concrete walls that are sandwiched between two layers of insulation material. These systems are strong and energy efficient.

Energy Efficient

It has the potential to significantly reduce the heating and cooling costs of a particular building. That’s also the most impressive feature of ICF walls; they can release heat in the summer and store heat in the winter. In some instances, ICFs are estimated to save about **20%** of total energy costs.



CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

Vernacular Buildings of North-East India

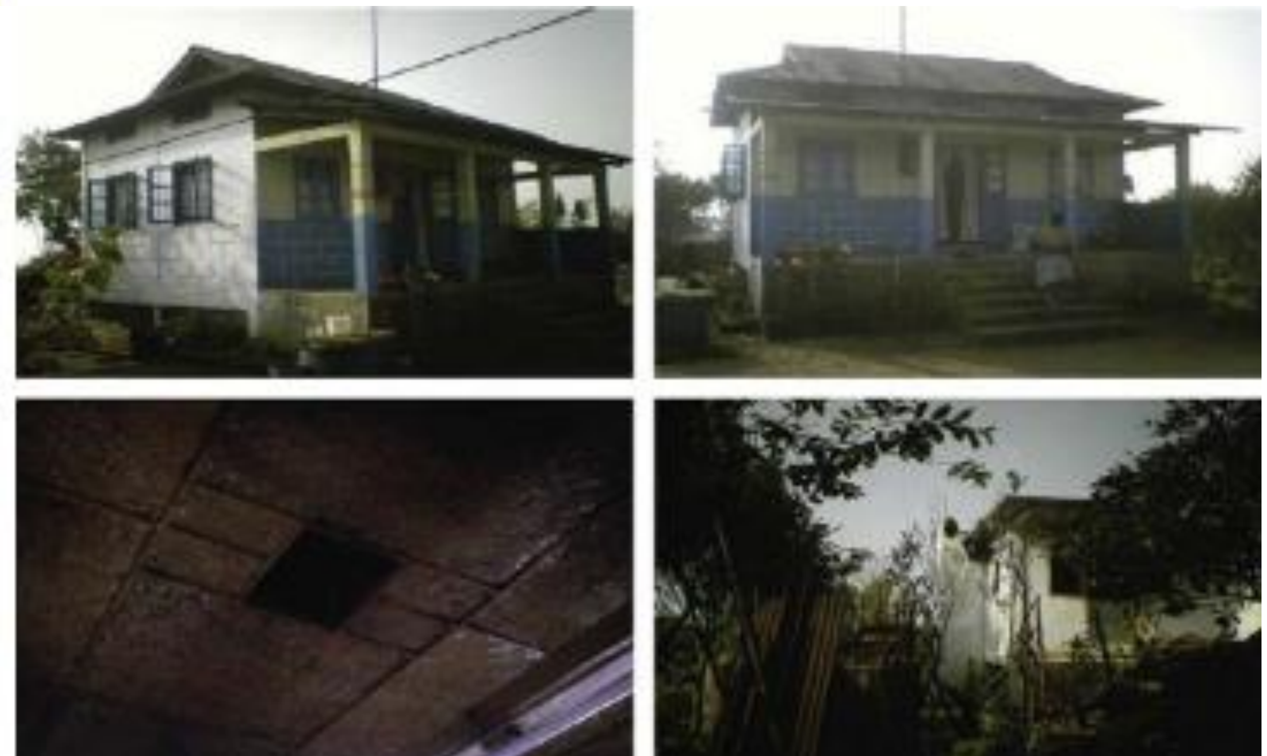
Features	Warm and Humid	Cool and Humid (Urban)	Cold and cloudy
Built up-area	94 sq. m.	77 sq. m.	44 sq. m.
Wall material and thickness	Brick, cement, and sand (0.127 m)	Processed mud and bamboo (0.076 m)	Rock slab, cement, and sand (0.20 m–0.25 m)
False ceiling and roof type	Asbestos sheet/wood. Galvanized tin sheet and tilted on two sides	Rare. Galvanized tin sheet and tilted on three sides	Asbestos sheet/ cane/bamboo mat/ wood. Galvanized tin sheet and tilted on four sides
Ventilation	High ventilation	Medium ventilation	Low ventilation
Layout and orientation	Open layout with courtyard; No specific orientation	Courtyard in rural housing only; East–west orientation and south facing	No courtyard; South sloping and east–west orientation
Prominent passive features	Air gap in ceiling, shading, extended roof used as overhang, chimney arrangement for effective ventilation	Houses are compact, proper care for ventilation	More compact, minimum surface to volume ratio, south sloping to receive maximum sun

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

Vernacular Buildings of North-East India

Various studies have been undertaken to understand the features of vernacular houses and their contributions towards thermal comfort in the North-East India.

Warm-Humid Climate



Cold-Humid Climate

Cold-Cloudy Climate

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

The study analyzed the relationship between indoor operative temperatures and the corresponding thermal sensation votes of occupants of the selected houses in Tezpur (warm-humid) and Imphal (cool-humid).

Major conclusions of the research have been listed below

- ✓ Indoor temperature swings are within 10°C for all months in the case of representative houses located in warm-humid and cool-humid climates which is permissible limit for naturally ventilated buildings.
- ✓ For the representative house in the cold and cloudy climate, the temperature swings are higher. This can be attributed to lower insulation and thermal inertia of walls than required.
- ✓ Larger adaptability in Tezpur and Imphal as observed in Figure 128 (larger width of neutral temperatures) indicates higher adaptability of occupants in naturally ventilated buildings.
- ✓ None of the houses exhibit significantly thermally comfortable environments in the winter months
- ✓ Occupants have enhanced control over indoor environments in the vernacular houses because they have the flexibility to control their personal and environmental conditions in the form of different adaptations.
- ✓ For all the cases studied, range of comfort temperatures lies between 6°C and 7.3°C

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

Pol Houses And Conventional Houses In Ahmedabad

A comparison of thermal performance of pol houses (PH) with contemporary houses (CH) in the city of Ahmedabad is discussed in this case study. The locations of five PH and five CH selected for the research are highlighted in images. The climate of Ahmedabad is classified as hot-dry according to the National Building Code of India (BIS, 2016).

Observations

- ✓ Both PH and CH perform almost similar with respect to comfort hours for both IMAC and ASHRAE-55 models
- ✓ The relationship between indoor air temperature and outdoor air temperature for pol houses (red regression line) and contemporary houses (blue regression line) is quite similar and moderately strong as
- ✓ In terms of response time to the outdoor conditions, PH were found to be marginally faster than CH.

Conclusions

Traditional knowledge and qualitative literature highlight thermal mass as one of the most important strategies to keep the heat out. However, the observations indicated that thermal mass alone may not be the best strategy in all situations

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

Rajkot Smart GHAR III

The Smart GHAR III in Rajkot is an affordable housing project under PMAY Untenable Slum Redevelopment.

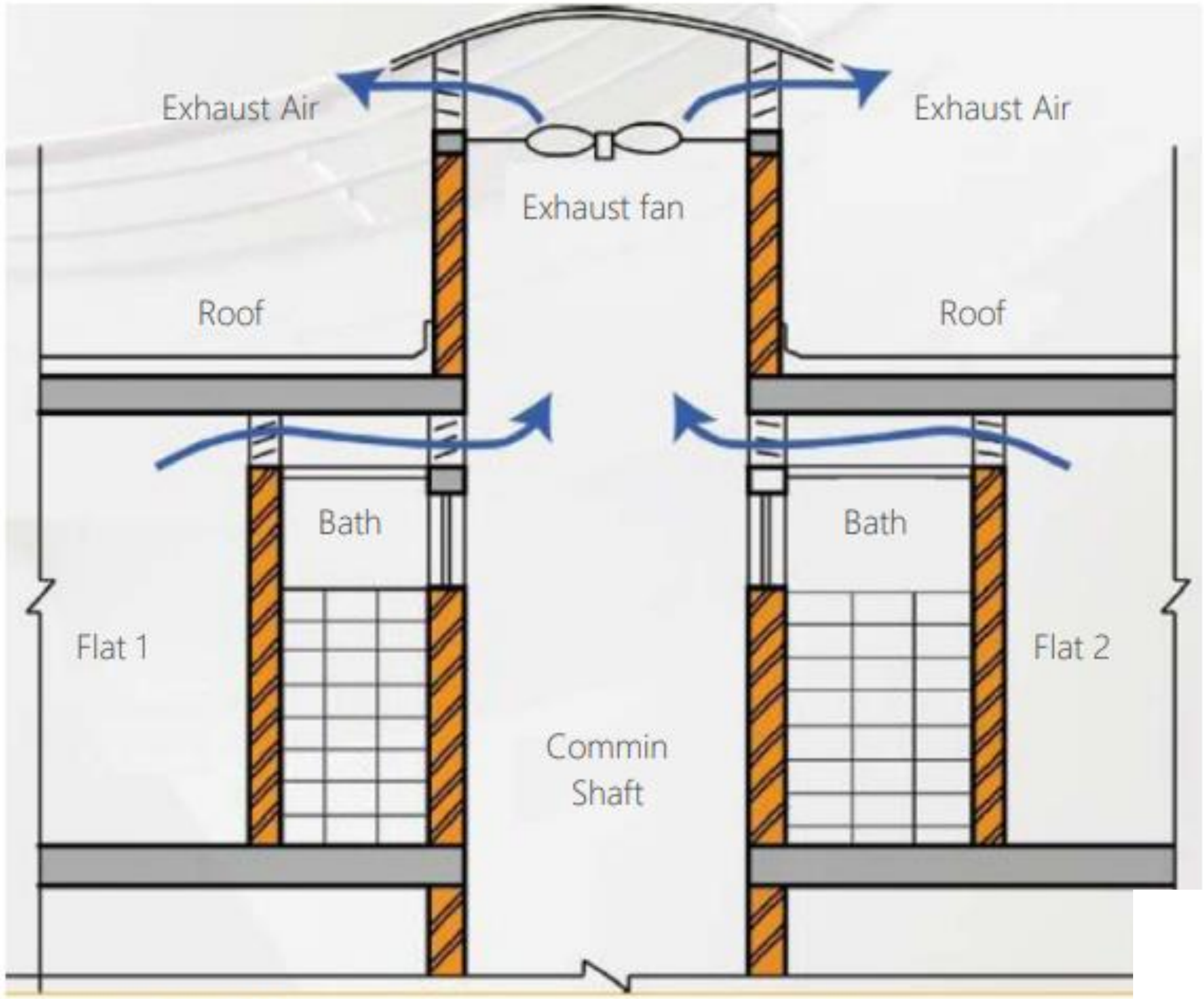
Some of the project details are listed below (Indo-Swiss Building Energy Efficiency Project (BEEP), 2021):

Site Area: 17,593 m2 ,	Built-up Area: 57,408 m2
No. of dwelling units (DU): 1176	Type of dwelling units: 1bhk
Built-up area per DU: 33.6 m2	Carpet area per DU: 29 m2
No. of residential towers: 11	No. of floors: Stilt + 7

Site layout for Rajkot Smart GHAR-III (PMAY) project.

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

Raikot Smart GHAR III



Reducing heat gains through walls and roof

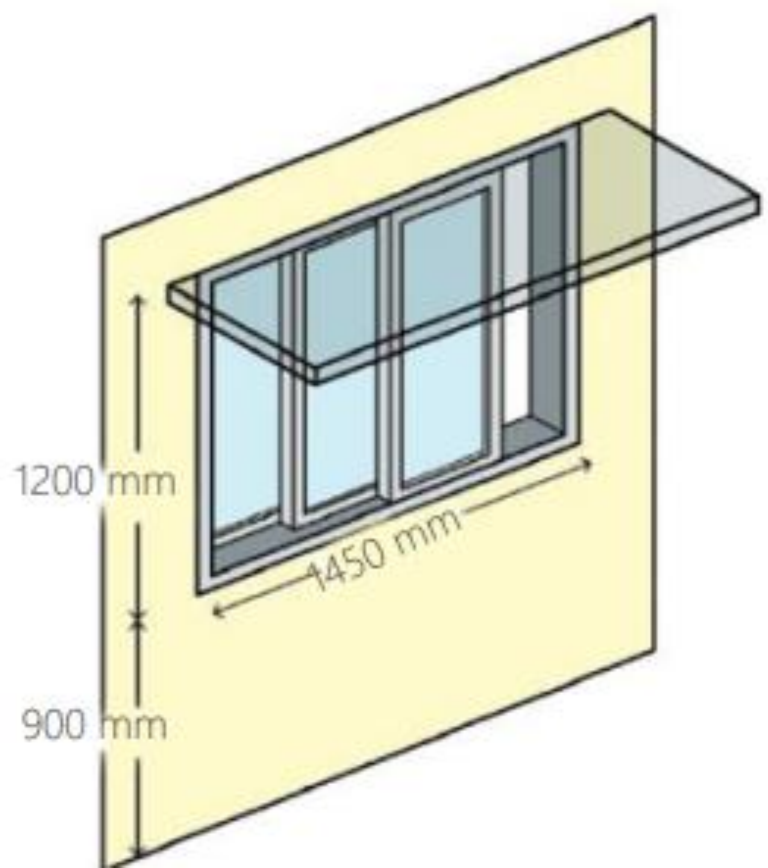
- ✓ Walling material was changed to 230mm thick AAC blocks instead of 230 mm burnt clay bricks. In doing so, the U-value of walls dropped to 0.8 W/m2 K from 2 W/m2 K
- ✓ 40mm PU foam insulation was added to the roof to bring the roof U-value to 0.56 W/m2 K from 2.7 W/m2 K
- ✓ 40mm PU foam insulation was added to the roof to bring the roof U-value to 0.56 W/m2 K from 2.7 W/m2 K

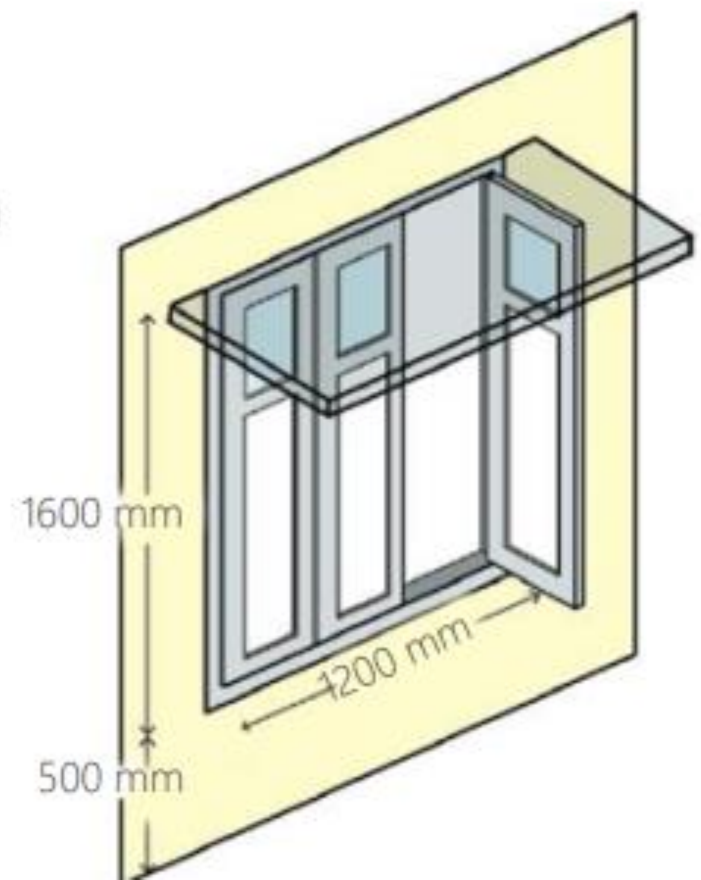
Improving ventilation through common service shaft

- ✓ To maintain a desirable wind flow rate for cooling through ventilation (10 air changes per hour) at all times, the existing service shaft between two buildings was modified
- ✓ A roof feature with exhaust fans on top of the shaft was added to create negative pressure in the shaft at all times

Fully glazed window design (left) was improved to taller, partially glazed casement windows (right)

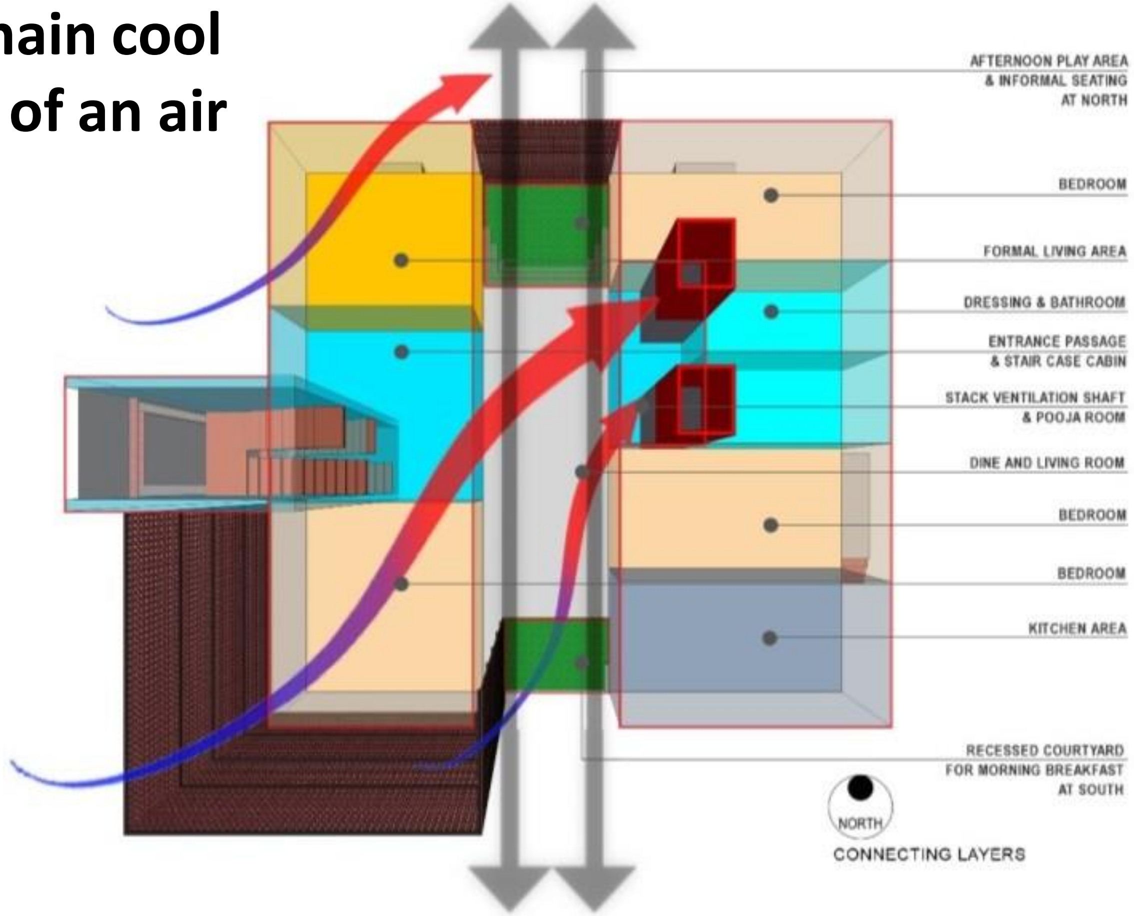
- ✓ This design was changed to a taller partially glazed casement type for selected windows. The 90% openable casement windows allowed for better ventilation flow rates
- ✓ The threeshutter design included two opaque and one glazed panel. The opaque panels cut the solar heat gains to 1/3rd of the original design while the 1/3rd glazed panel allowed daylight penetration into the spaces.





CASE STUDY - RAM BAUGH, BURHANPUR

A residence which has been designed to remain cool without the use of an air conditioner.



Key Features

- mutual shading
- optimal building orientation

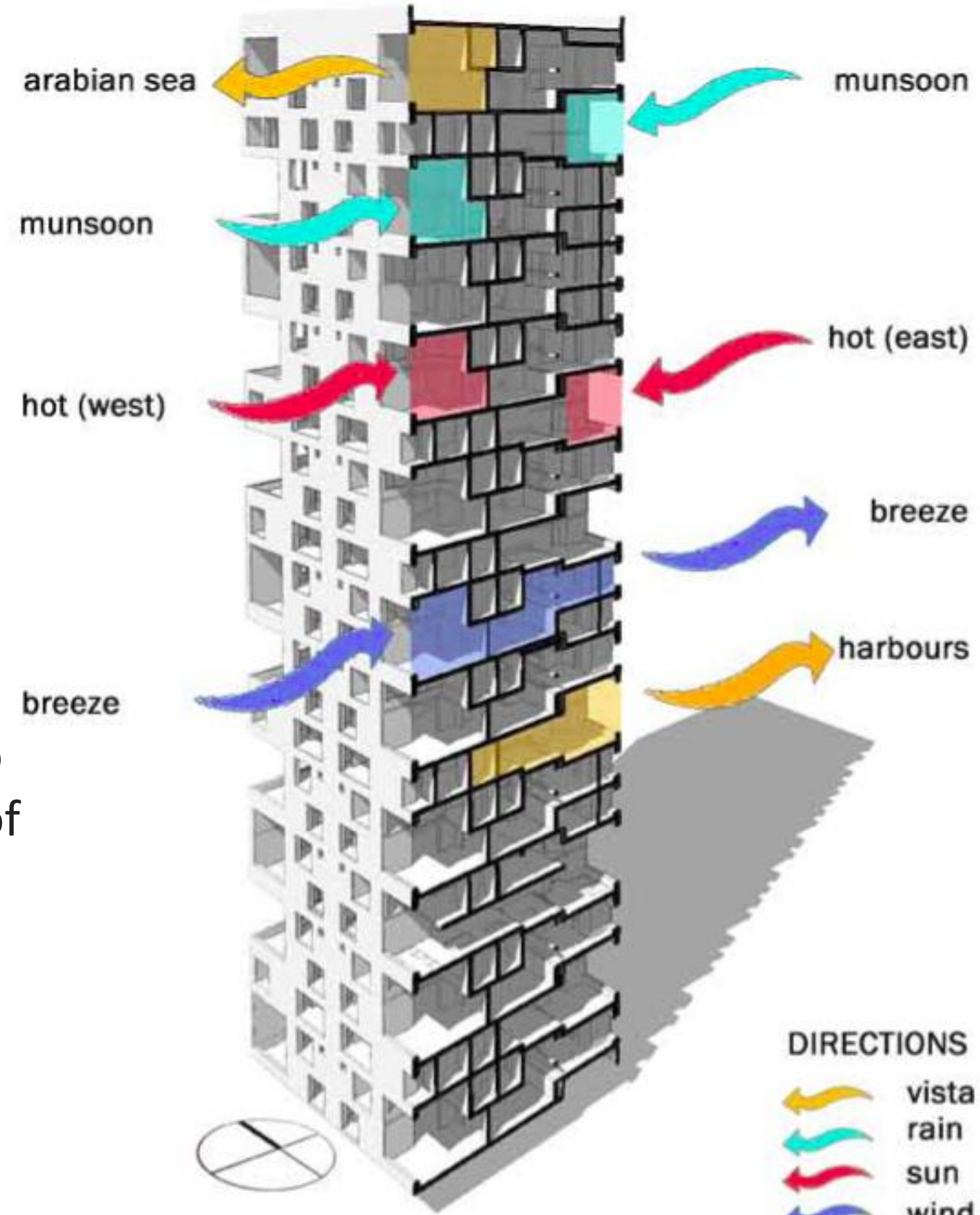
Source: Parekh Collaborative

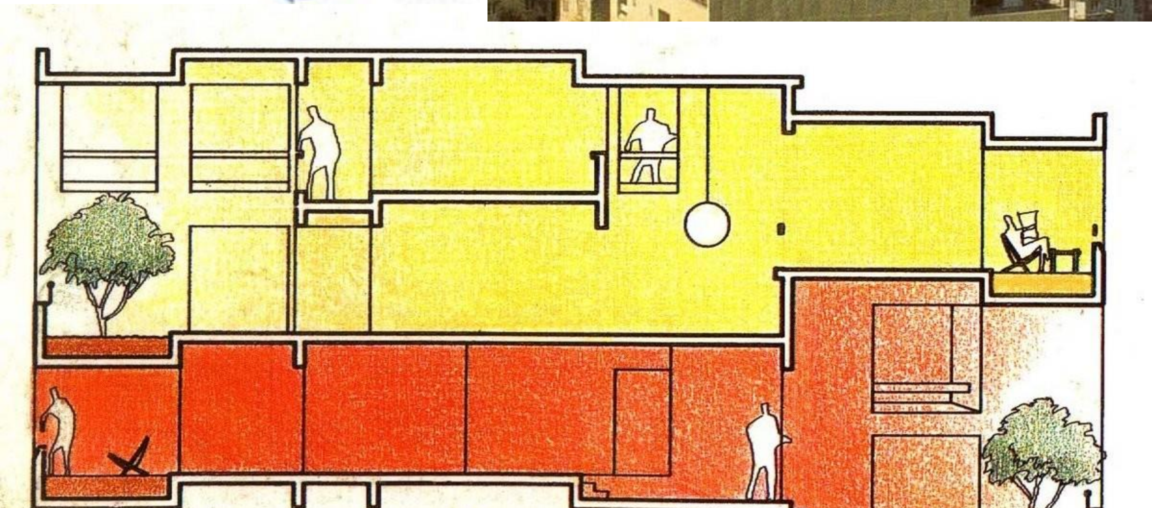
CASE STUDY - KANCHANJUNGA APARTMENTS

- **Architect:** Charles Correa
- **Location:** Bombay, India
- **Completed on:** 1983
- **Building Type:** Skyscraper multi-family housing
- **Construction System:** Concrete
- **Floors:** 32

Key Features

The main living spaces with an enclosed verandah whilst turning that buffer zone into a garden, thriving on the problem. Because of climatic considerations with existing views, the massing settled upon a configuration facing east and west





Typical section, showing interlock of basic units

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

LHP Indore Project Actual View

Typical Floor-plan

Wall U Value 1.37 W/m² °K
EPS Sandwich Panel, 120 mm

Roof U Value 1.80 W/m² °K
Deck sheet + RCC slab + brick-bat-coba + china mosaic tile, 135mm

Glass U Value 5.35 W/m² °K
VLT: 0.90, SHGC: 0.86

Natural Ventilated
Openings: Windows , doors

LPD (W/m²): 13:BR & LR, 10:Kt, 7.5:RR
LED technology based lightings

External Auxiliary Load Density: 8W/m²
If conventional utilities are being used

40+ lakh of investment to be done for upgradation of roof assembly for all towers

PROPOSED
PARAMETERS & ESTIMATIONS

Wall U Value 1.37 W/m² °K
EPS Sandwich Panel, 120 mm

Glass U Value 3.50 W/m² °K
VLT: 0.45, SHGC: 0.43

LPD (W/m²): 2.3:BR, 11.2:LR, 7.7:Kt, 5.0:RR
LED technology based lightings

₹ 950/ flat/ month
i.e. approx. 135 unit consumption/ flat/ month

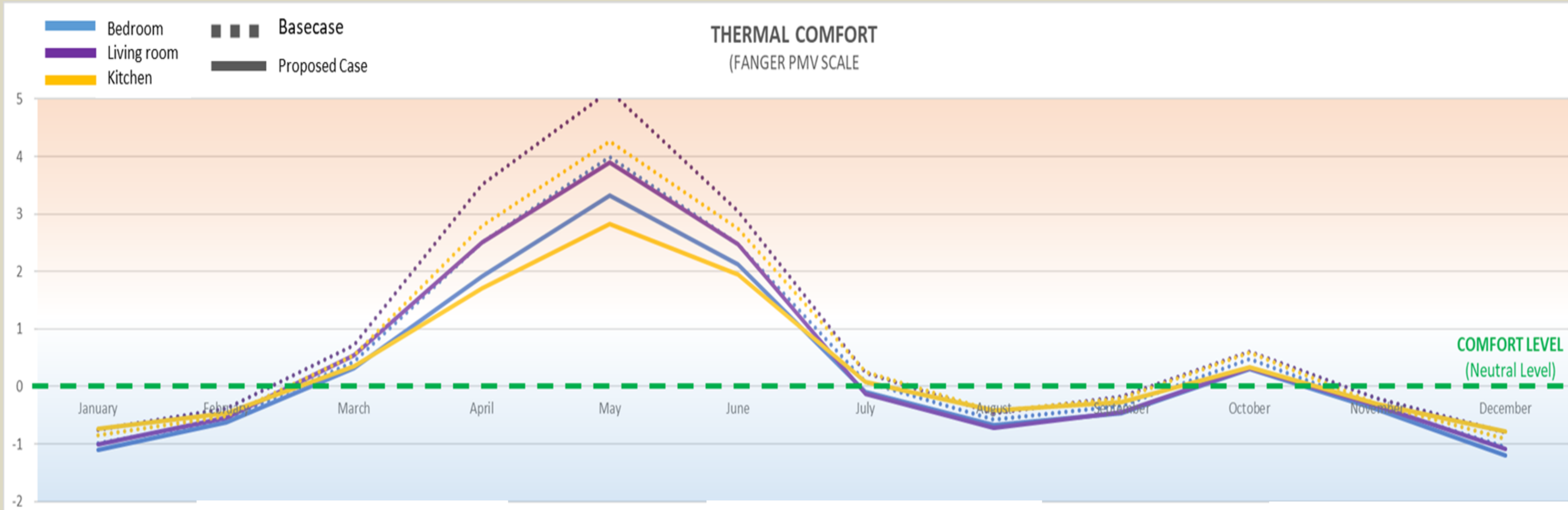
26%
(Reduction of annual energy consumption against conventional practice)
**estimation on the basis of simulation analysis*

Roof U Value 0.45 W/m² °K
Deck sheet + overdeck Insulation + RCC slab + brick-bat-coba + china mosaic tile, 150mm

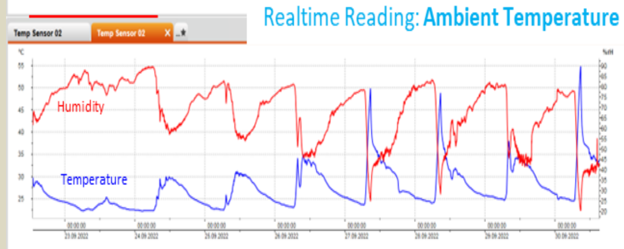
'0.72' PMV Scale i.e. Comfort level
Fanger's Natural Ventilated Index

External Auxiliary Load Density: 7.2W/m²
BEE Certified utilities are used

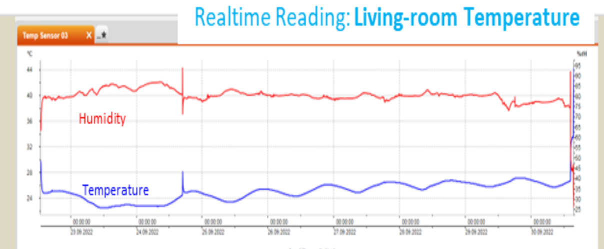
₹ Approx. ₹4850 annual savings on Energy Bills
i.e. approx. 700 unit consumption/ flat/ month



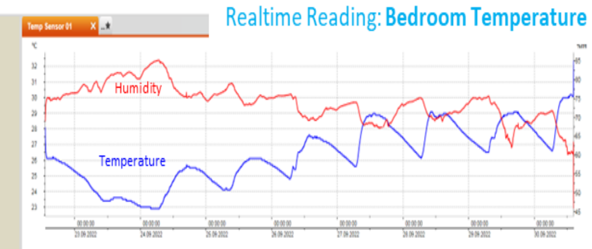
Realtime Reading: **Ambient Temperature**



Realtime Reading: **Living-room Temperature**



Realtime Reading: **Bedroom Temperature**

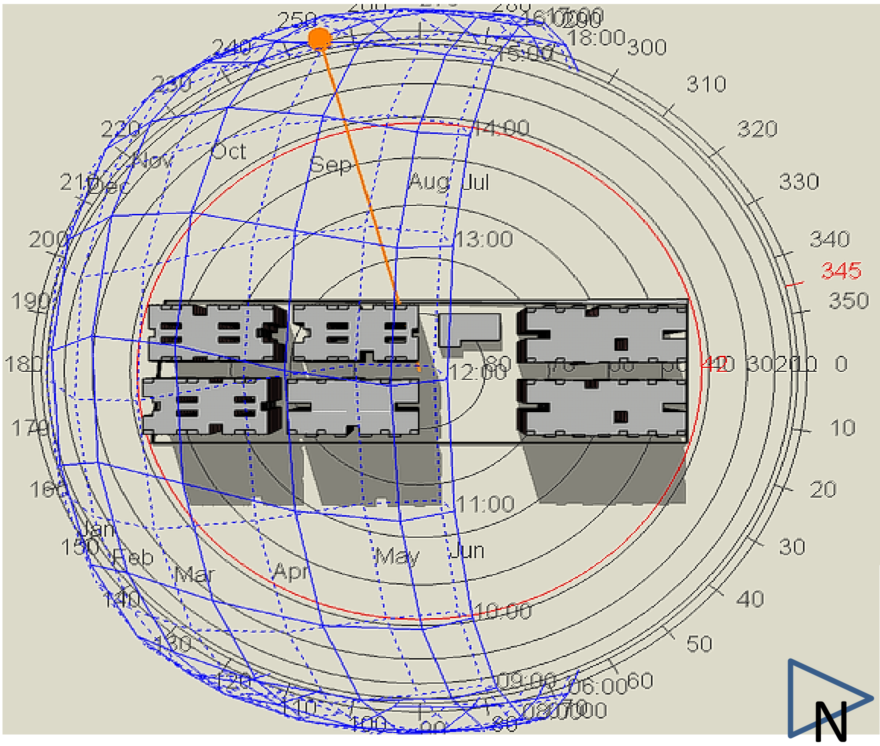


Advantages:
Reduction in Cooling Load – Approx 30%
Reduction in Electricity Consumption – Approx 26%

Key features:
Provision of Solar Rooftop System
Provision of Rain Water Harvesting
Provision of STP for re-use of treated water

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING
Demo Projects

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING



Project Details

Projects name- Lotus Green, Gita Nagar, Akola, Maharashtra

Climate Zone (as per NBC 2016) - Hot & Dry

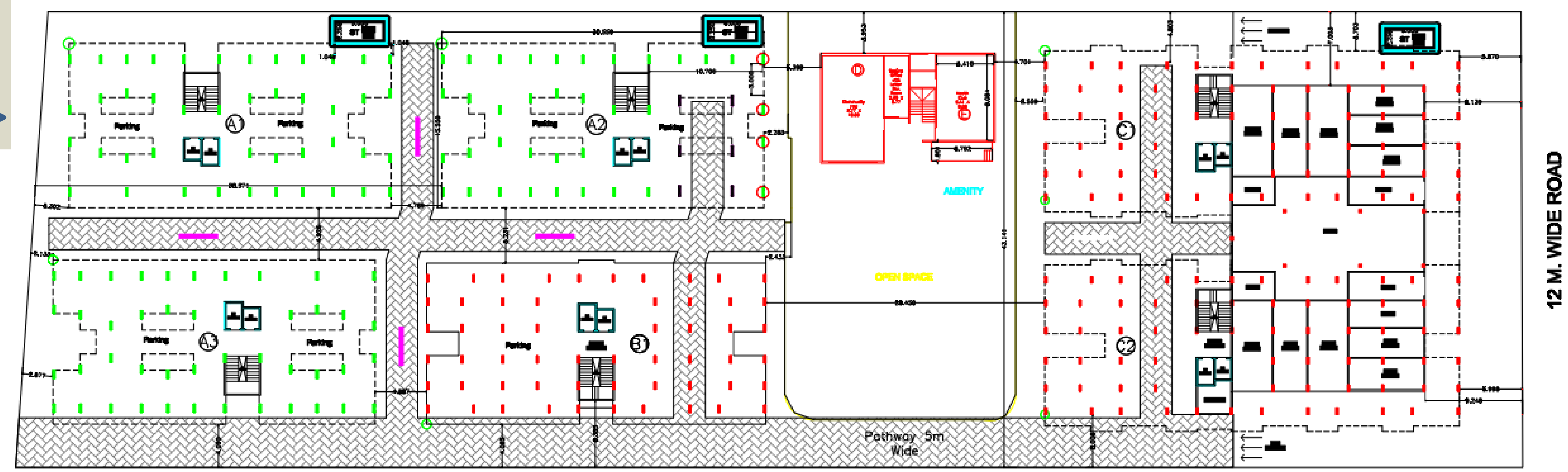
Site Area - 6100.00 sq. mt

Total Built-up Area 19751.26 sq. mt

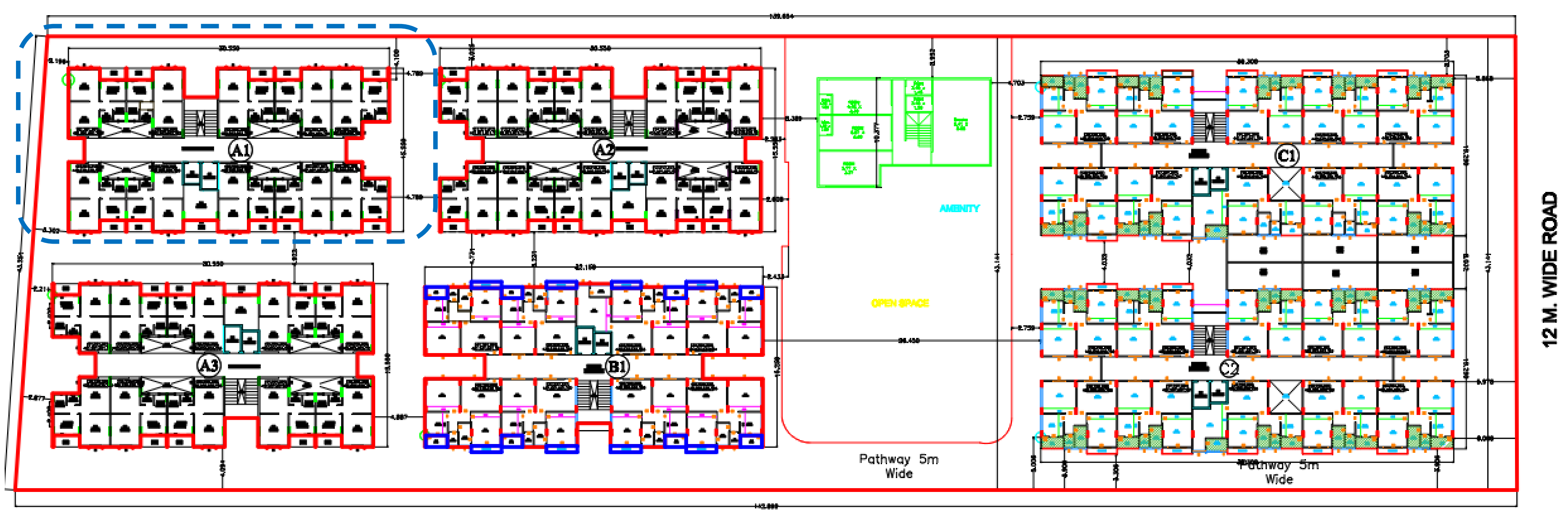
Structural system- RCC

Innovative design - Sandwich EPC Sheet in Outer concrete wall.

Aluform (mione – Technology) Construction work.



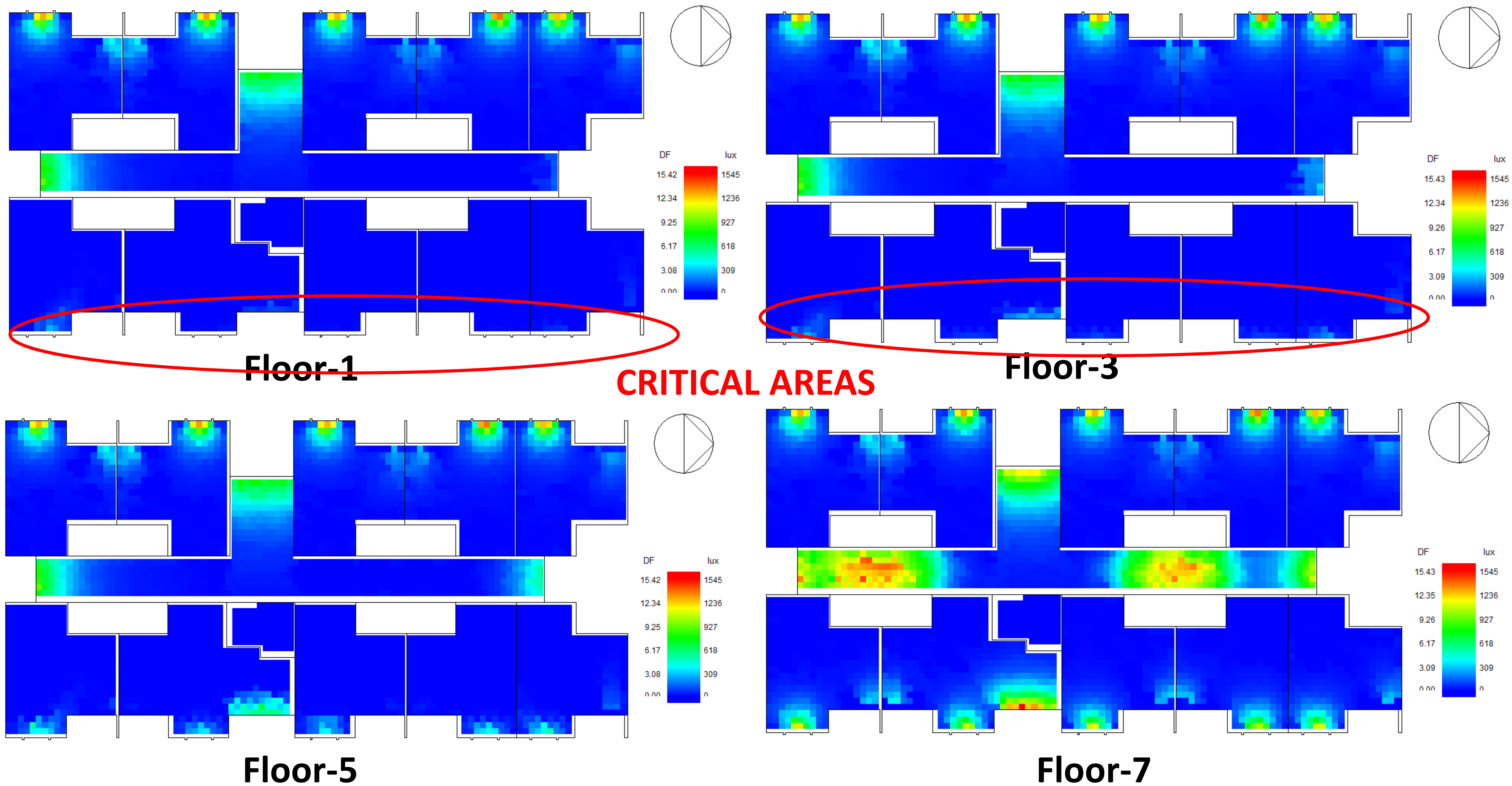
GROUND FLOOR - LAYOUT



TYPICAL 1ST TO 7TH FLOOR - LAYOUT

***Under Analysis Stage**

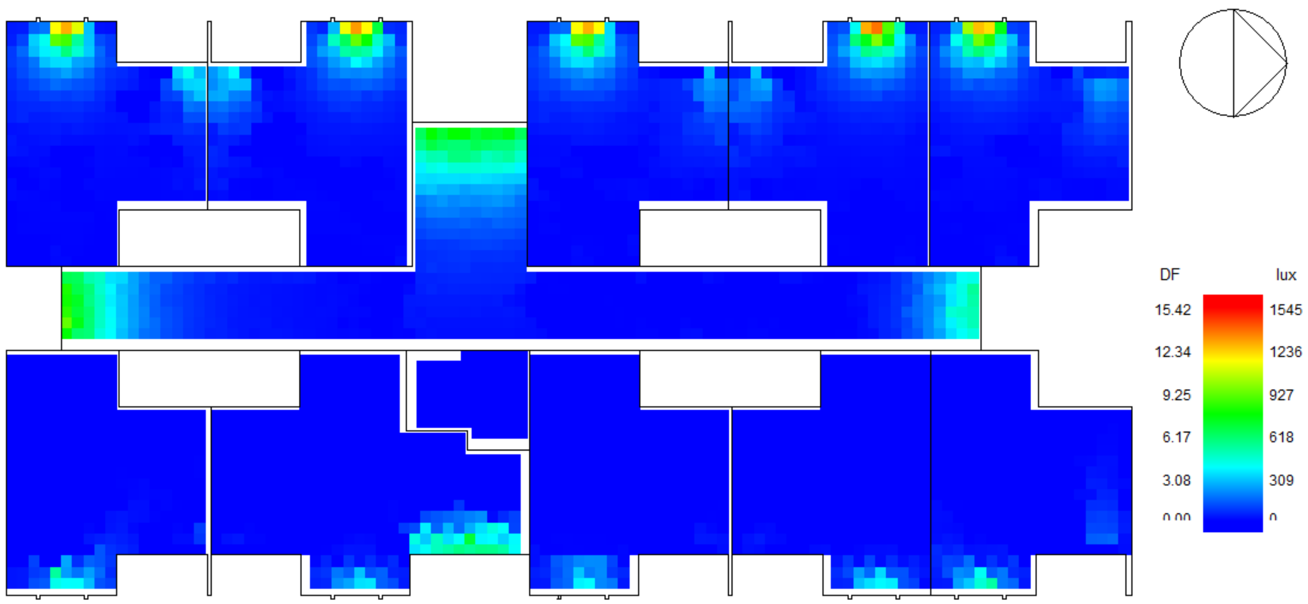
Daylight Analysis : Block-A1 (Base case)



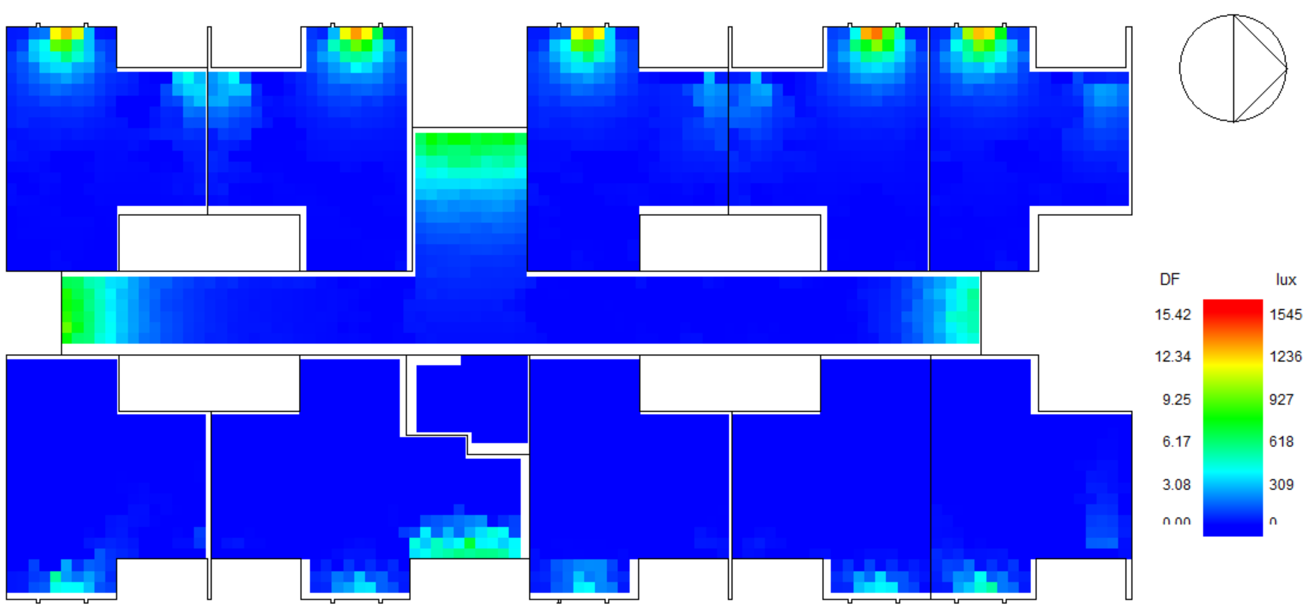
Analysis: shows that the inner side of blocks does not get daylighting up to 3rd floor due to mutual shading of nearby building blocks, above that 4th to 5th floor get the daylight but not in sufficient amount & Above 5th floor sufficient daylight is achieved.

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

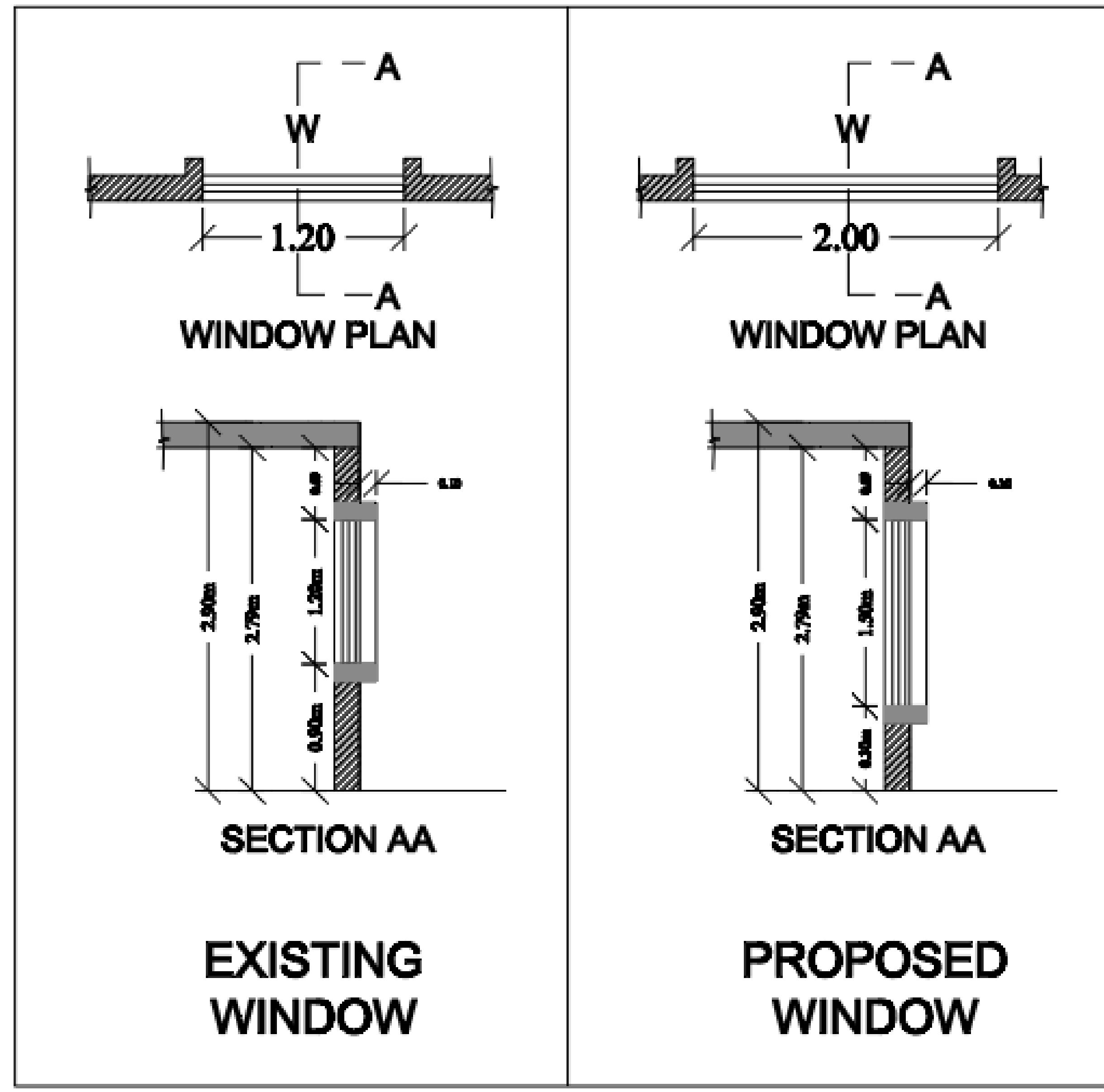
Daylight Analysis : Proposed Case
Block-A1,A2 Vise-versa for A3 (Proposed case)



Floor-1



Floor-3



As the Horizontal shading is provided only 100 mm depth, for Windows increasing the height by 300mm & width 800mm will enhance the daylight in the flats. But still won't be able to match the required useful Day lighting in the first to third floor.

Window To Floor Area Ratio (WFR)

Openable window-to-floor area ratio (*WFRop*) indicates the potential of using external air for ventilation. Ensuring minimum *WFRop* helps in ventilation, improvement in thermal comfort, and reduction in cooling energy.

CODE PROVISIONS

- ***Openable Window-to-Floor Area Ratio (WFRop)*** - it indicates the potential of using external air for ventilation.
- Ensuring minimum WFRop helps in ventilation, improvement in thermal comfort, and reduction in cooling energy
- It is the ratio of openable area to the carpet area of dwelling units.

$$WFR_{OP} = A_{openable} / A_{carpet}$$

3.1.3 The openable window-to-floor area ratio (WFR_{op}) shall not be less than the values[14] given in Table 1.

TABLE 1 Minimum requirement of window-to-floor area ratio (WFR_{op})

Climatic zone	Minimum WFR_{op} (%)
Composite	12.50
Hot-Dry	10.00
Warm-Humid	16.66
Temperate	12.50
Cold	8.33

SOURCE Adapted from Bureau of Indian Standards (BIS). 2016. National Building Code of India 2016. New Delhi: BIS.

Blocks	Windows Area	Carpet Area	
Block-A1	324.45	1906.75	16.13
Block-A2	324.45	1906.75	
Block-A3	324.45	1906.75	
Block-B1	367.92	2345.00	
Block-C1	436.59	2833.04	
Block-C2	436.59	2833.04	
Total WFR	2214.45	13731.33	
			(Required >10% as per ENS-Hot & dry Climate)

Window To Wall Area Ratio (WWR)

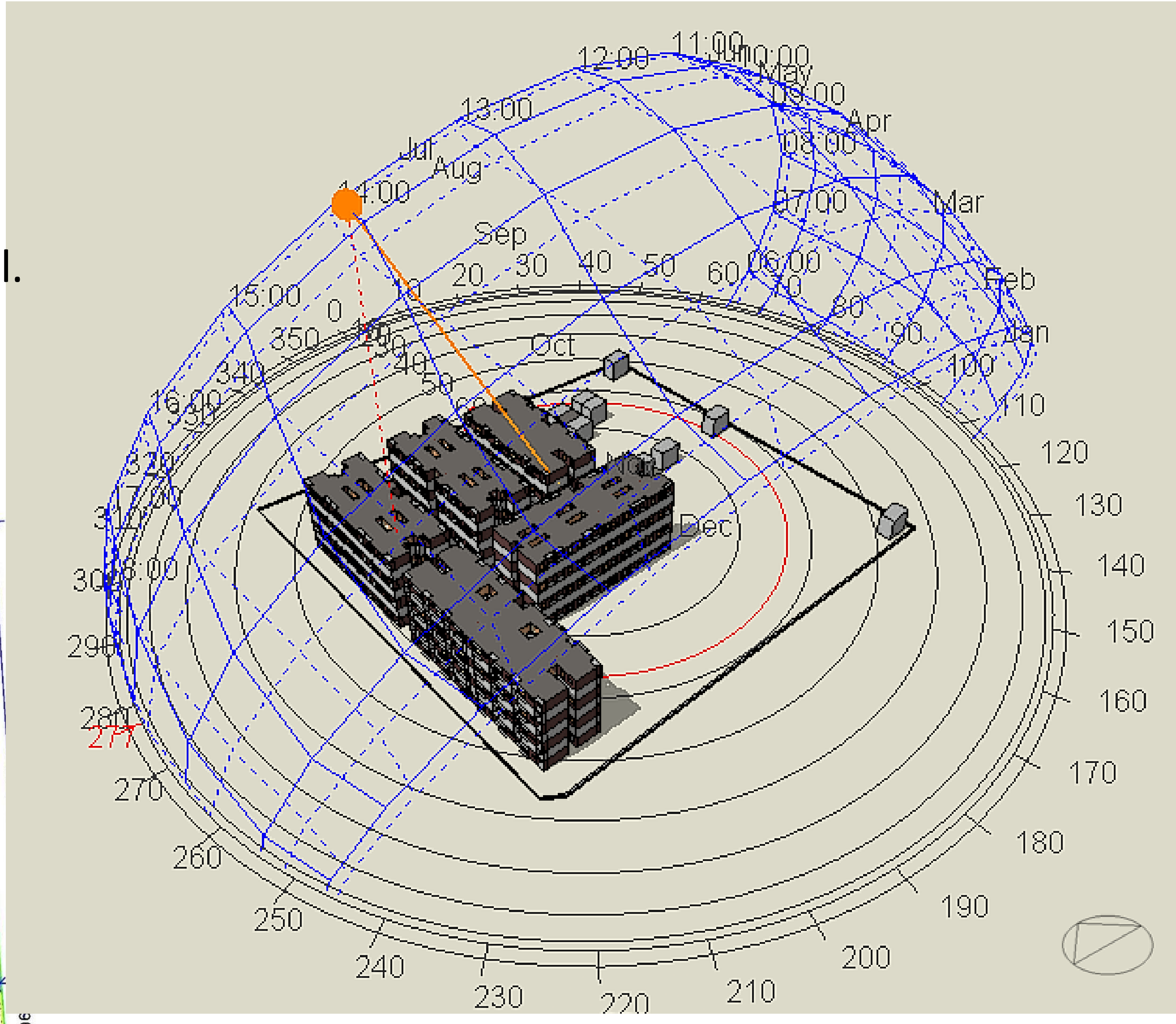
The Window-to-Wall Ratio (WWR) is **the fraction of the above grade wall area that is covered by fenestration, calculated as the ratio of the wall fenestration area to the gross above grade wall area.**

Block A1,A2,& A3			
Windows	WallArea	WWR (%)	
225.54	2464.42	9.15	(Excluding staircase & Passage Area)
Block B1			
Windows	WallArea	WWR (%)	
335.44	2633.925	12.74	(Excluding staircase & Passage Area)
Block C1 & C2			
Windows	WallArea	WWR(%)	
390.32	3019.625	12.93	(Excluding staircase & Passage Area)
TOTAL WWR (%)			
Windows	WallArea	WWR(%)	
951.3	8117.97	**11.72**	(Excluding staircase & Passage Area)

The Window-to-Wall Ratio (WWR) is found **11.72%,** WWR is directly proportional to daylighting areas, Hence, impact of WWR is shown in floor plans, therefore increasing in WWR helps to enhance the daylight area in the building blocks.

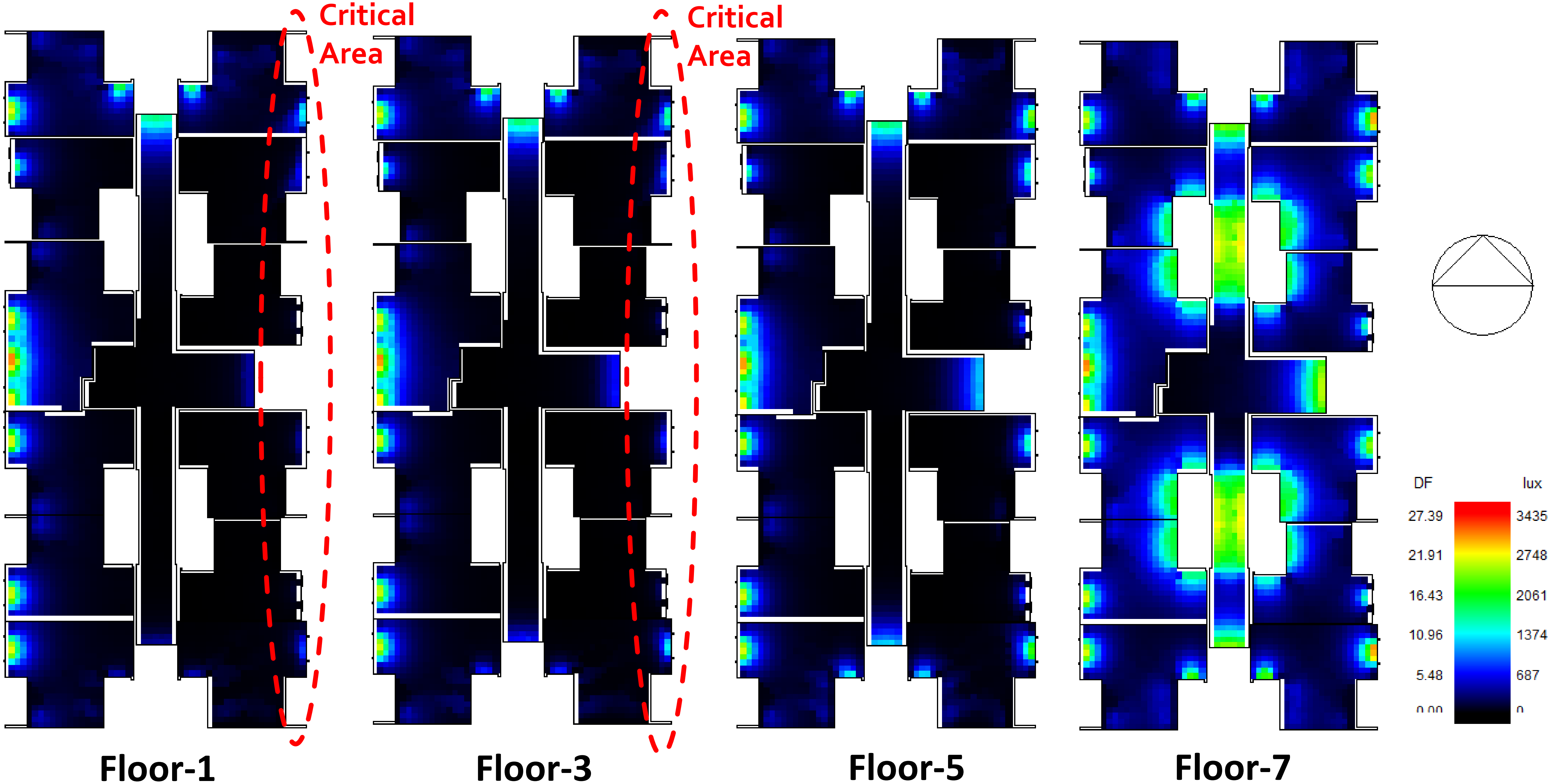
CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

Projects name- Lotus Park, S.No. 4/1A Of Mouje Shivni, Akola, Maharashtra
Climate Zone (as per NBC 2016) - Hot & Dry
Site Area - 12700.00 sq. mt
Total Built-up Area - 19995.45 sq. mt
Structural system - RCC
Innovative design - Sandwich EPC Sheet in Outer concrete wall.
Aluform (mione – Technology) Construction work.



***Under Analysis Stage**

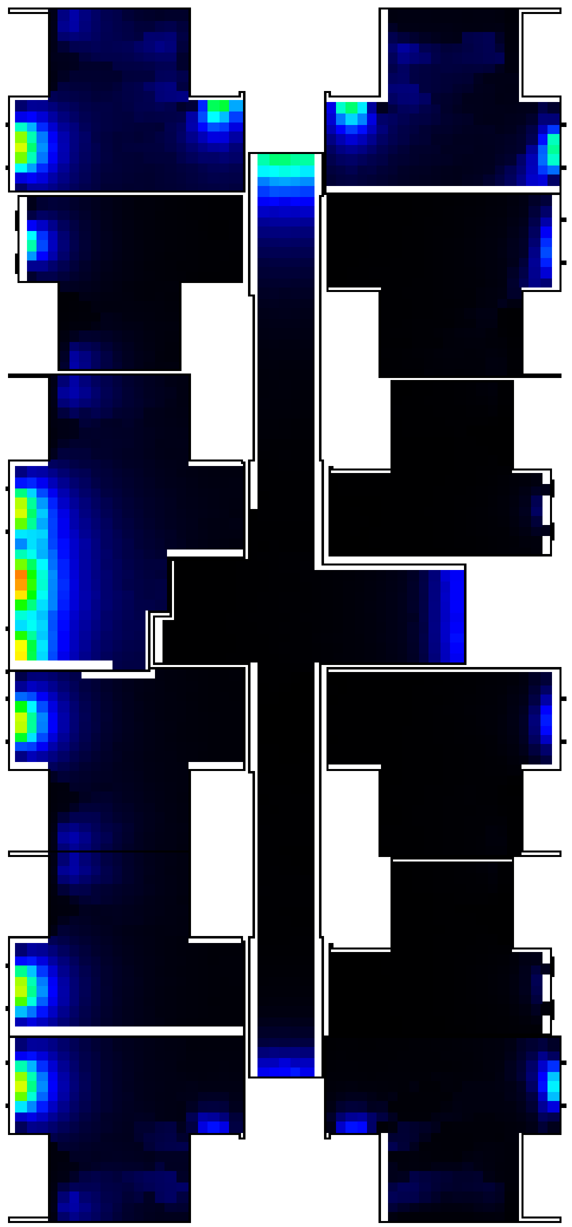
Daylight Analysis : Block-A1 (Base case)



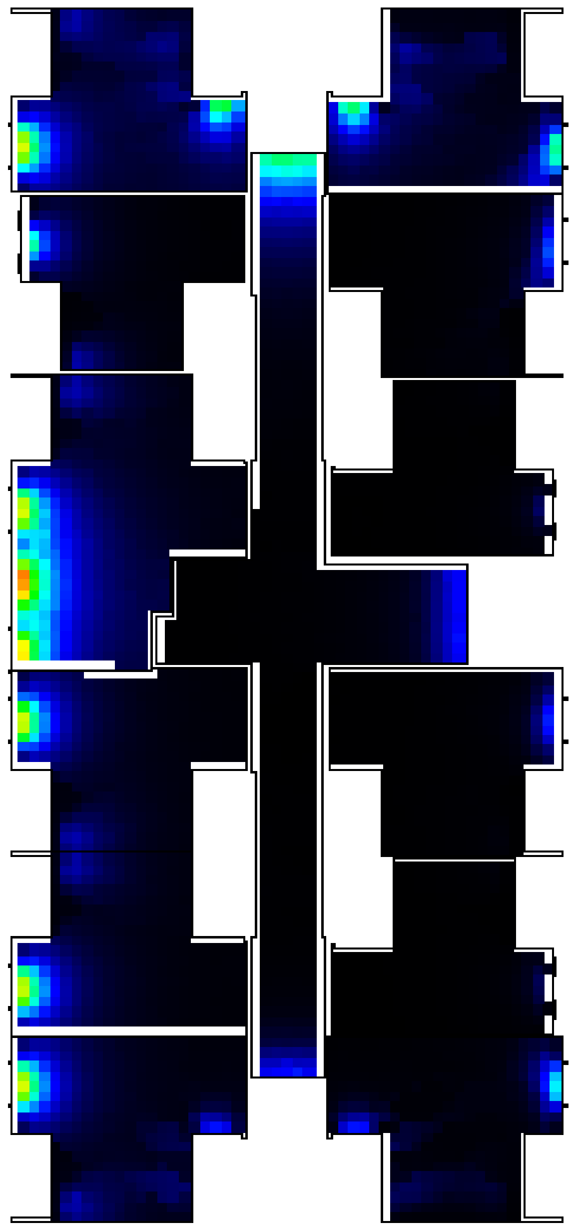
Daylight Analysis in Block Al shows that floors 1st & 3rd are the most critical areas where daylight is not in sufficient Amount due to mutual shading of neighbour Building block (i.e. shading form East side)

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

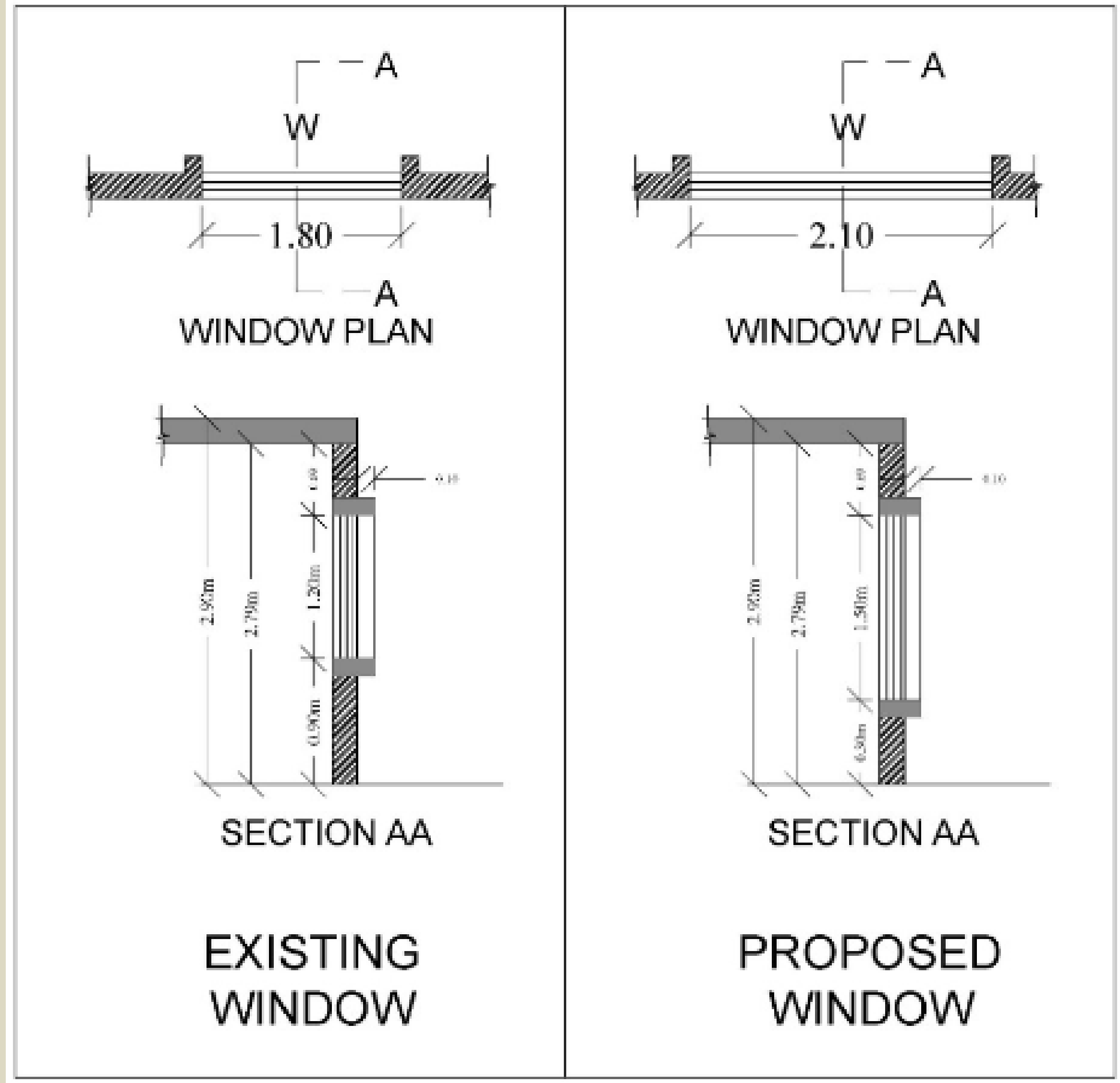
Daylight Analysis : Proposed Case
Block-A1, A2



Floor-1



Floor-3



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Warm-Humid	16.66
Temperate	12.50
Cold	8.33

SOURCE Adapted from Bureau of Indian Standards (BIS). 2016. National Building Code of India 2016. New Delhi: BIS.

<table>
<tr><th>Blocks</th><th>Windows Area</th><th>Carpet Area</th><th></th></tr>
<tr><td>Block-A1</td><td>387.87</td><td>2330.23</td><td rowspan="7">15.91</td></tr>
<tr><td>Block-A2</td><td>387.87</td><td>2330.23</td></tr>
<tr><td>Block-A3</td><td>387.87</td><td>2330.23</td></tr>
<tr><td>Block-B1</td><td>551.34</td><td>3495.73</td></tr>
<tr><td>Block-C1</td><td>349.37</td><td>2340.66</td></tr>
<tr><td>Block-C2</td><td>349.37</td><td>2340.66</td></tr>
<tr><td>Total WFR</td><td>2413.69</td><td>15167.74</td></tr>
<tr><td></td><td></td><td></td><td>>10% (as per ENS-Hot & dry Climate)</td></tr>
</table>

Window To Wall Area Ratio (WWR)

The Window-to-Wall Ratio (WWR) is **the fraction of the above grade wall area that is covered by fenestration, calculated as the ratio of the wall fenestration area to the gross above grade wall area.**

	Block A1 & A2		
Windows	WallArea	WWR (%)	
284.76	2760.8	10.31	(Excluding staircase & Passage)
	Block A3		
Windows	WallArea	WWR (%)	
291.48	2963.8	9.83	(Excluding staircase & Passage)
	Block B1		
Windows	WallArea	WWR(%)	
415.8	3339.35	12.45	(Excluding staircase & Passage)
	Block B2		
Windows	WallArea	WWR(%)	
359.94	3019.625	11.92	(Excluding staircase & Passage)
	TOTAL WWR (%)		
Windows	**WallArea**	**WWR(%)**	
1351.98	**12083.575**	**11.19**	(Excluding staircase & Passage)

The Window-to-Wall Ratio (WWR) is found **11.19%,** WWR is directly proportional to daylighting areas, Hence, impact of WWR is shown in floor plans, therefore increasing in WWR helps to enhance the daylight area in the building blocks.

CASE STUDIES FOR APPLICATION OF THERMAL COMFORT IN AFFORDABLE HOUSING

Project	Construction of 235 EWS DU's under PMAY Scheme
Location	Talegaon Dabhade, Pune, Maharashtra.
Climate Zone	Composite
Site Area	3941 sq meter
Built Up Area	15286 sq meter
Wall Material	AAC Block Masonry

Project	Construction of 210 EWS Dwelling Units under PMAY – AHP at Gut No. 818, Chakan. Ta. Khed, Dist - Pune
Location	Chakan, Pune, Maharashtra.
Climate Zone	Composite
Site Area	11434 sq meter
Built Up Area	12133 sq meter
Wall Material	AAC Block Masonry

.

Project	Construction of 560 EWS DU's and Commercial under PMAY
Location	Talegaon Dabhade, Pune, Maharashtra.
Climate Zone	Composite
Site Area	8729 sq meter
Built Up Area	35262 sq meter
Wall Material	AAC Block Masonry

***Under Analysis Stage**

THERMAL COMFORT STUDY METHODS

Thermal comfort studies can be undertaken in one or combination of following ways:

Field Studies

- Occupant Behaviour
- User Behaviour
- Productivity

Laboratory Studies

- Thermal Comfort
- Body Parts
- Cooling Systems
- Control Systems
- Productivity

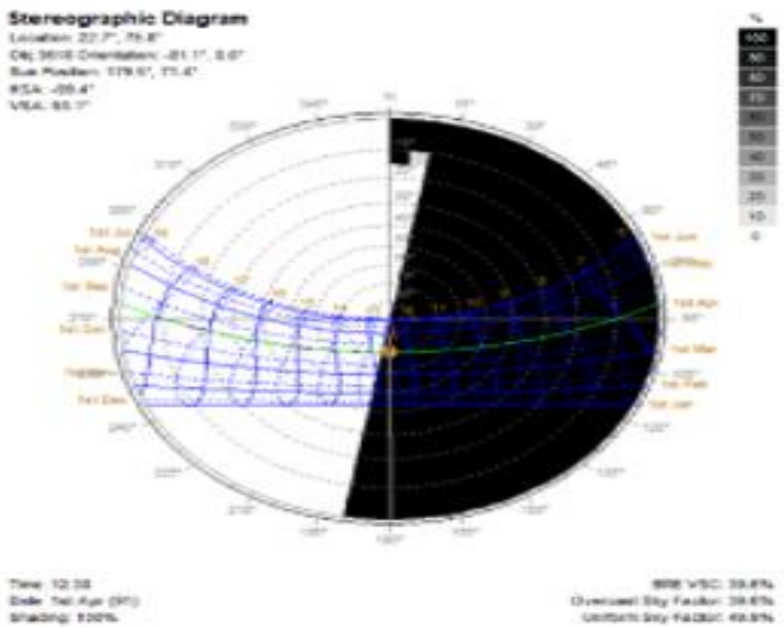
Digital Simulations

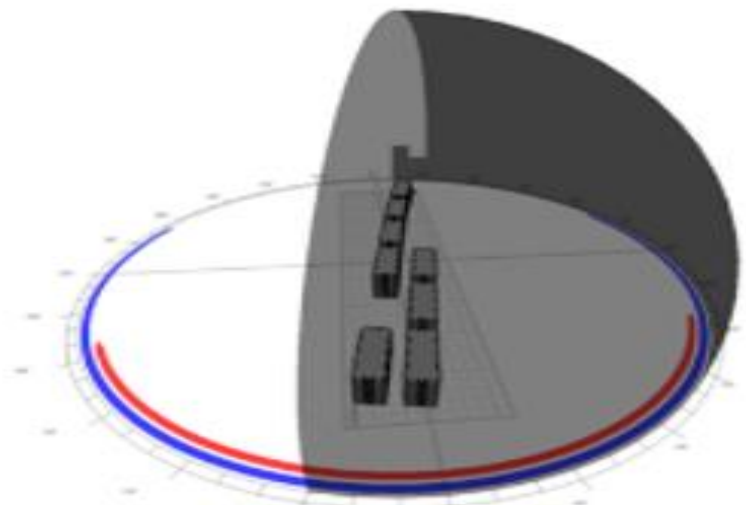
- Thermal Comfort
- Body Parts
- Cooling Systems
- Control Systems

THERMAL COMFORT STUDY METHODS

Digital Simulation Analysis – LHP Indore

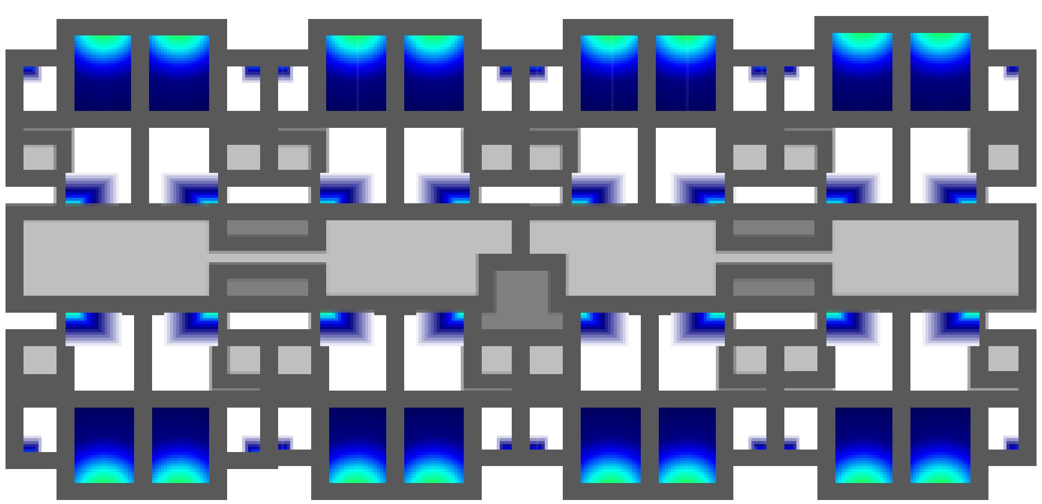
WINDOW SHADING ANALYSIS





Shading Analysis shows East side window shading (Chajja-450mm) Will suffice shading requirements, eventually cut off direct heat gain from East side. On other side, West side too suffice shading requirements.

DAY LIGHTING ANALYSIS

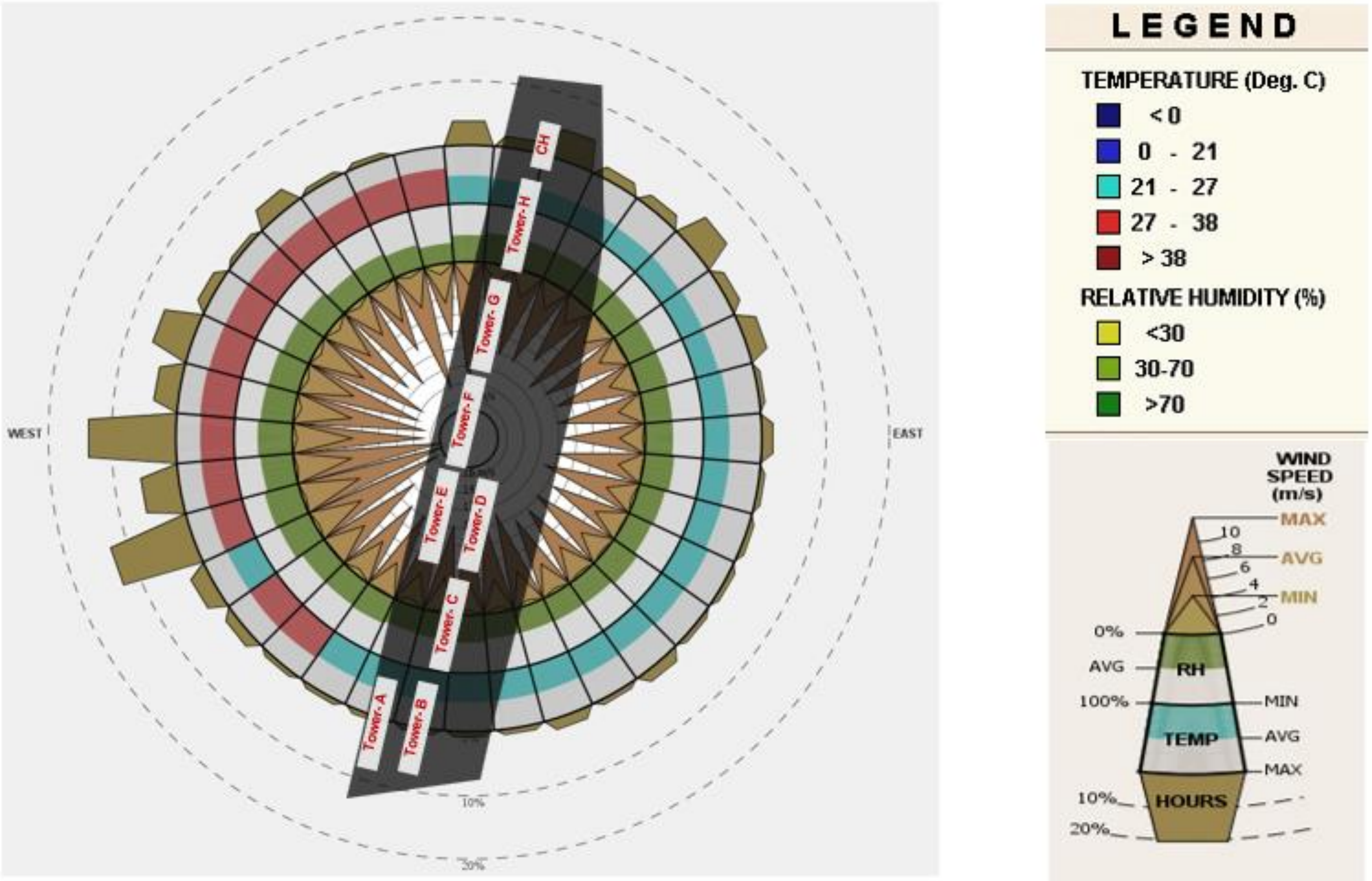


Daylighting analysis shows that 1st & 5th floors having sufficient day lighting in Bedroom & Kitchen while Living room is having less day light while 8th floor, all spaces having sufficient day light availability.

THERMAL COMFORT STUDY METHODS

Digital Simulation Analysis – LHP Indore

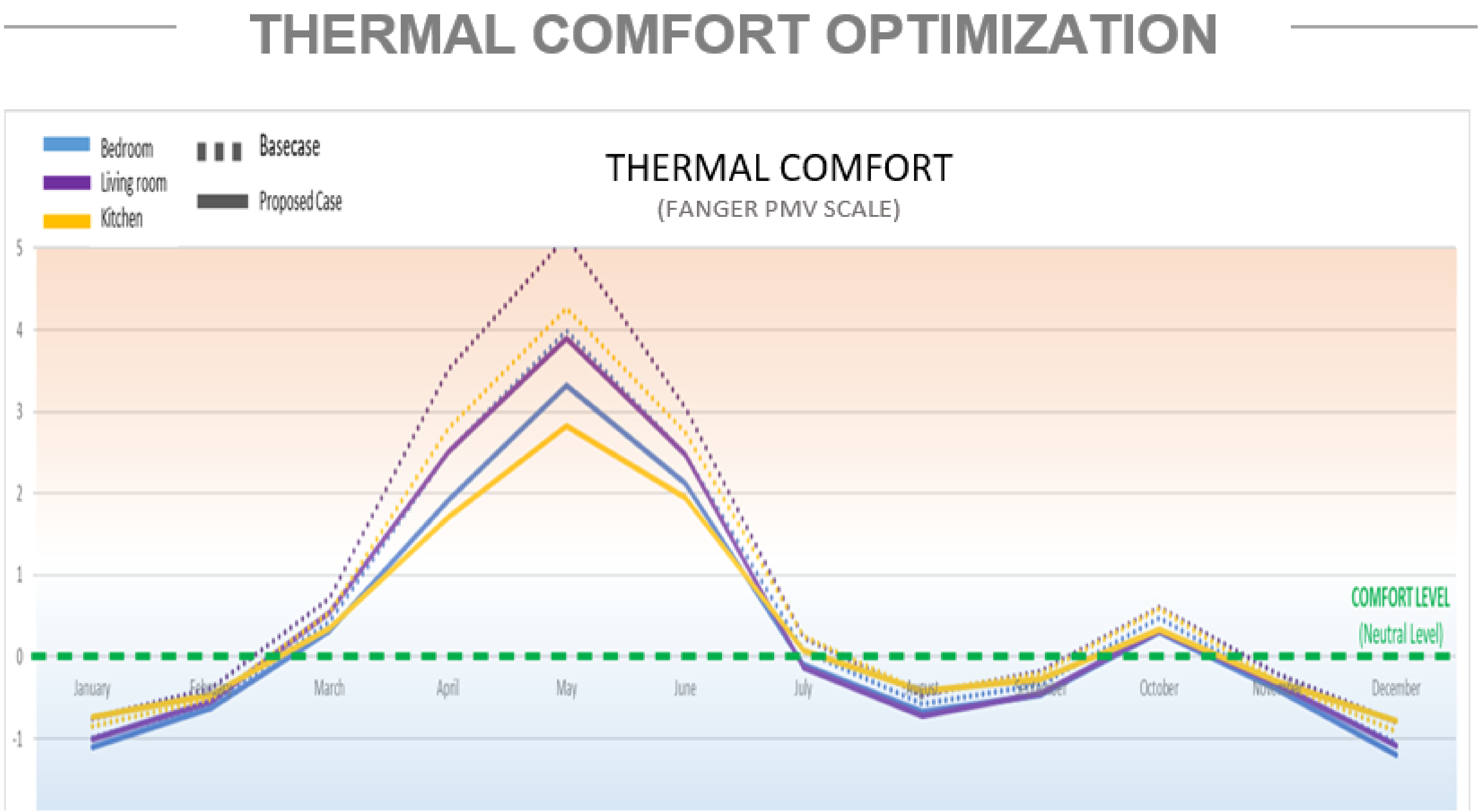
ORIENTATION OPTIMIZATION AS PER SITE



Analysis shows that building blocks orientation getting maximum hours wind from west side throughout the year which help to enhance the natural ventilation.

THERMAL COMFORT STUDY METHODS

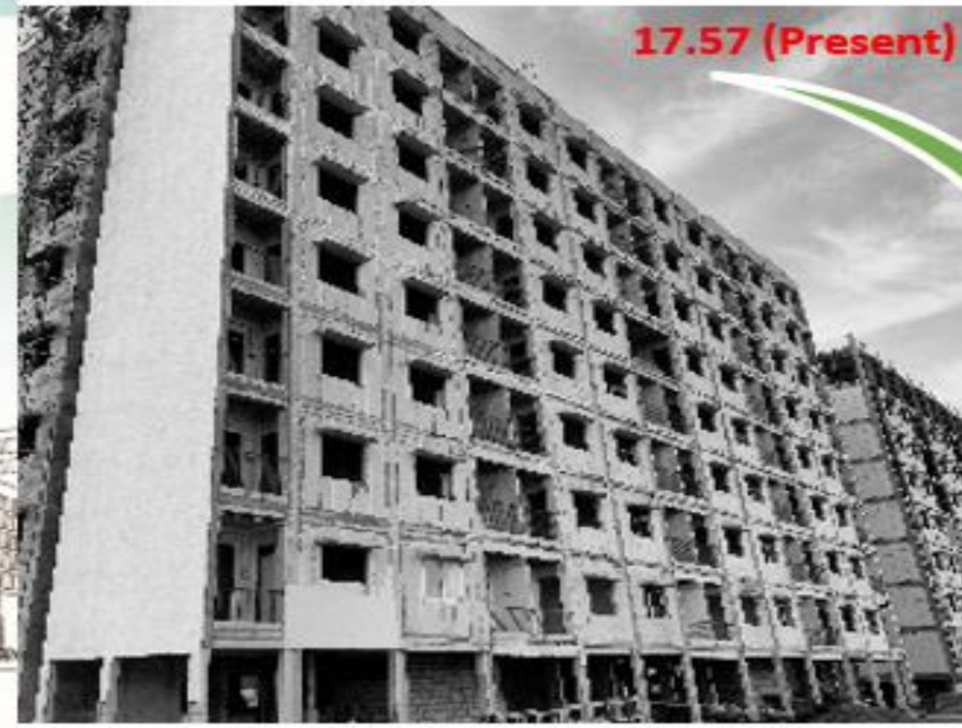
Digital Simulation Analysis – LHP Indore



Analysis shows Thermal Comfort can be achieved as Fanger PMV Index is 0.72 (<1) for Naturally Ventilated Building. Achieving Thermal Comfort, related to reduction in Cooling Load requirement of the building.

Digital Simulation Analysis – LHP Indore

ENS RETV COMPLIANCE



14.72 (Proposed)

14.29 (Proposed)

Threshold Value - 15 W/m^2

POSSIBLE ENERGY SAVINGS & CARBON EMISSION REDUCTION

ENERGY SAVING

26%

approx. ***7.1 Lakh units*** to be saved per annum

savings as compare to conventional Operational Practices

CO_2

605 t CO_2

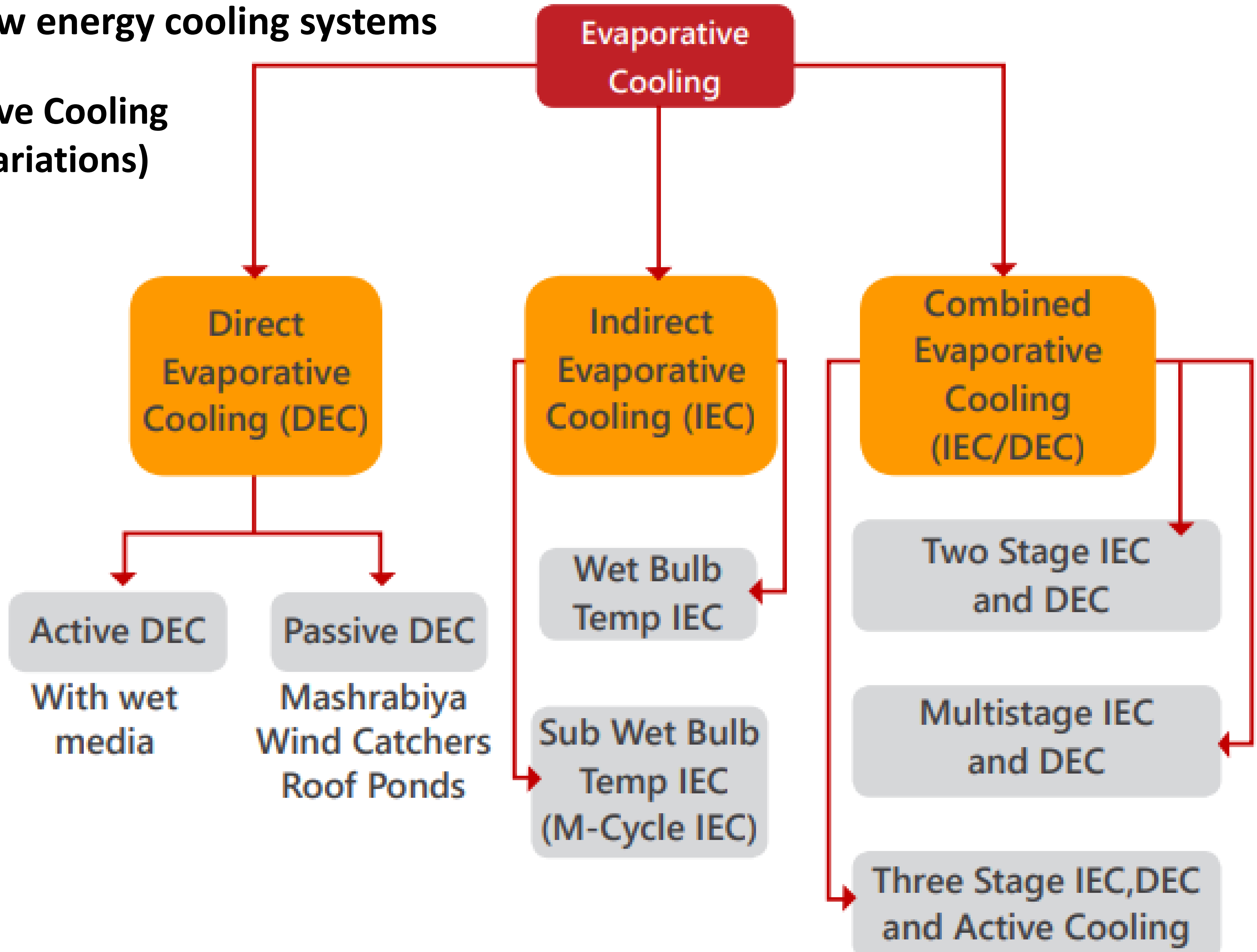
savings as compare to conventional Operational Practices

Importance of Low-energy Cooling Systems

- ✓ Low energy cooling technologies is a relatively new term with no commonly accepted scientific definition
- ✓ It can be loosely defined to include technologies that do not use vapor compression cycles which is traditionally the most used refrigeration cycle in current mechanical devices for cooling

Categories of Low energy cooling systems

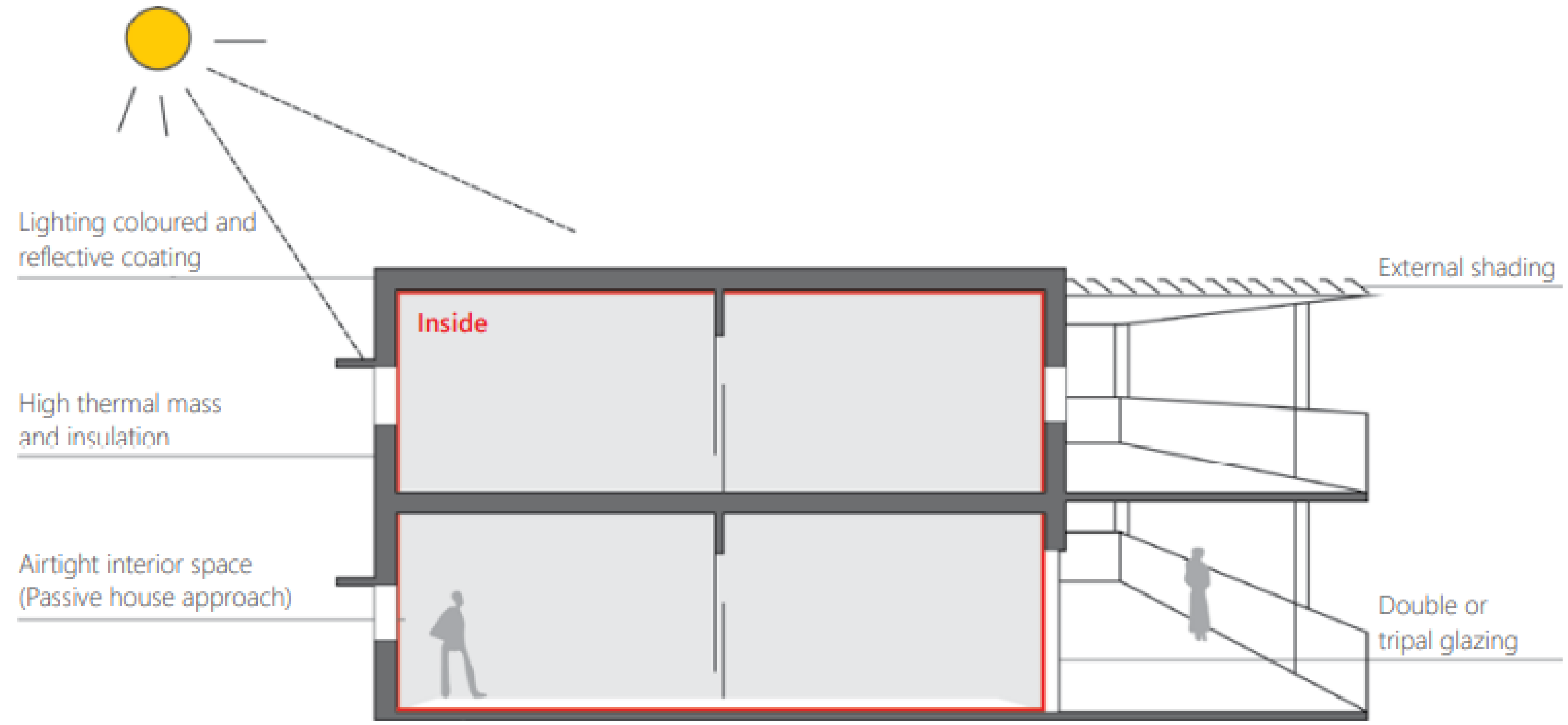
Evaporative Cooling (and its variations)

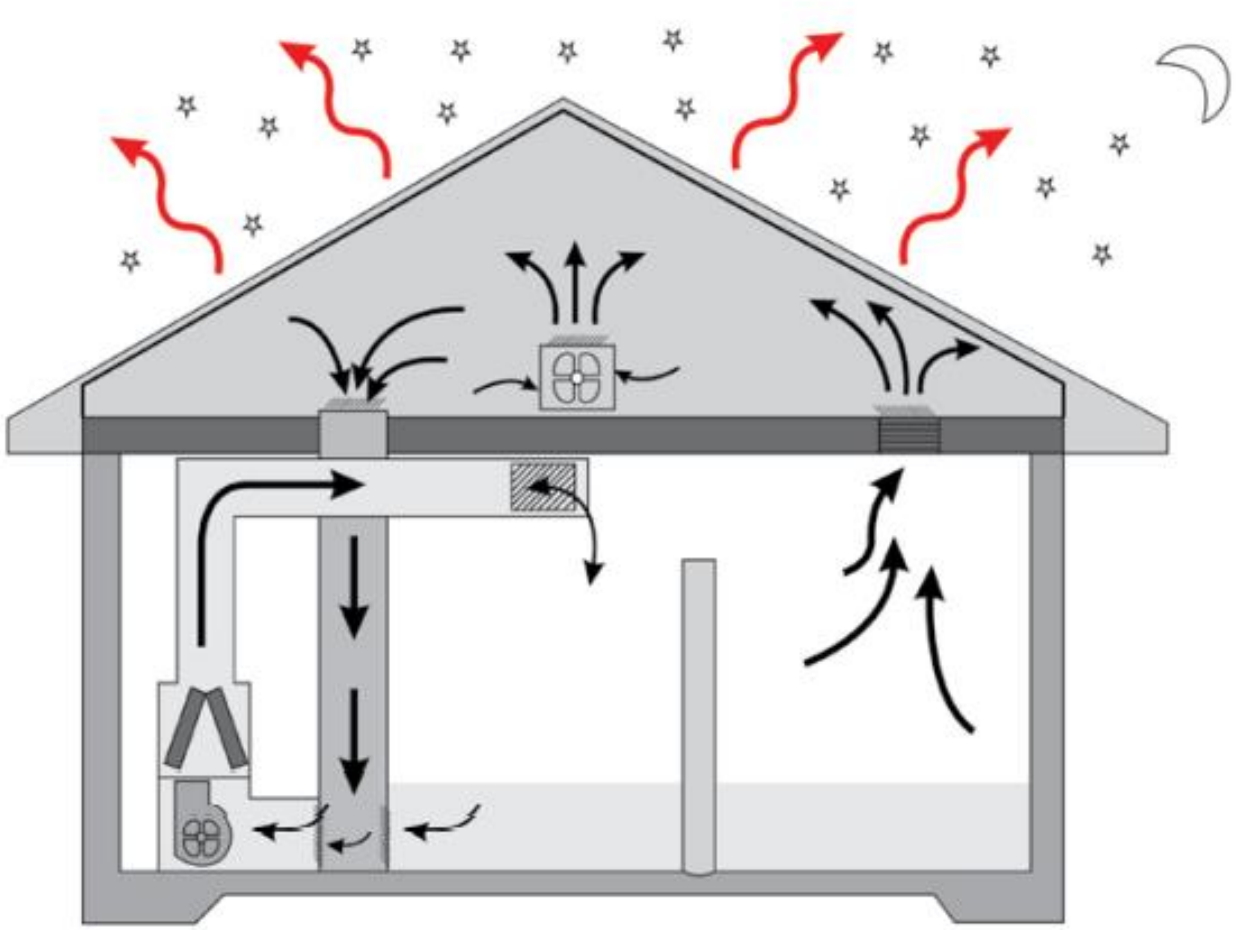


LOW ENERGY COOLING TECHNOLOGIES AND COMFORT

Categories of Low energy cooling systems

Night Cooling through Natural Ventilation

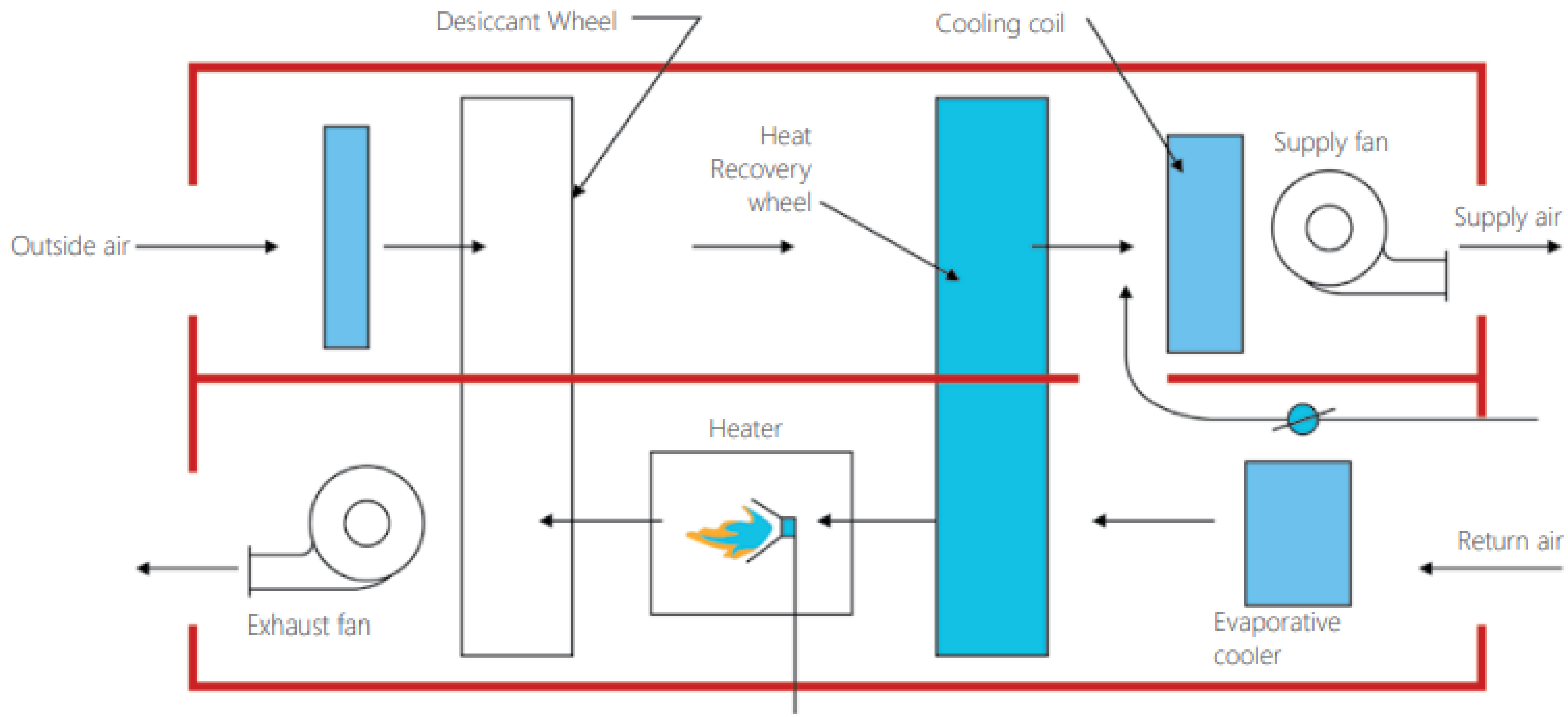




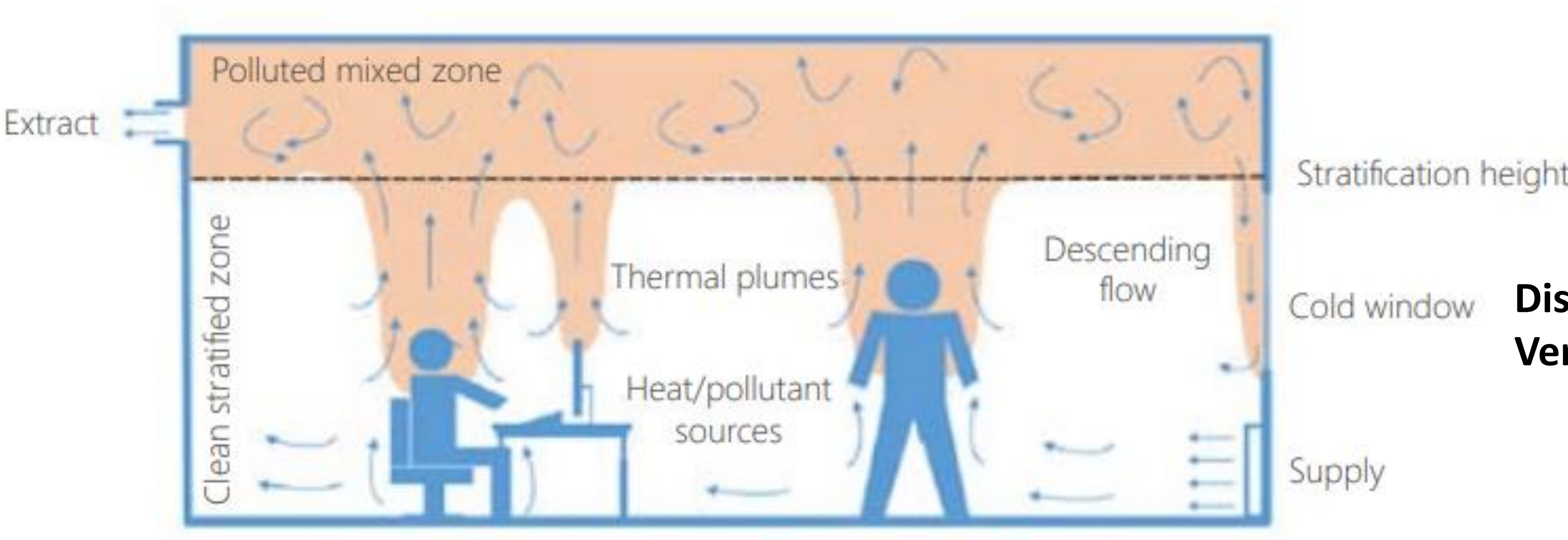
Night cooling through mechanical ventilation

Categories of Low energy cooling systems

Desiccant Cooling Systems



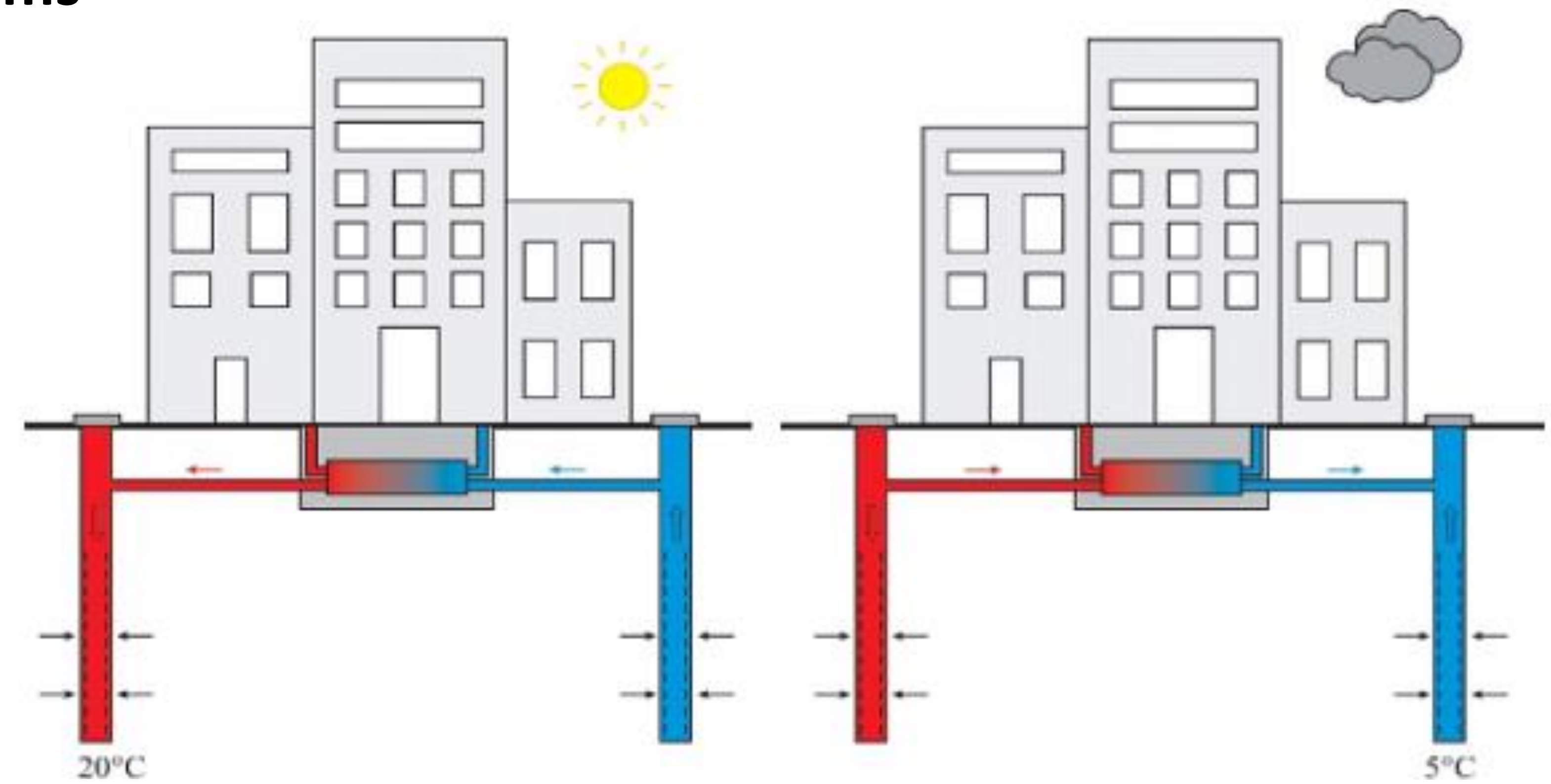
Displacement Ventilation

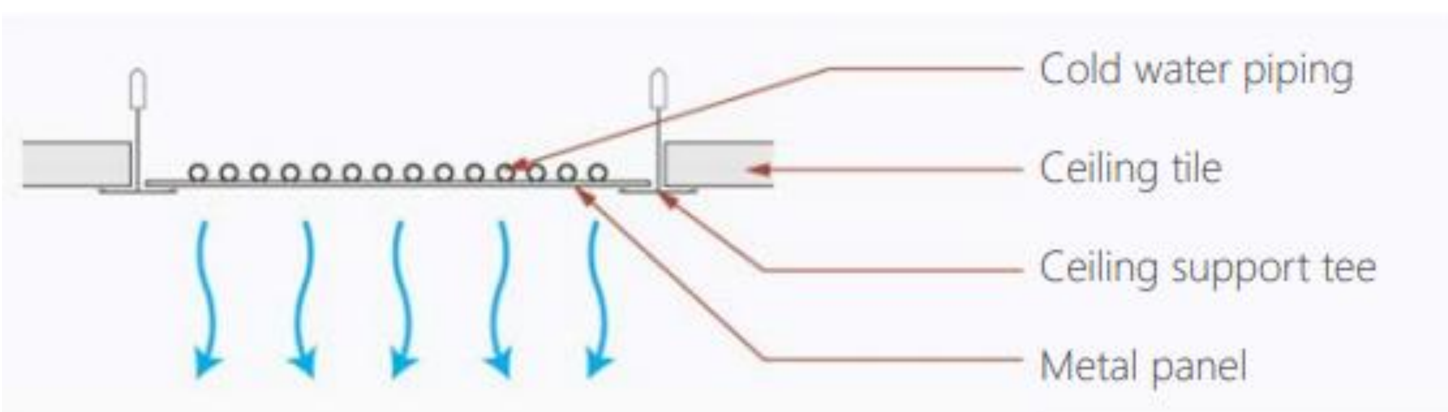


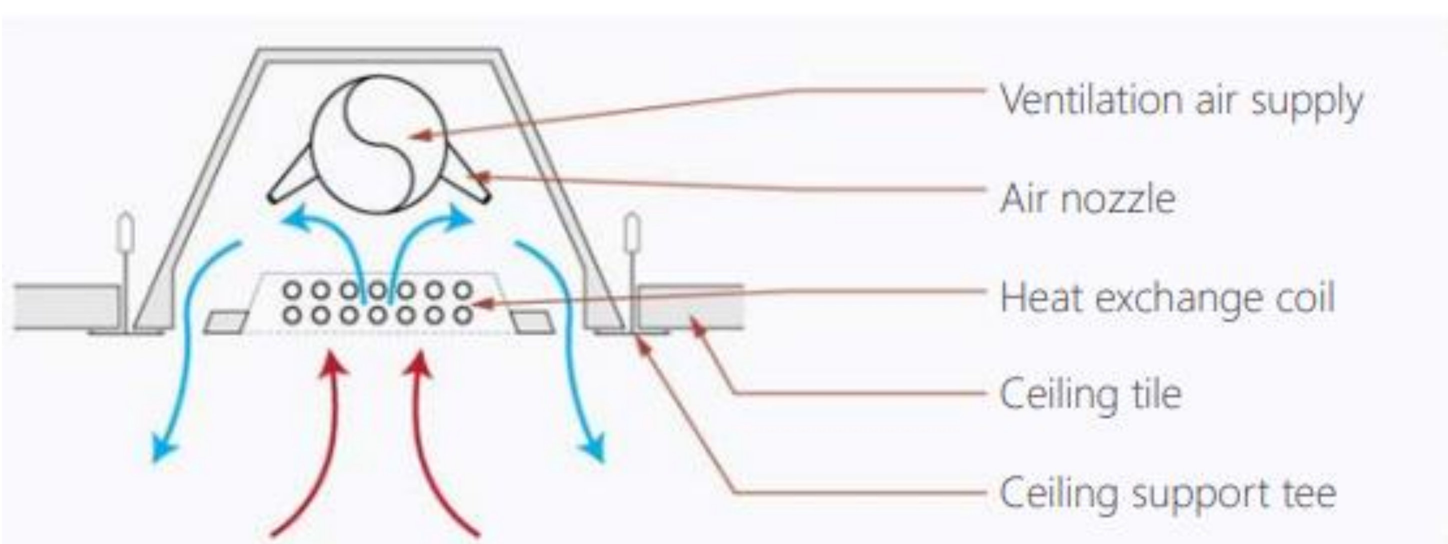
LOW ENERGY COOLING TECHNOLOGIES AND COMFORT

Categories of Low energy cooling systems

Ground and Aquifer cooling



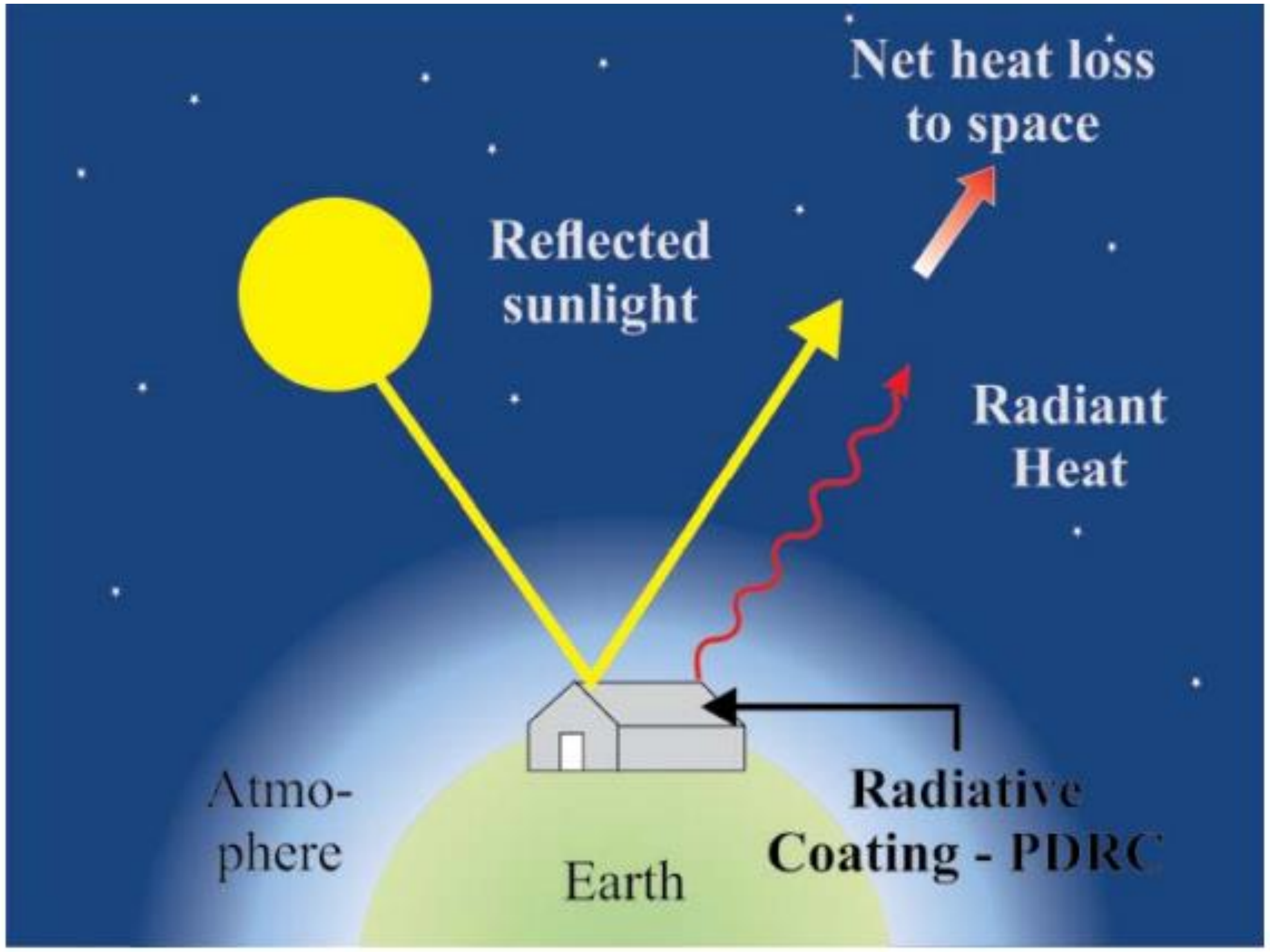


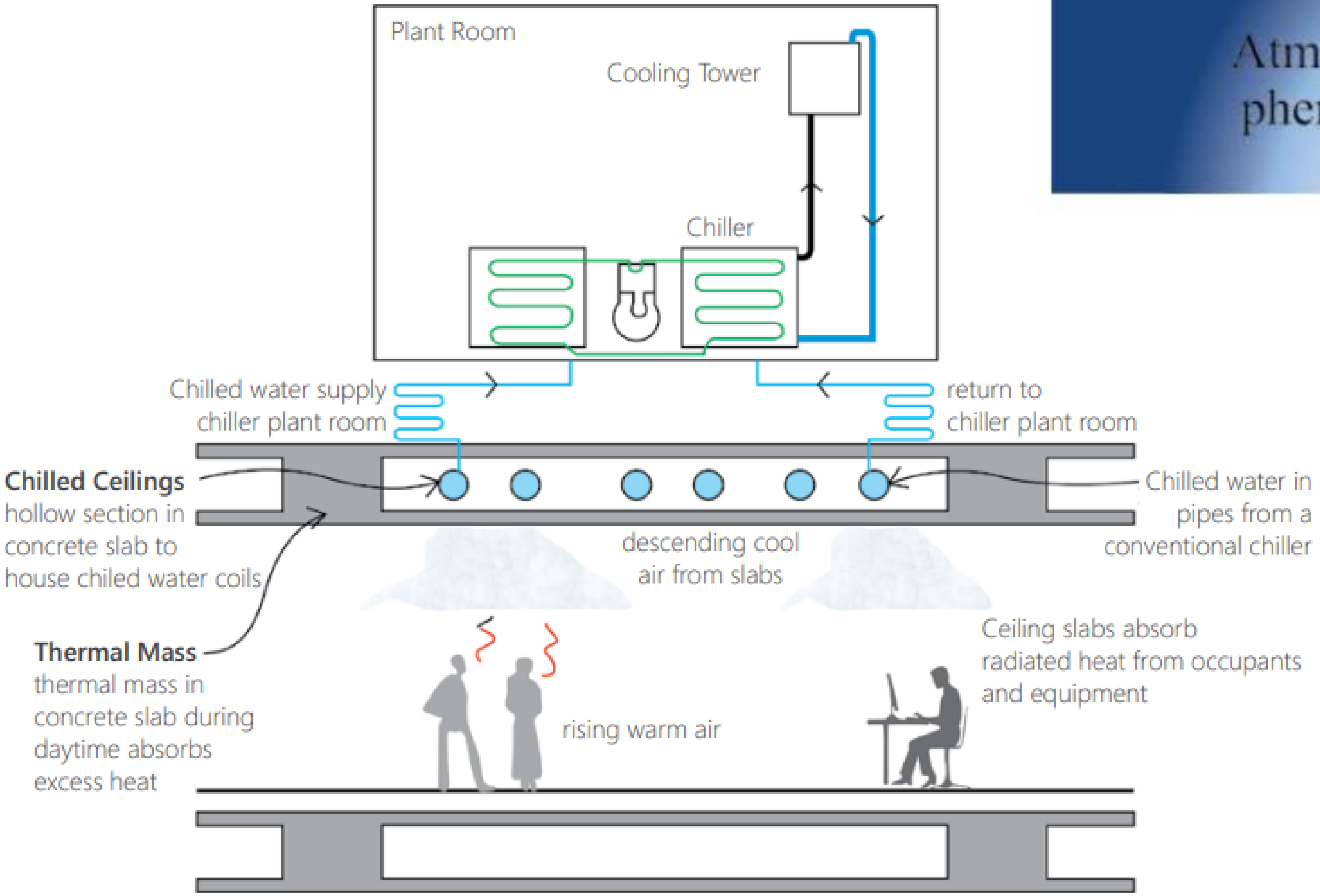


Chilled Ceiling and Beams

Categories of Low energy cooling systems

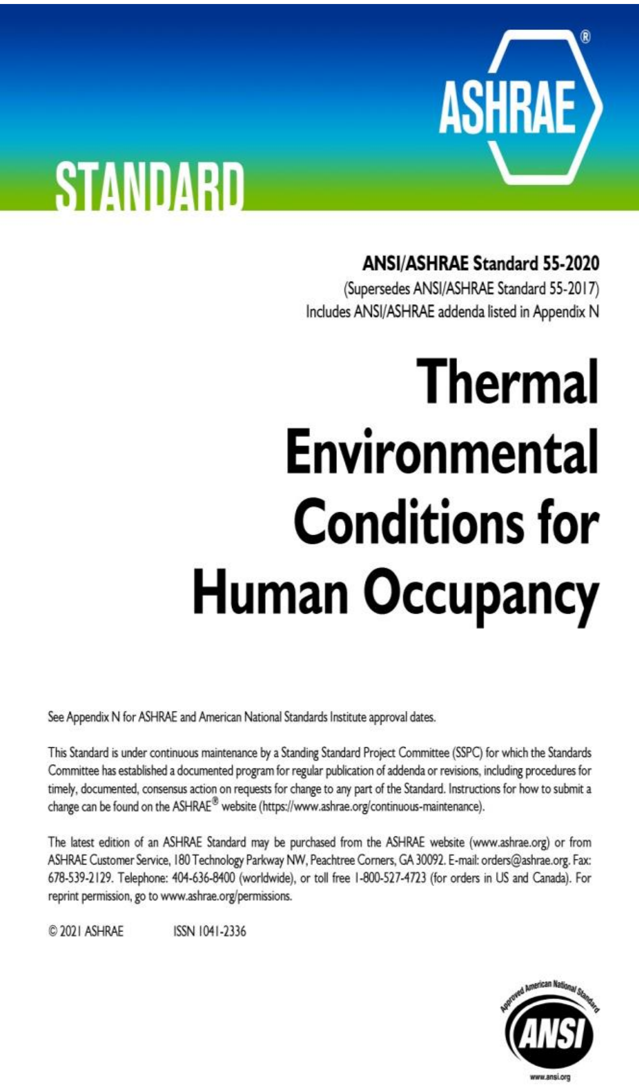
Radiative Cooling

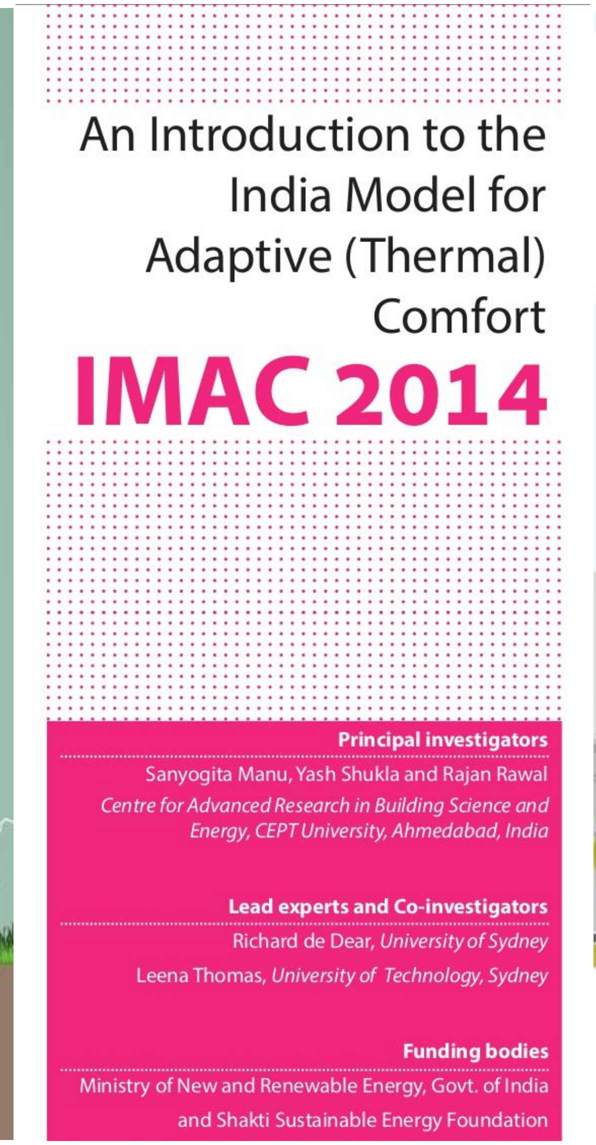


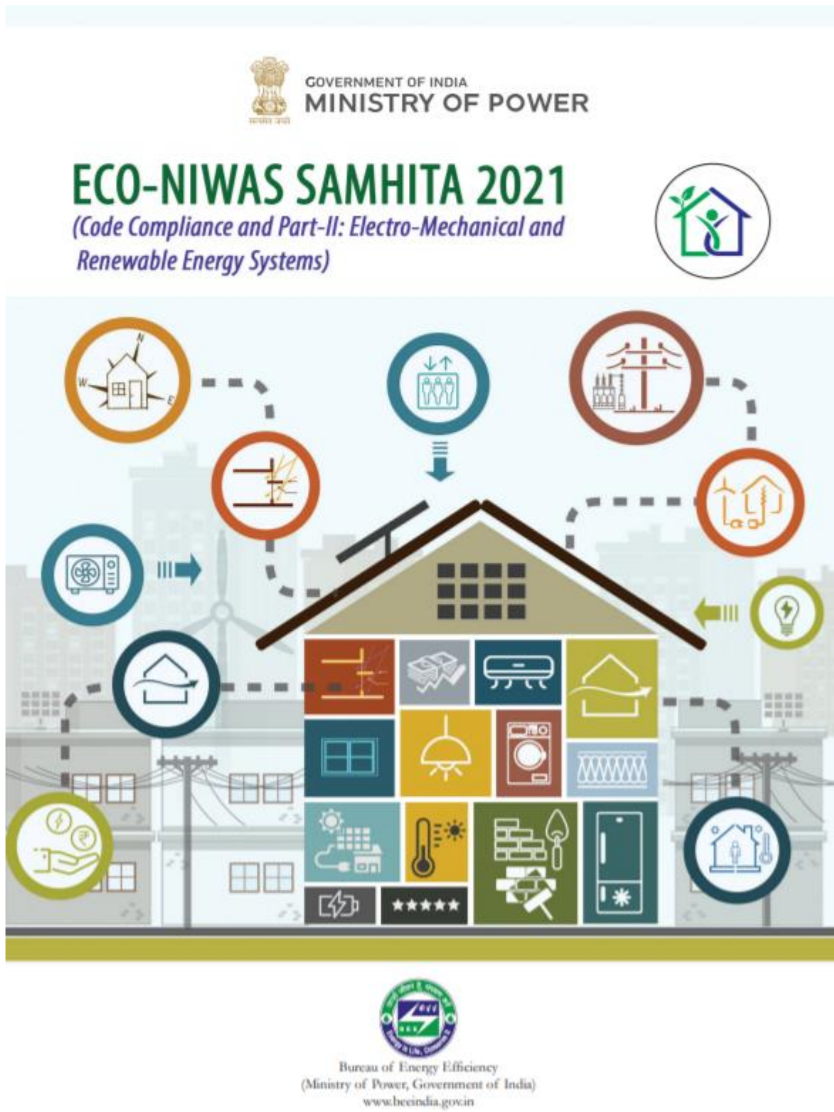


Radiant Structural Cooling

EXISTING STANDARDS FOR IMPROVING THERMAL COMFORT







Standard 55-2020, Thermal Environmental Conditions for Human Occupancy (ANSI Approved)
Standard 62.1-2019, Ventilation for Acceptable Indoor Air Quality
Standard 62.2-2019, Ventilation and Acceptable Indoor Air Quality in Residential Buildings
Standard 90.1-2019, Energy Standard for Buildings Except Low-Rise Residential Buildings
Standard 90.2-2018, Energy Efficient Design of Low-Rise Residential Buildings
Standard 100-2018, Energy Efficiency in Existing Buildings

EXISTING STANDARDS FOR IMPROVING THERMAL COMFORT

ASHRAE-55

CENTER FOR THE BUILT ENVIRONMENT

CBE Thermal Comfort Tool

Help | Other CBE tools

ASHRAE-55 | EN-16798 | Compare | Ranges | Upload | Fans & Heat | PHS

Inputs

Select method: PMV method

Operative temperature: 25 °C

Air speed: 0.1 m/s — No local control

Relative humidity: 50 % — Relative humidity

Metabolic rate: 1 met — Seated, quiet: 1.0

Clothing level: 0.61 clo — Trousers, long-sleeve shi

Create custom ensemble

Dynamic predictive clothing

Solar gain on occupants

Set pressure | SI/IP

Local discomfort | Globe temp

Reset | Save | Reload | Share

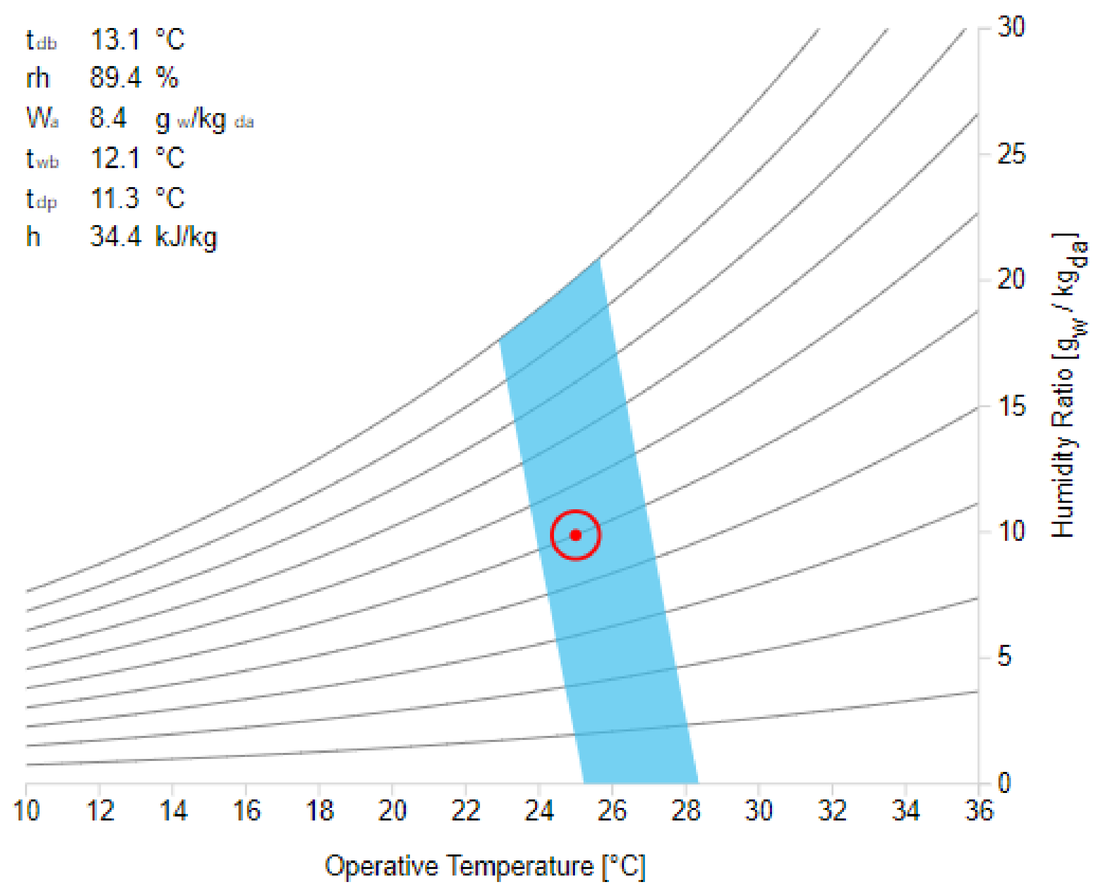
Documentation

✔ Complies with ASHRAE Standard 55-2020

PMV = -0.16
Sensation = Neutral

PPD = 6 %
SET = 24.8 °C

Psychrometric (operative temperature)



NOTE: In this psychrometric chart the abscissa is the operative temperature and for each point dry-bulb temperature equals mean radiant temperature (DBT = MRT). The comfort zone represents the combination of conditions with the same DBT and MRT for which the PMV is between -0.5 and +0.5, according to the standard.

Limits of Applicability: This standard is only applicable to healthy individuals. This standard does not apply to occupants: a) whose clothing insulation exceed 1.5 clo; b) whose clothing is highly impermeable; or c) who are sleeping, reclining in contact with bedding, or able to adjust blankets or bedding.

The CBE comfort tools automatically calculates the relative air speed and the dynamic clothing insulation .

EXISTING STANDARDS FOR IMPROVING THERMAL COMFORT

National Building Code of India (NBC 2016)

National Building Code (NBC) of India is a standard which unifies the building regulations all over the country.

Type	Adaptive comfort model as per NBC 2016
Naturally ventilated building	$T_{in}=0.54T_{rm}+12.83$ 90% acceptability range: ±2.38 °C
Mixed mode building	$T_{in}=0.28T_{rm}+17.87$ 90% acceptability range: ±3.48 °C
Air-conditioned building	Air temperature-based approach: $T_{in}=0.078T_{rm}+23.25$ 90% acceptability range: ±1.5 °C
	Standard Effective Temperature based approach: $SET_{in}=0.014T_{rm}+24.53$ 90% acceptability range: ±1.0 °C

Tin: Indoor operative temperature (in °C) is neutral temperature

Trm: 30-days running mean outdoor temperature

SETin: Standard effective temperature (in °C) is neutral temperature

Adaptive Thermal Comfort Equation for determining acceptable indoor conditions as per NBC 2016

According to the IMAC model, **neutral temperature in naturally ventilated buildings varies from 19.6 to 28.5 °C for 30-day outdoor running mean air temperatures ranging from 12.5 to 31 °C**.

EXISTING STANDARDS FOR IMPROVING THERMAL COMFORT

Eco-Niwas Samhita (Energy Conservation Building Code for Residential Buildings)

Eco-Niwas Samhita 2018 (BEE, 2018) is the new Energy Conservation Building Code for Residential Buildings (ECBC-R) which has following provisions:

1. To minimize the heat gain in cooling dominated climate or heat loss in heating dominated climate,

a. Through the building envelope (excluding roof):

   i. Maximum RETV for cooling dominated climate (Composite Climate, Hot-Dry Climate, Warm-Humid Climate, and Temperate Climate)

   ii. Maximum U-value for the cold climate

b. Through the Roof: Maximum U-value for Roof

2. For natural ventilation potential

a. Minimum openable window-to-floor area ratio with respect to the climatic zone

3. For daylight potential

a. Minimum visible light transmittance with respect to window-to-wall ratio

This code focuses on building envelope and aims to improve the thermal comfort and reduce the energy required for cooling and lighting in Residential buildings.

ENS CODE *ANALYSIS WITH LHP,INDORE*

CODE PROVISIONS

1. Openable Window-to-Floor Area Ratio (WFRop)
2. Visible Light Transmittance (VLT)
3. Thermal Transmittance of Roof (Uroof)
4. Residential envelope transmittance value (RETV) for building envelope (except roof) for four climate zones, namely, Composite Climate, Hot-Dry Climate, Warm-Humid Climate, and Temperate Climate
5. Thermal transmittance of building envelope (except roof) for cold climate (Uenvelope,cold)

CODE COMPLIANCE

ECO NIWAS SAMHITA TOOL VIA VIDEO

CODE PROVISIONS

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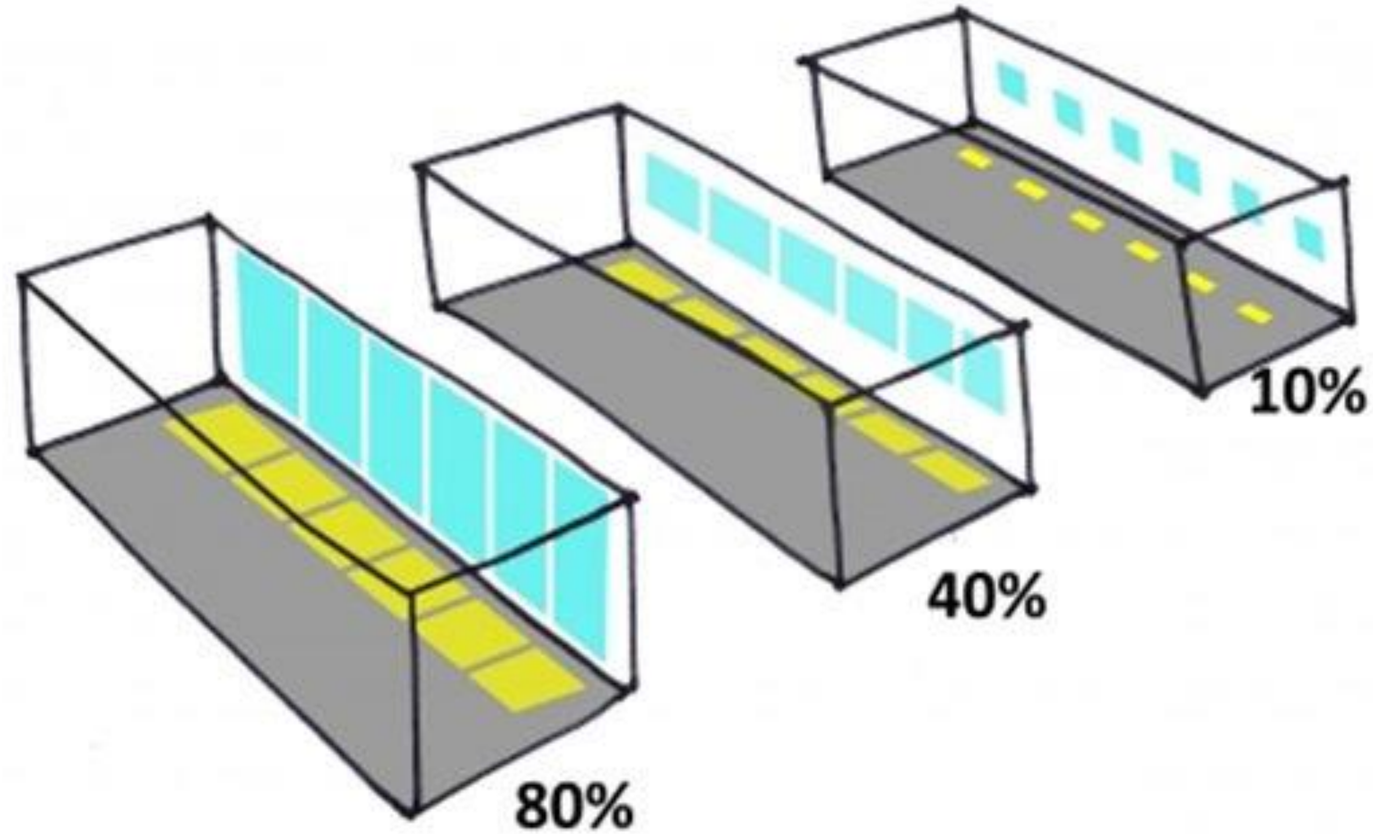

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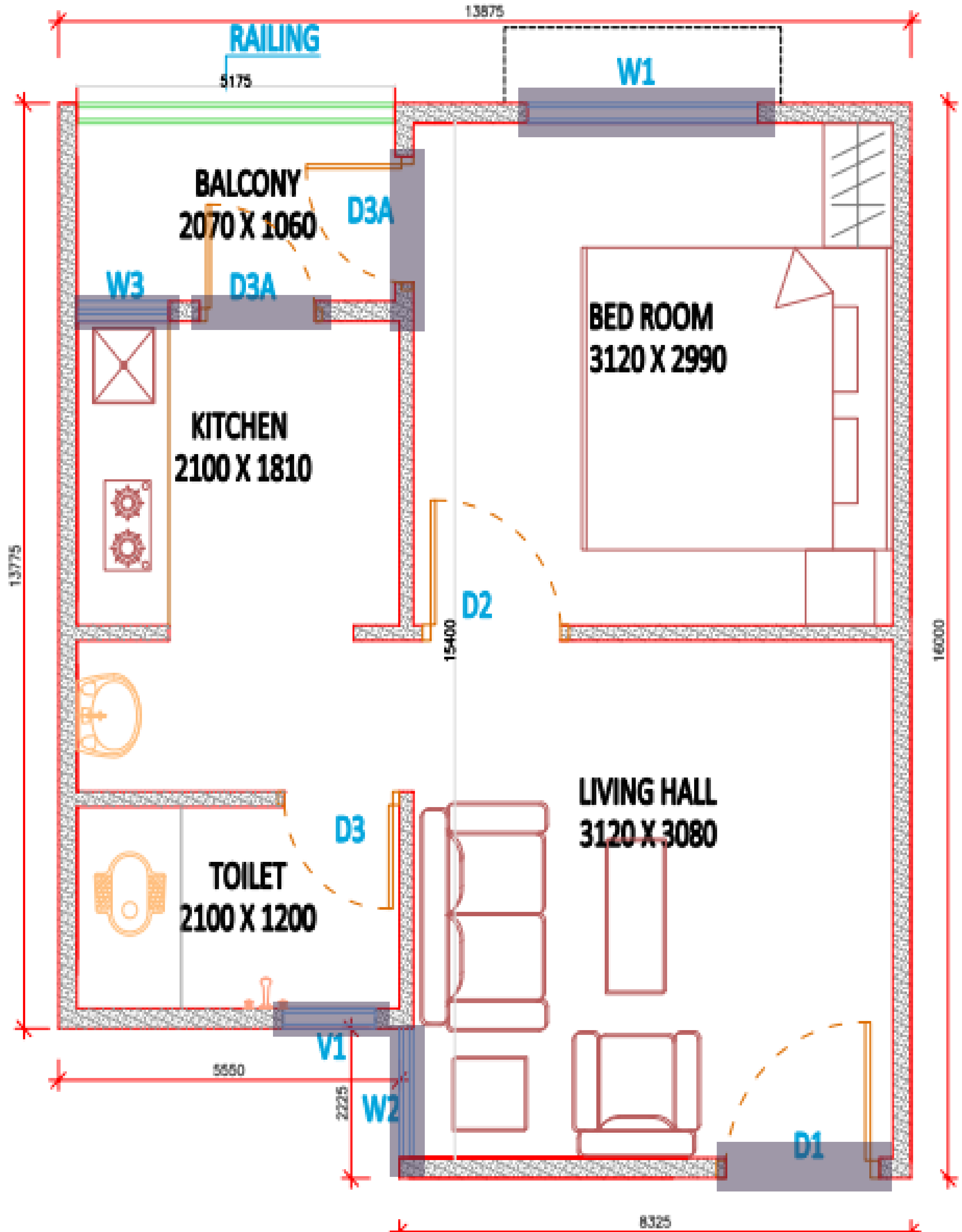
Temperate	12.50
Cold	8.33

SOURCE Adapted from Bureau of Indian Standards (BIS). 2016. National Building Code of India 2016. New Delhi: BIS.

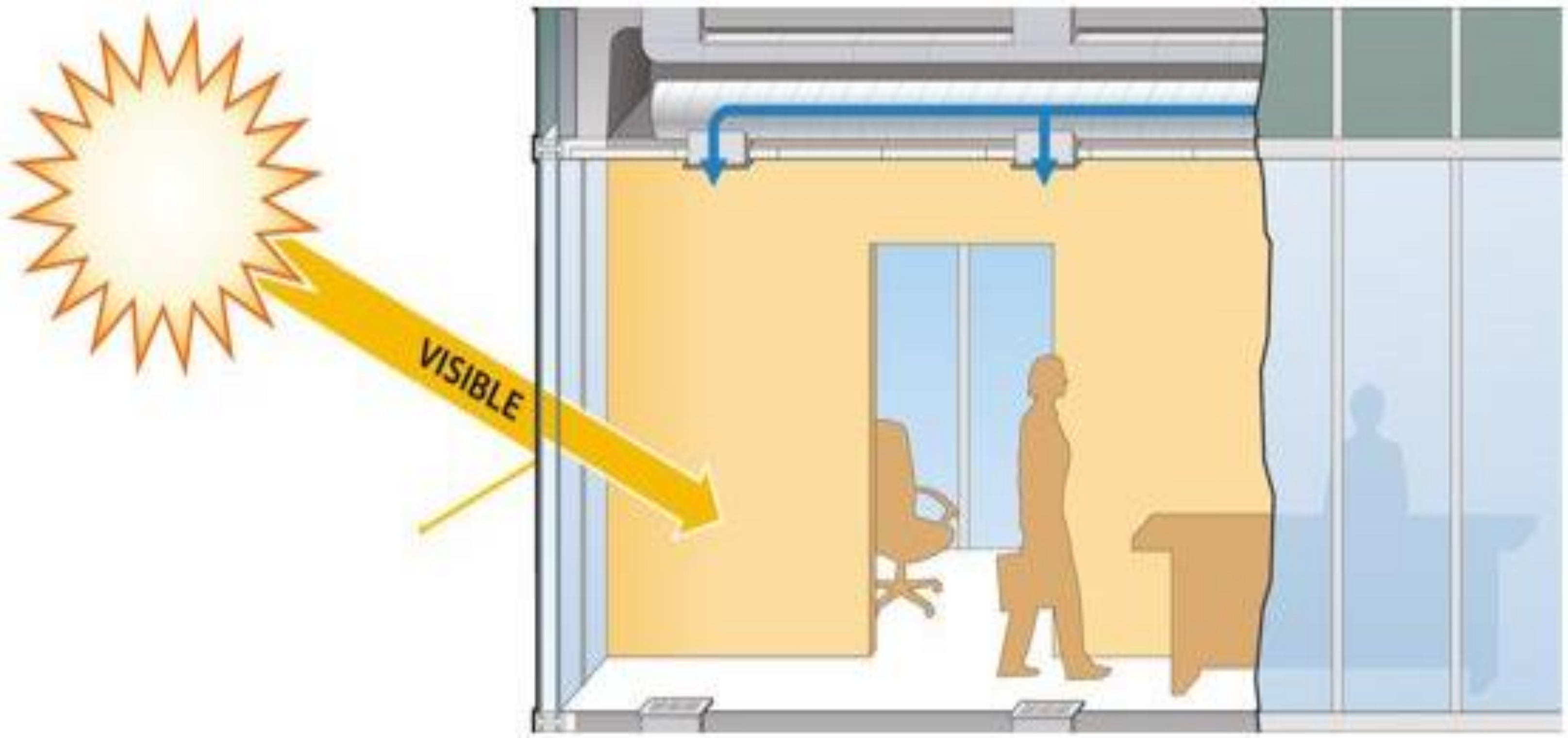
LHP INDORE

Opening Name	Opening Area, m2	Openable Area, m2	No	Effective Openable area m2
W1	2.40	1.20	1.00	1.20
W2	1.20	0.60	1.00	0.60
W3	0.90	0.81	1.00	0.81
V1	0.27	0.24	1.00	0.24
GD	1.58	1.42	2.00	2.84
openable area for 1 flat				5.69
openable area for 128 flat				728.06
$A_{\text{unit carpet area}}$		128	29.92	3829.76
WFR	$A_{\text{openable}} / A_{\text{carpet}}$			**19.01**
For Composite minimum 12.5%				



Visible Light Transmittance (VLT)

VLT of non-opaque building envelope indicates the potential of using daylight. Ensuring minimum VLT helps in improving day lighting, thereby reducing the energy required for artificial lighting



WWR = $A_{(Non\text{ - }Opaque)} / A_{(envelope)}$

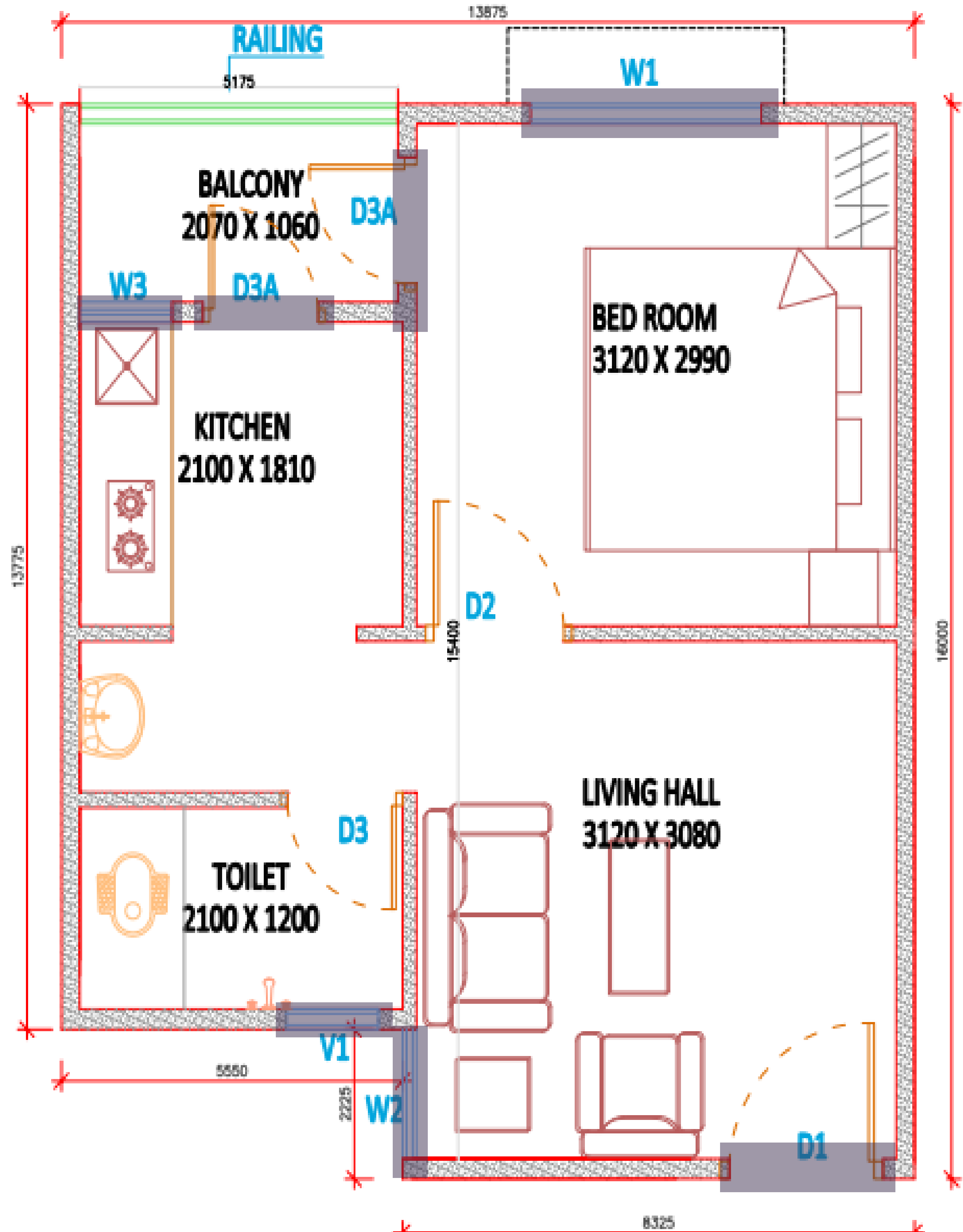
TABLE 2 Minimum visible light transmittance (VLT) requirement[15]

Window-to-wall ratio (WWR)[16]	Minimum VLT [17]
0–0.30	0.27
0.31–0.40	0.20
0.41–0.50	0.16
0.51–0.60	0.13
0.61–0.70	0.11

SOURCE Bureau of Indian Standards (BIS). 2016. National Building Code of India 2016. New Delhi: BIS.

LHP INDORE

Calculation of Window to Wall Ratio							
Orientation	Opening Name	Opening Area, m2	Non - opaque (Glass) Area in Opening, m2	No of openings	Total Opening Are, m2	Total Non-opaque (Glass) Area, m2	Total opaque (PVC, Frame) Area, m2
North	W2	1.2	0.77	16	19.2	12.29	6.91
South	W2	1.2	0.77	16	19.2	12.29	6.91
East	W1	2.4	1.54	64	153.6	98.30	55.30
East	W3	0.9	0.58	64	57.6	36.86	20.74
West	W1	2.4	1.54	64	153.6	98.30	55.30
West	W3	0.9	0.58	64	57.6	36.86	20.74
East	V1	0.27	0.15	16	4.32	2.42	1.90
West	V1	0.27	0.15	16	4.32	2.42	1.90
East	GD	1.58	0	128	201.6	0	0
West	GD	1.58	0	128	201.6	0	0
					872.64	299.75	169.69
					WWR	0.11	
Window-to-wall ratio (WWR)		Minimum VLT					
0–0.30		0.27					
MINIMUM IS 27% while IN LHP INDORE IT IS 90%							



As per Table 2, for WWR of 0.21 (range 0–0.30), the minimum required VLT is 27%. The glass used in this project has a VLT of 90% (as per certified specification for the product). Thus, this project complies with this requirement. Also, it complies with the recommended value.

HOW SOLAR REFLECTANCE HELPS MODERATE TEMPERATURES, RESULTING IN LOWER DEMAND ON COOLING SYSTEMS

Thermal transmittance

(U_{roof}) characterizes the thermal performance of the roof of a building. *Thermal transmittance of roof shall comply with the maximum* U_{roof} *value of 1.2 W/m2 .K.*

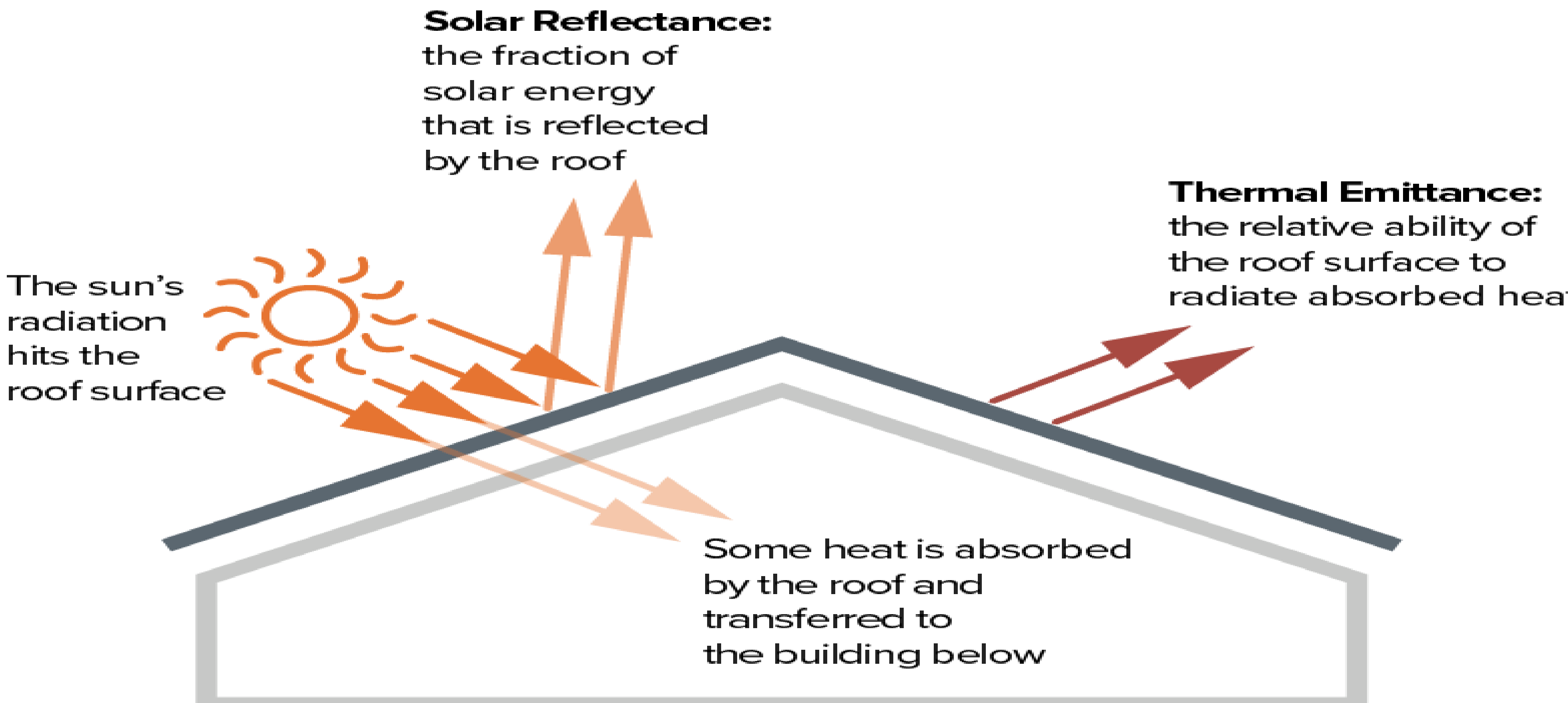


Illustration: Cool Roof Rating Council

3.3.3 The calculation[18] shall be carried out, using Equation 3 as shown below.

$$U_{roof} = \frac{1}{A_{roof}}\left[\sum_{i=1}^{n}(U_i \times A_i)\right] \qquad \ldots(3)$$

where,

U_{roof} : thermal transmittance of roof (W/m².K)

A_{roof} : total area of the roof (m²)

U_i : thermal transmittance values of different roof constructions (W/m².K)

A_i : areas of different roof constructions (m²)

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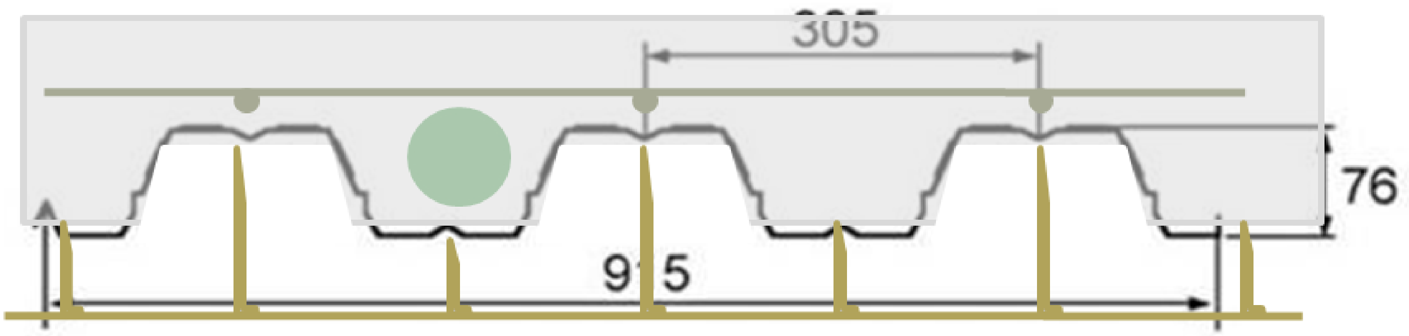


Roof Assembly					
Layer no.	***Material***	***Thickness (m)***	***Conductivity (W/m-K)***	***R value m^2K/W***	***Source***
1	Rsi	0.003	-	0.170	As per ENS guidelines 2018 (roof section), Composite climate
2	Gypsum Board (False Ceiling)	12.500	0.160	0.078	From Manufacturer (Gyproc) Technical Data Sheet
3	Air Gap, 100 mm	0.100	0.500	0.200	As per ENS guidelines 2018, Composite climate
4	Deck Sheet (GI sheet)	0.001	61.060	0.000	As per ENS guidelines 2018, Composite climate
5	RCC Slab	0.098	1.580	0.062	Density Value - from Site team Others (Spc heat, R & K Values) - as per ENS guidelines 2018
6	Brick Bat Coba (Solid Burnt Black Clay Bricks)	0.090	0.620	0.145	As per ENS guidelines 2018, Composite climate
7	Rse	0.003	-	0.04	As per ENS guidelines 2018 (roof section), Composite climate
8	**R Total**			**0.695**	
U value of assembly				**1.439**	

This is greater than the maximum Uroof value of 1.2 W/m2 .K.

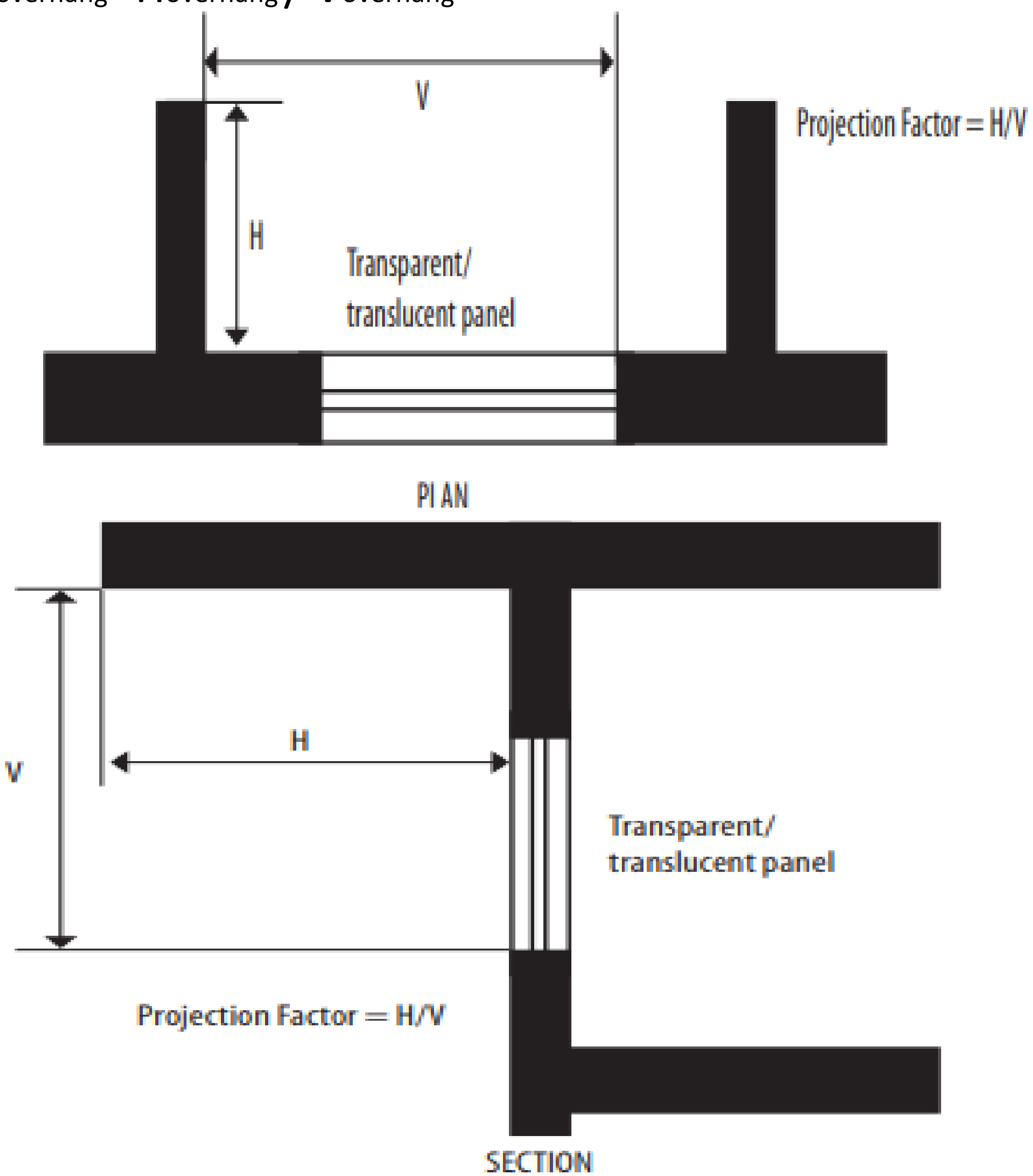
Roof U value is 1.44, it can be reduced to 0.4 W/m2.k via adding PUF insulation.

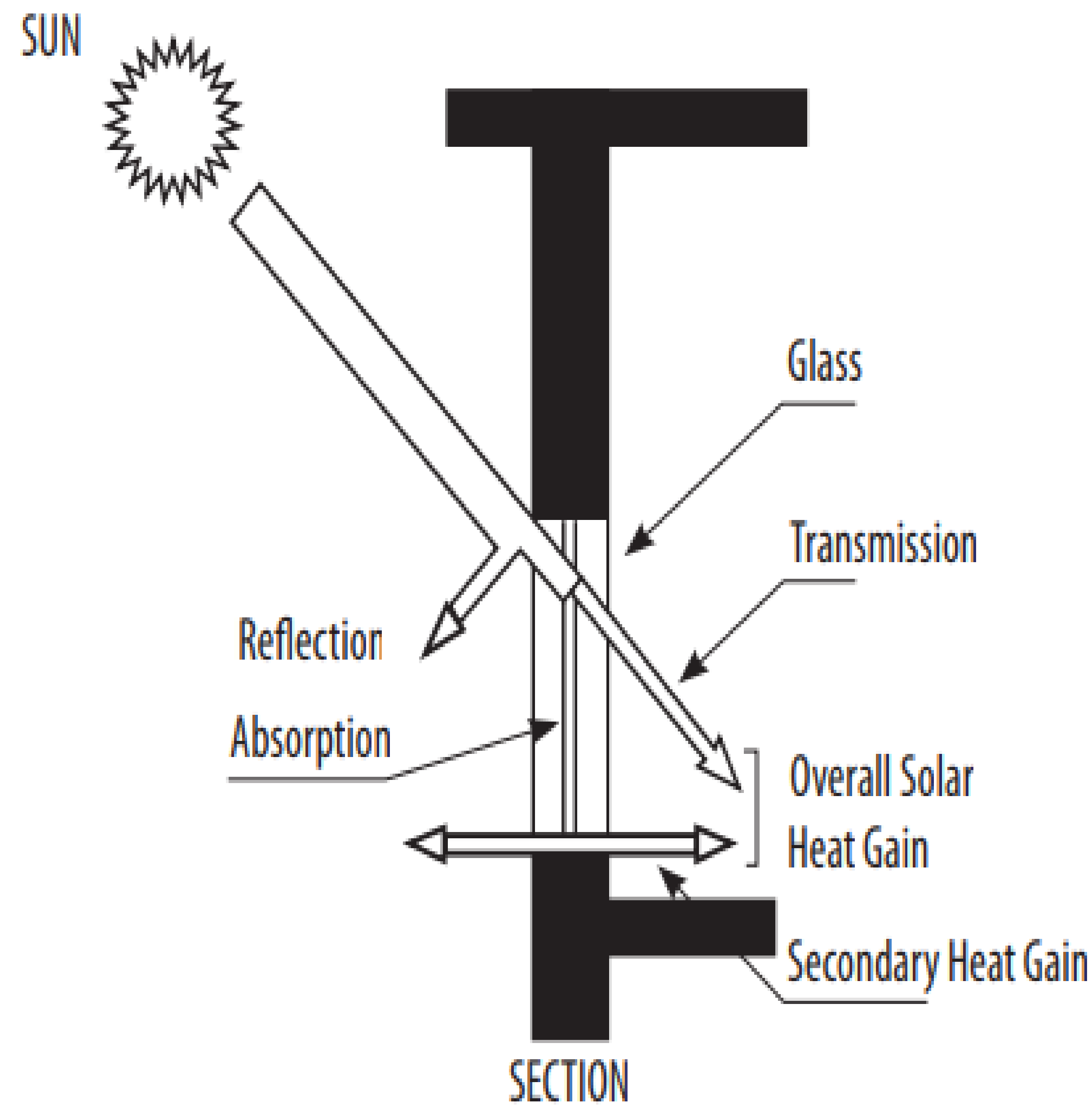
ECO NIWAS SAMHITA 2018 -Energy Conservation Building Code for Residential Buildings

Solar Heat Gain Coefficient (SHGC): SHGC is the fraction of incident solar radiation admitted through non-opaque components, both directly transmitted, and absorbed and subsequently released inward through conduction, convection, and radiation

Projection factor, overhang: the ratio of the horizontal depth of the external shading projection (Hoverhang) to the sum of the height of a non-opaque component and the distance from the top of the same component to the bottom of the farthest point of the external shading projection (Voverhang), in consistent units.

$PF_{overhang} = H_{overhang} / V_{overhang}$





LHP INDORE

TABLE 11 External Shading Factor for Overhang ($ESF_{overhang}$) for LAT<23.5°N

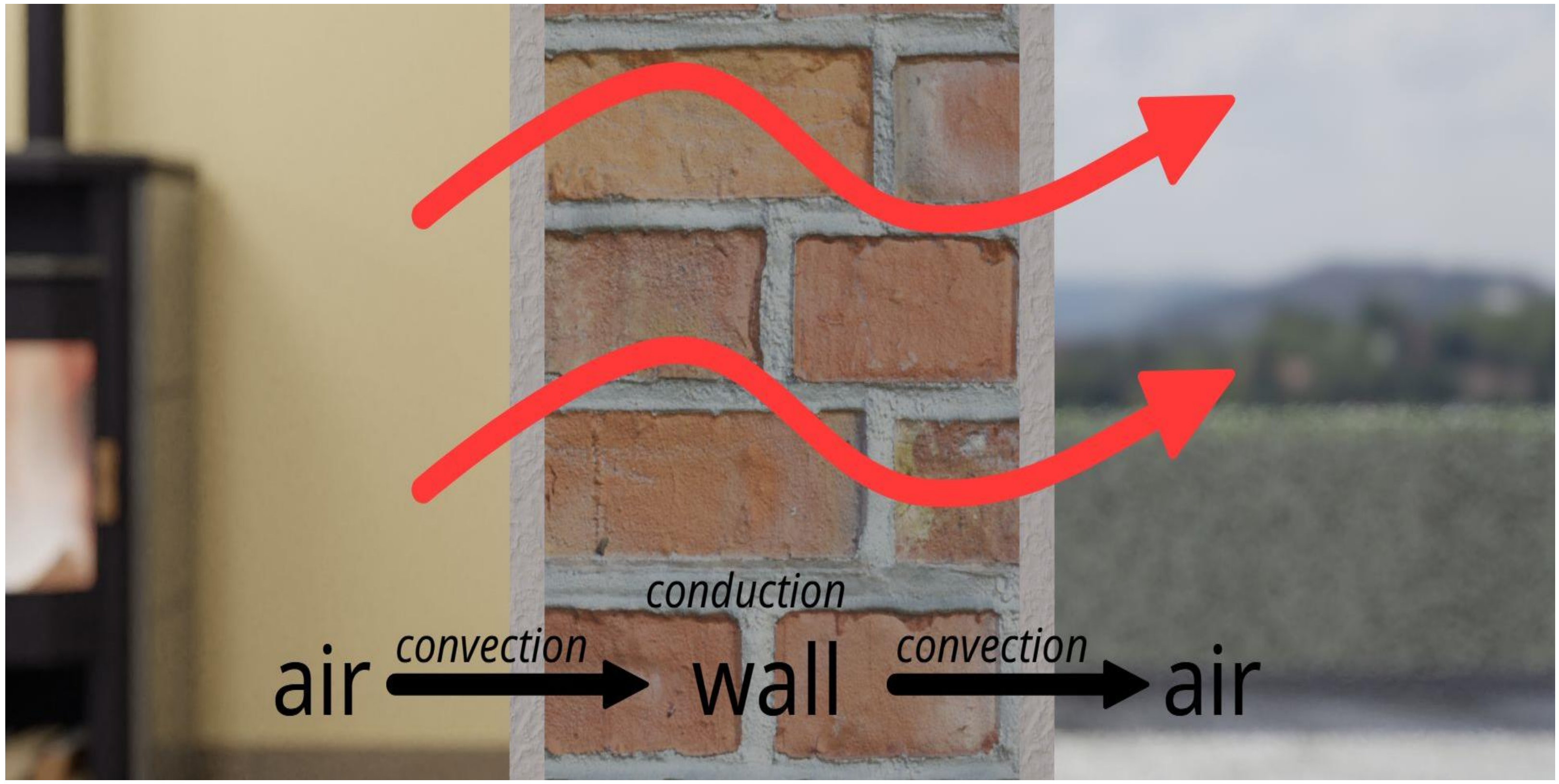
Orientation	External Shading Factor for Overhang ($ESF_{overhang}$) for LAT < 23.5°N							
$PF_{overhang}$	North (337.6°–22.5°)	North-east (22.6°–67.5°)	East (67.6°–112.5°)	South-east (112.6°–157.5°)	South (157.6°–202.5°)	South-west (202.6°–247.5°)	West (247.6°–292.5°)	North-west (292.6°–337.5°)
<0.10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.10-0.19	0.931	0.924	0.922	0.910	0.896	0.910	0.922	0.924
0.20-0.29	0.888	0.864	0.855	0.834	0.816	0.834	0.854	0.864
0.30-0.39	0.860	0.818	0.797	0.771	0.754	0.771	0.796	0.818
0.40-0.49	0.838	0.782	0.747	0.721	0.708	0.720	0.746	0.782
0.50-0.59	0.820	0.755	0.705	0.682	0.675	0.681	0.705	0.755

$$SHGC_{eq} = SHGC_{Unshaded} \times ESF_{total}$$

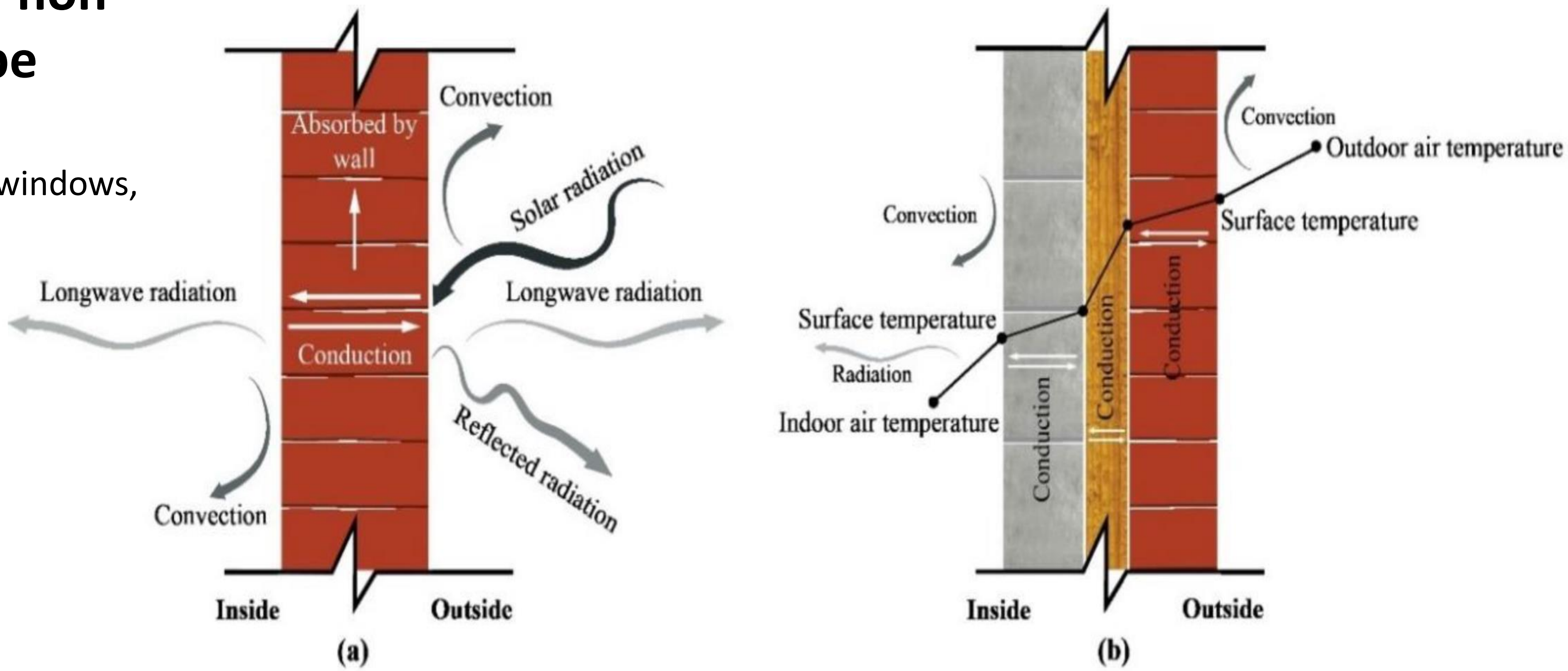
Calculation on equivalent SHGC of Non Opaque Opening for each Orientation

Orientation	Name	Width of Glass, m	Height of Glass, m	Nos of Windows	Glas Area, m2	H, overhabg	V, overhang	PF, overhang	H, right, m	V, right, m	PF, right	H, left, m	V, left, m	PF, left	ESF, overhang	ESF, right	ESF, left	ESFsidefin	ESF, total	SHGCunshaded	SHGC Eq
North	W2	0.64	1.2	16	12.29	0	0	0.00	2.2	0.8	2.75	2.2	0.8	2.75	1	0.86	0.85	0.71	0.71	0.86	**0.61**
South	W2	0.64	1.2	16	12.29	0	0	0.00	2.2	0.8	2.75	2.2	0.8	2.75	1	0.86	0.86	0.72	0.72	0.86	**0.62**
East	W1	1.2	1.28	64	98.30	0.45	1.6	0.28	0	0	0	0	0	0	0.86	1	1	1	0.86	0.86	**0.74**
East	W3	0.48	1.2	64	36.86	1.1	1.6	0.69	1.1	0.6	1.83	1.1	2.1	0.52	0.67	0.88	0.94	0.82	0.55	0.86	**0.47**
West	W1	1.2	1.28	64	98.30	0.45	1.6	0.28	0	0	0	0	0	0	0.85	1	1	1	0.85	0.86	**0.73**
West	W3	0	1.2	64	0	1.1	1.6	0.69	1.1	0.6	1.83	1.1	2.1	0.52	0.67	0.91	0.91	0.83	0.55	0.86	**0.48**

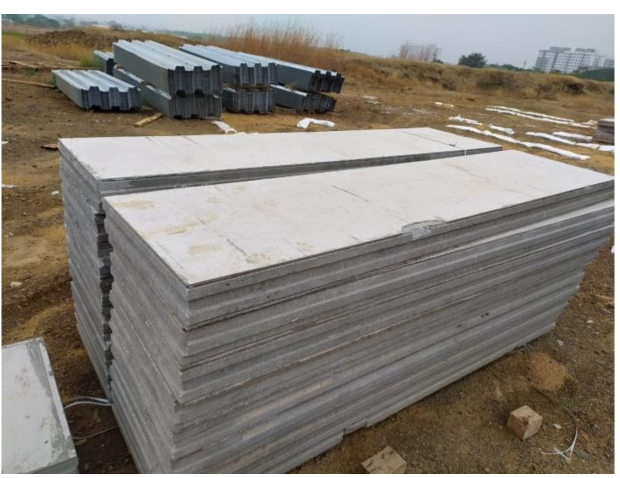
Thermal transmittance of building envelope (except roof)



- Thermal transmittance characterizes the thermal performance of the building envelope (except roof).
- U value takes into account the following:
    - Heat conduction through ***opaque building envelope components***
      (wall, opaque panels in door, window, ventilators, etc.)
    - Heat conduction through **non-opaque building envelope components**
      (transparent/translucent panels in windows, doors, ventilators, etc.).



LHP INDORE



External Wall Assembly, 120 mm

Layer no.	Material	Density	Specific Heat	Thickness	Conductivity	R value	Source
		(kg/m3)	(kJ/kg.K)	(m)	(W/m-K)	m^2K/W	
1	Rsi	-	-	0.003	-	0.130	As per ENS guidelines 2018, Composite climate
2	sandwich panel 120mm	780.0	-	0.120	0.220	0.560	
3	Rse	-	-	0.003	-	0.040	As per ENS guidelines 2018, Composite climate
4	R Total					0.730	
U value of assembly						**1.370**	

Internal Wall Assembly, 90 mm

Layer no.	Material	Density	Specific Heat	Thickness	Conductivity	R value	Source
		(kg/m3)	(kJ/kg.K)	(m)	(W/m-K)	m^2K/W	
1	Rsi	-	-	0.003	-	0.130	As per ENS guidelines 2018, Composite climate
2	sandwich panel 90mm	780.000	-	0.090	0.220	0.420	Test Certificate - Rising Japan Infra Mumbai Rising HONGFA (R90 value provided by Manufacturer)
3	Rse	-	-	0.003	-	0.040	As per ENS guidelines 2018, Composite climate
4	R Total					0.590	
U value of assembly						**1.695**	

Internal Wall Assembly, 60 mm

Layer no.	Material	Density	Specific Heat	Thickness	Conductivity	R value	Source
		(kg/m3)	(kJ/kg.K)	(m)	(W/m-K)	m^2K/W	
1	Rsi	-	-	0.003	-	0.130	As per ENS guidelines 2018, Composite climate
2	sandwich panel 60mm	780.0	-	0.060	0.220	0.280	
3	Rse	-	-	0.003	-	0.040	As per ENS guidelines 2018, Composite climate
4	R Total					0.450	
U value of assembly						**2.222**	

Residential Envelope Transmittance Value

RETV characterizes the thermal performance of the building envelope ***(except roof).*** Limiting the RETV value helps in reducing heat gains from the building envelope, thereby improving the thermal comfort and reducing the electricity required for cooling.

Its unit is W/m2 .

$$RETV = \frac{1}{A_{envelope}} \times \left[\begin{array}{l} \left\{ 6.06 \times \sum_{i=1}^{n} \left(A_{opaque_i} \times U_{opaque_i} \times \omega_i \right) \right\} \\ + \left\{ 1.85 \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times U_{non-opaque_i} \times \omega_i \right) \right\} \\ + \left\{ 68.99 \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times SHGC_{eq_i} \times \omega_i \right) \right\} \end{array} \right] \begin{array}{l} Term\text{-}I \\ Term\text{-}II \\ Term\text{-}III \end{array}$$

TABLE 3 Coefficients (a, b, and c) for RETV formula

Climate zone	a	b	c
Composite	6.06	1.85	68.99
Hot-Dry	6.06	1.85	68.99
Warm-Humid	5.15	1.31	65.21
Temperate	3.38	0.37	63.69
Cold	Not applicable (Refer Section 3.5)		

LHP INDORE

Orientation	Description	Area, m2	U Value, W/m2.k	Orientation Factor, w	TERM-I a*b*c	TERM-II a*b*c
NORTH	Non-opaque (glass) area	12.29	5.35	0.66	0.00	43.32
NORTH	Opaque area 1 (Sandwich Panel)	297.56	1.37	0.66	268.62	
NORTH	Opaque area 2 (PVC FRAME)	6.91	4.80	0.66	21.86	
NORTH	Opaque area 3 (Wooden doors)	0.00	0.17	0.66	0.00	
SOUTH	Non-opaque (glass) area	12.29	5.35	0.97	0.00	63.51
SOUTH	Opaque area 1 (Sandwich Panel)	297.56	1.37	0.97	393.76	
SOUTH	Opaque area 2 (PVC FRAME)	6.91	4.80	0.97	32.05	
SOUTH	Opaque area 3 (Wooden doors)	0.00	0.17	0.97	0.00	
EAST	Non-opaque (glass) area	137.59	5.35	1.16	0.00	850.19
EAST	Opaque area 1 (Sandwich Panel)	676.99	1.37	1.16	1071.13	
EAST	Opaque area 2 (PVC FRAME)	77.93	4.80	1.16	432.06	
EAST	Opaque area 3 (Wooden doors)	201.60	0.17	1.16	40.52	
WEST	Non-opaque (glass) area	137.59	5.35	1.16	0.00	850.92
WEST	Opaque area 1 (Sandwich Panel)	676.99	1.37	1.16	1072.05	
WEST	Opaque area 2 (PVC FRAME)	77.93	4.80	1.16	432.43	
WEST	Opaque area 3 (Wooden doors)	201.60	0.17	1.16	40.55	
					3805.03	**1807.94**

Orientation	Name	Total Opening Are, m2	Orientation Factor, w	TERM-III a*b*c
North	W2	19.2	0.66	7.71
South	W2	19.2	0.97	11.45
East	W1	153.6	1.16	130.45
East	W3	57.6	1.16	31.40
West	W1	153.6	1.16	130.41
West	W3	57.6	1.16	31.69
				343.11

RETV – 17.75

RETV is >15 W/m2 where clear glass SHGC is 0.86. RETV can be achieved <15, with Clear Glass of SHGC of 0.55.

ENS CODE COMPLIANCE

Table 1: Minimum ENS Score Requirement

Project Category	Minimum ENS Score
Low rise buildings	47
Affordable Housing	70
High rise buildings	100

Table 2: Component wise Distribution of ENS Score

Section	Components	Minimum points	Additional Points	Maximum Points
6.4	Building Envelope			
	Building Envelope	47	40	87
6.5	Building Services			
	Common area and exterior lighting	3	6	9
	Elevators	13	9	22
	Pumps	6	8	14
	Electrical Systems	1	5	6
6.6	Indoor Electrical End-Use			
	Indoor Lighting		12	12
	Comfort Systems		50	50
	ENS Score	70	130	200

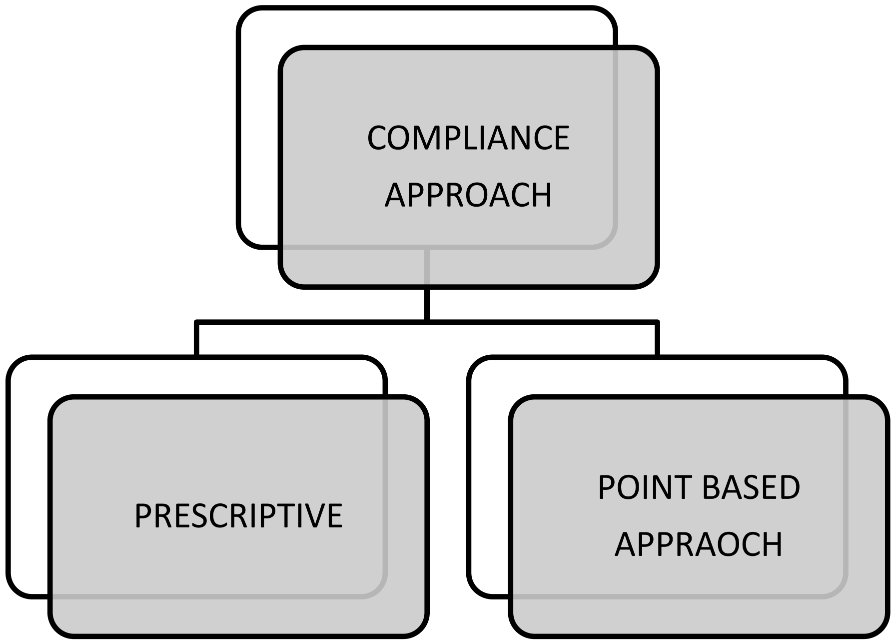
Table 9: Score for Renewable Energy System Components

Renewable Energy Systems Components	Minimum Points	Additional Points	Maximum Points
Solar Hot Water Systems		10	10
Solar Photo Voltaic		10	10
Additional ENS Score		20	20

The purpose of Eco Niwas Samhita 2021

The code applies to –

- Residential buildings built on a plot area of ≥ 500 m2
- Residential part of Mixed land-use building projects, built on a plot area of ≥ 500 m2 .



Compliance Approaches

ENS CODE COMPLIANCE

LHP INDORE Component wise Distribution of ENS Score

ENS Score	80	210	100
Components	**Minimum Points**	**Maximum Points**	**LHP Indore (Proposed)**
Building Envelope	47	87	51
Building Services			
Common area & exterior lighting	3	9	6
Elevators	13	22	17
Pumps	6	14	6
Electrical Systems	1	6	0
Indoor Electrical End-Use			
Indoor Lighting	-	12	9
Comfort Systems	-	50	6
Renewable	10	10	5

Common Area and exterior Lighting

- Light installation will be done in a way where W/m2 will meet the criteria
- Fixture Lm/W, Lumens will se selected in a way where Lm/W will be more than 95

Elevators

- Proposal from Elevator OEM meeting all the requirement / criteria. It is proposed to go for same proposal / BOQ line items
- Choose VVVF technology based elevator. (part of proposal). This will help in achieving extra points

Pumps

Expected that PMC team will go for BEE 4 star rated pumps as Hydro-Pneumatic is expensive technology. Project can achieve 06 points

Renewable Energy Systems

As per drawings provided, Installation of 79 Panels need approx. 132 sqm area which is approx. to 24% of tower roof area occupied by Panels. Hence project can achieve 5 points.

BEE Star labelling for Residential Buildings

BEE STAR LABELLING FOR RESIDENTIAL BUILDINGS

Labeling Types

"Applied For" label	Applicable for new buildings with construction permit issued by the authorities having jurisdiction
"Final" Label	Applicable for existing and new buildings. For new building, this label can only be awarded after the occupancy certificate is issued by the authorities having jurisdiction

Labeling Process

Outline of process for awarding BEE Star Label for Residential Buildings

Preparation Stage
- Pre-requisites for applying
- Evaluation for eligibility requirements

Application processing
- Registration
- Online application
- Scrutiny of application
- Approval for label

Implementation
- Transfer from "Applied for" to "Final" label
- Ownership transfer
- Changes in label, already awarded

M&V
- Verification audits
- Data reporting

For more information: www.econiwas.com and www.beeindia.gov.in

About the Program

The program aims to develop national energy efficiency label for residential buildings to enhance energy efficiency in the residential sector.

A residential building label is a benchmark to compare a home over the other on the energy efficiency standards

Need of Residential Building Labeling Program

- Real estate market is expected to climb up to US$ 180 billion by 2020
- Residential sector is expected to contribute 11% to India's GDP by 2020.
- More than 3 billion square meters of new residential buildings will be added by 2030
- Electricity demand due to residential sector is expected to reach 698 billion units by 2030 from 2018 value of 250 billion units

BEE STAR LABELLING FOR RESIDENTIAL BUILDINGS

Program Objectives

The objective of the program is to provide:-

- information to consumers on the energy efficiency standard of the Homes
- Facilitation in the implementation of EcoNiwas Samhita 2018
- a consumer driven market transformation business model solution for Energy Efficiency in housing sector
- steering the construction activities of India towards international best practices norms

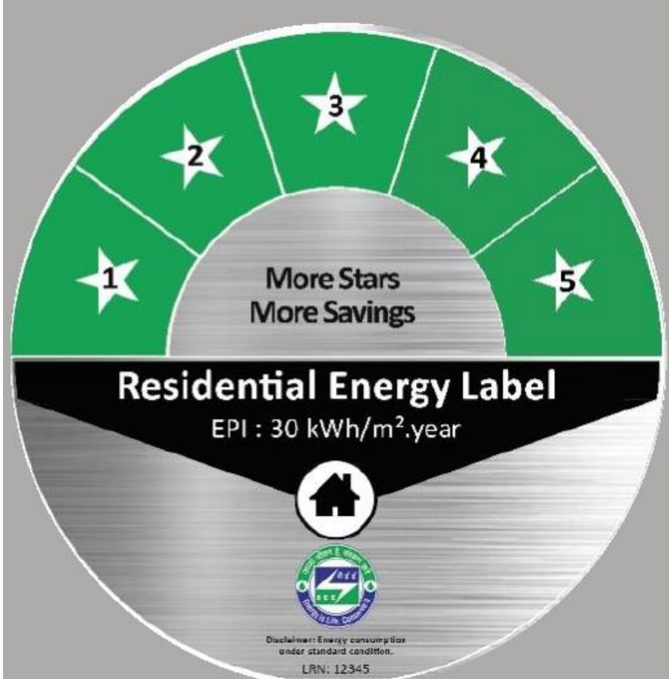
Program Scope

The program is applicable for all single and multiple dwelling unit in the country for residential purpose

5 star rated home is **40%** more energy efficient than 1 star rated home

Energy Savings

Annual saving of 90 Billion Units in the year of 2030



Benefits from the labeling program

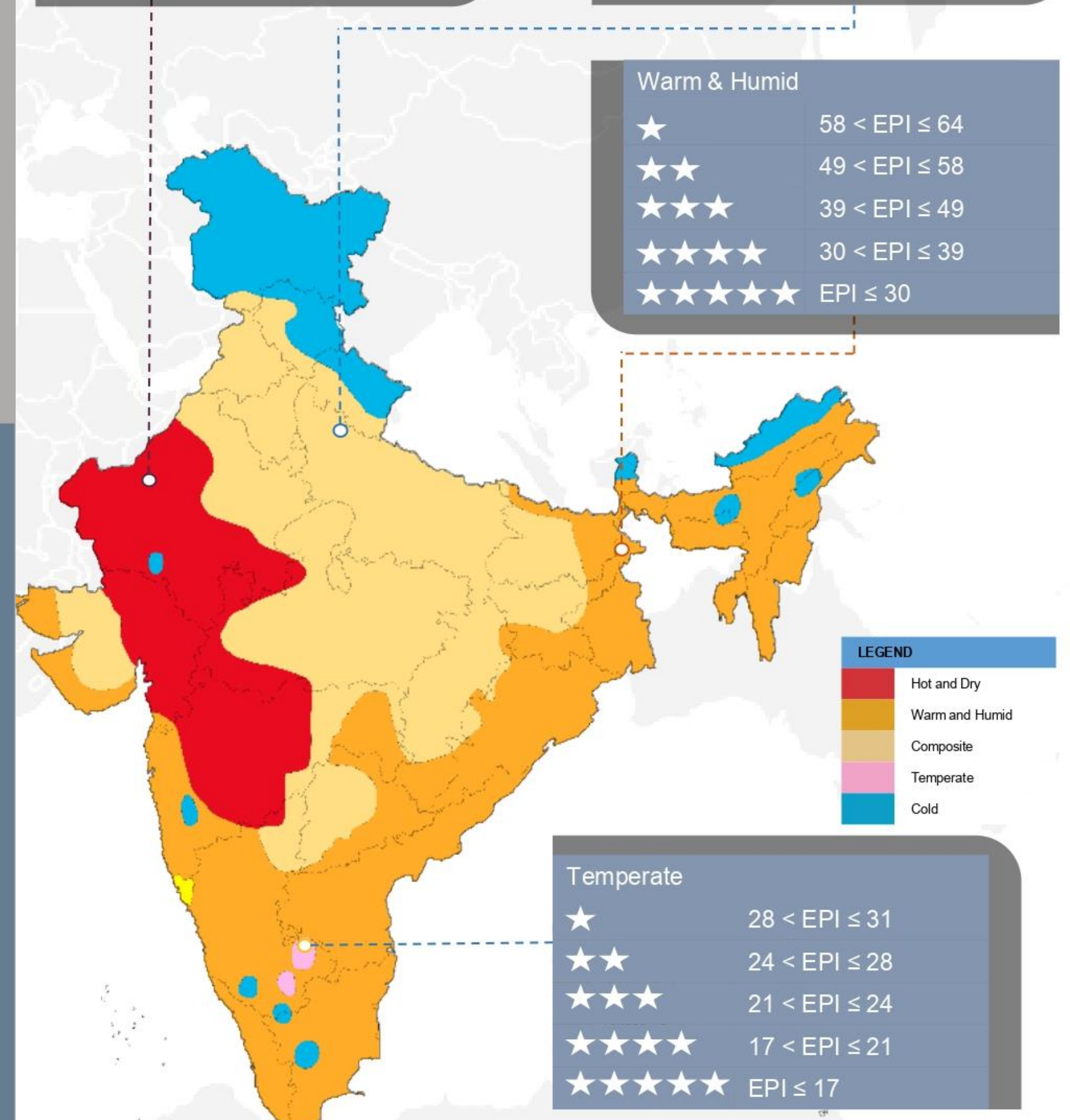
- Cumulative saving of 388 billion units of electricity by 2030
- Reduction of carbon emission by 3 billion tones by 2030
- Increased uptake of energy efficient construction in India
- Facilitate energy efficient materials and technologies market supporting the "Make in India" initiative
- Improve environmental resilience and energy security
- Sustainable living standards

Residential Building Star Rating Plan

Hot & Dry	
★	55 < EPI ≤ 67
★★	47 < EPI ≤ 55
★★★	38 < EPI ≤ 47
★★★★	29 < EPI ≤ 38
★★★★★	EPI ≤ 29

Composite	
★	52 < EPI ≤ 60
★★	45 < EPI ≤ 52
★★★	37 < EPI ≤ 45
★★★★	29 < EPI ≤ 37
★★★★★	EPI ≤ 29

Warm & Humid	
★	58 < EPI ≤ 64
★★	49 < EPI ≤ 58
★★★	39 < EPI ≤ 49
★★★★	30 < EPI ≤ 39
★★★★★	EPI ≤ 30



Temperate	
★	28 < EPI ≤ 31
★★	24 < EPI ≤ 28
★★★	21 < EPI ≤ 24
★★★★	17 < EPI ≤ 21
★★★★★	EPI ≤ 17

ENS SIMULATION TOOLS

ENS TOOLS ECONIWAS 2.0 - INTRODUCTION

- Building simulation allows engineers and architects to address key aspects of building performance throughout the whole building life cycle from early design stages through construction and even for major energy retrofitting.
- Building simulation is a way to test how elements of building design will perform under real-world conditions
- **Basic Tool**
- **Advanced Tool**
- **Envelope Optimization Tool**

https://www.econiwas.com/tools.php

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BUILDING PERFORMANCE ANALYTICS

Basic Tool

The basic tool is a quick evaluation platform for home owners, contractors and builders alike to rapidly evaluate the project's preliminary design intent on the scale ofenergy efficiency, carbon footprint and monetary savings with the selected project location, user specified area and orientation. The tool has various category of options from building envelope (wall, roof & window), Air-conditioning and Ventilation techniques to check the project performance. Click on the tool to explore more!

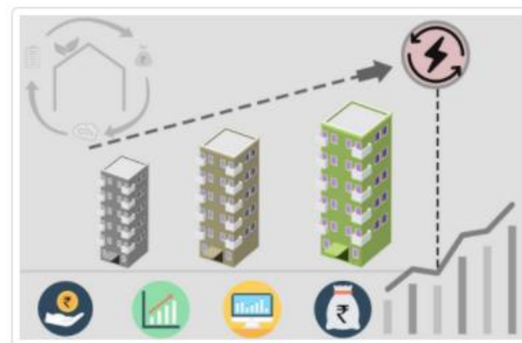
Tutorial Video

Advanced Tool (Trial Version)

The simulation based ECONIWAS Advanced tool is for the professionals (Architects,Engineers, MEP consultants, project developers, Industry professionals) who wish to perform detailed analysis of the project design features in terms of energy efficiency and economic feasibility. The tool has the provision of various inputs of building design parameter options ranging from Building Geometry, Envelope, Lighting, Equipment, HVACand Economicsto check the project performance. Dive in to learn more!

Tutorial Video

Optimization Tool (Trial Version)



The ECONIWAS Optimization tool is a quick evaluation moduleto compute the most optimized set of envelop parameters (best wall, best roof and best window)for the selected location based on life cycle cost of the envelope options. Just input the cost of most common envelope assemblies available at the project site and tool will indicate which envelope will be the best for your site. Click on the tool to explore more!

Tutorial Video

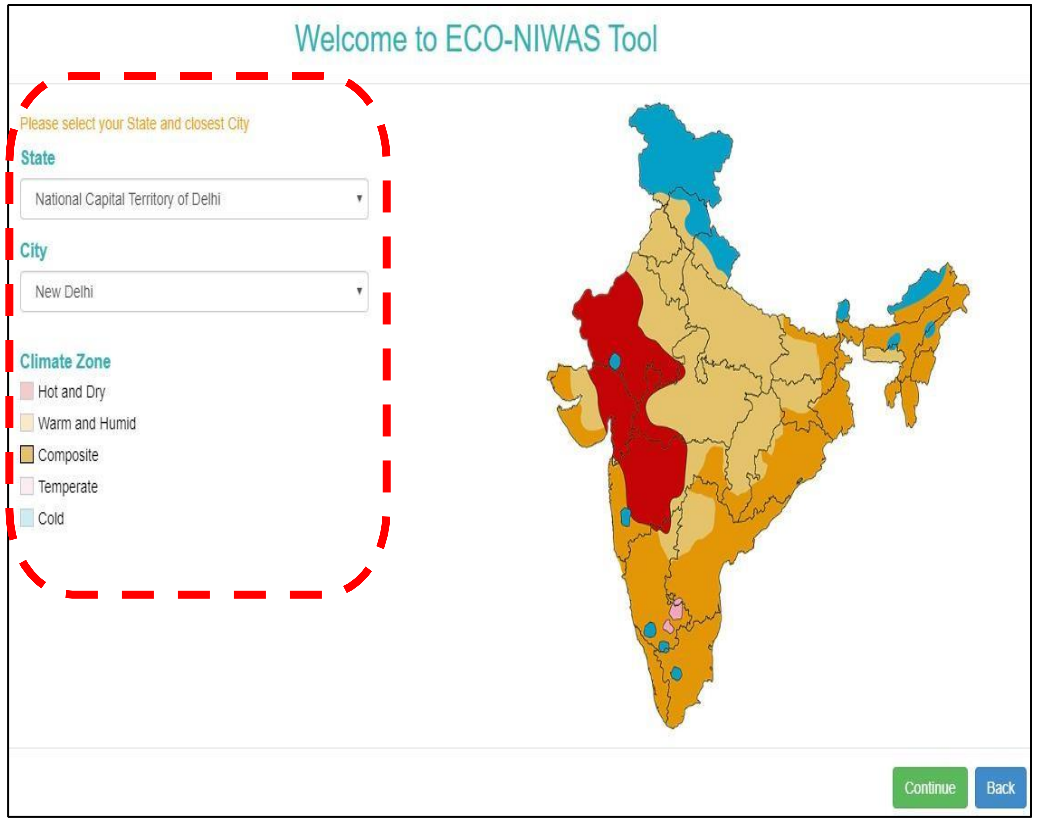
ECONIWAS 2.0 - MODULES

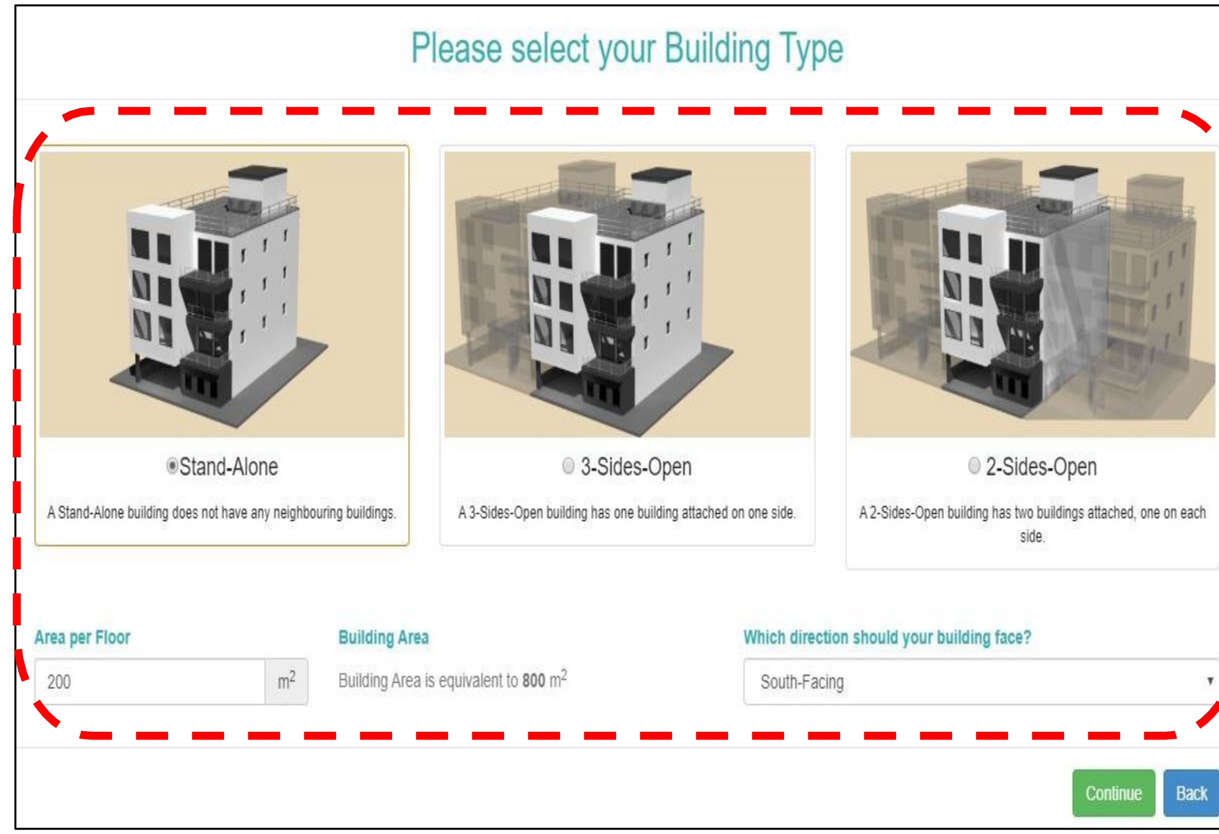
Basic Tool:

Quick evaluation platform for homeowners, contractors and builders alike to rapidly evaluate the project's preliminary design intent on the scale of energy efficiency, carbon footprint and monetary savings with the selected project location, user specified area and orientation, building envelope (wall, roof & window), Air-conditioning and Ventilation techniques.

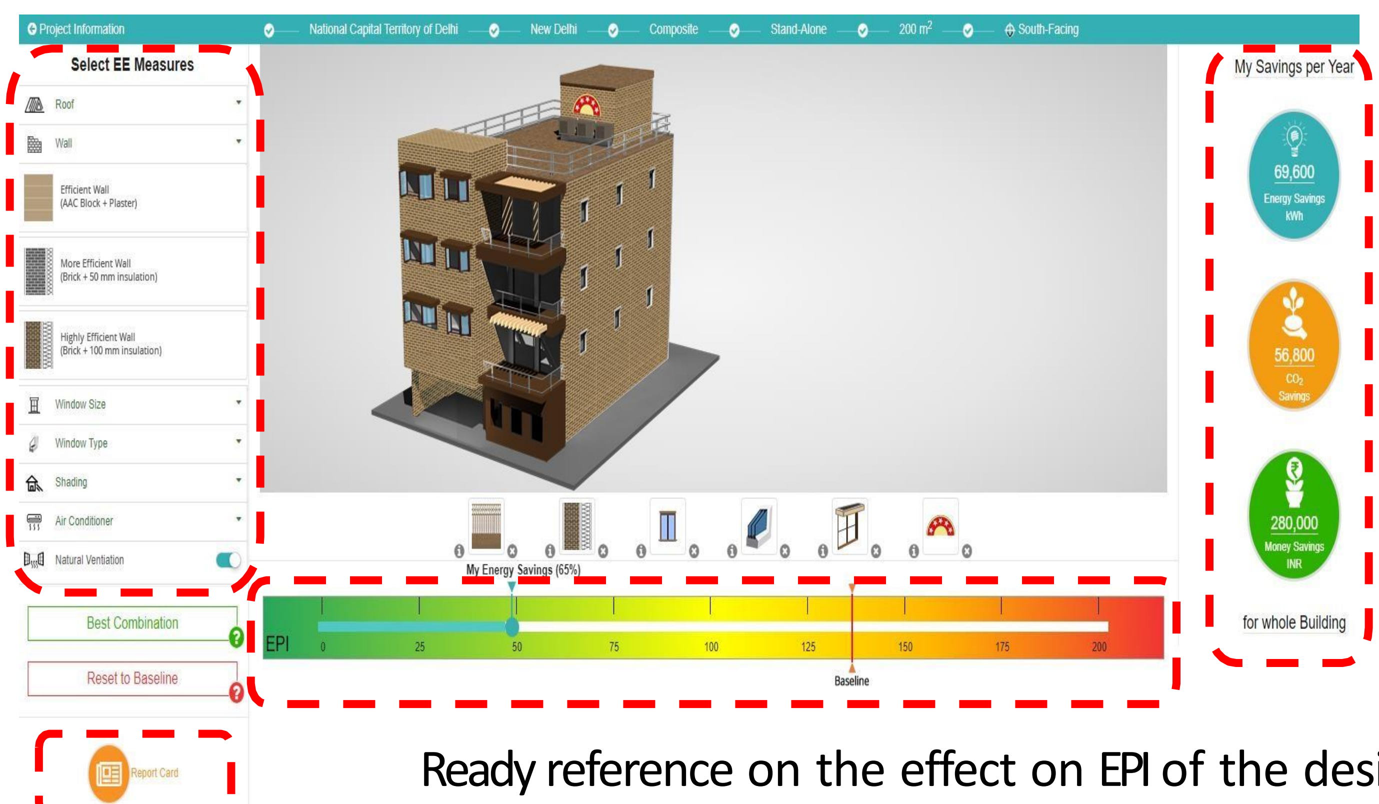
ECONIWAS 2.0 – BASIC TOOLS

Quick and Easy Inputs for defining primary information of Building including location, shading, area and orientation.





Most interactive drag and drop features to select and install energy efficient parameters in building design



Quick inference on the impact of selected design features on the energy, environment and monetary level.

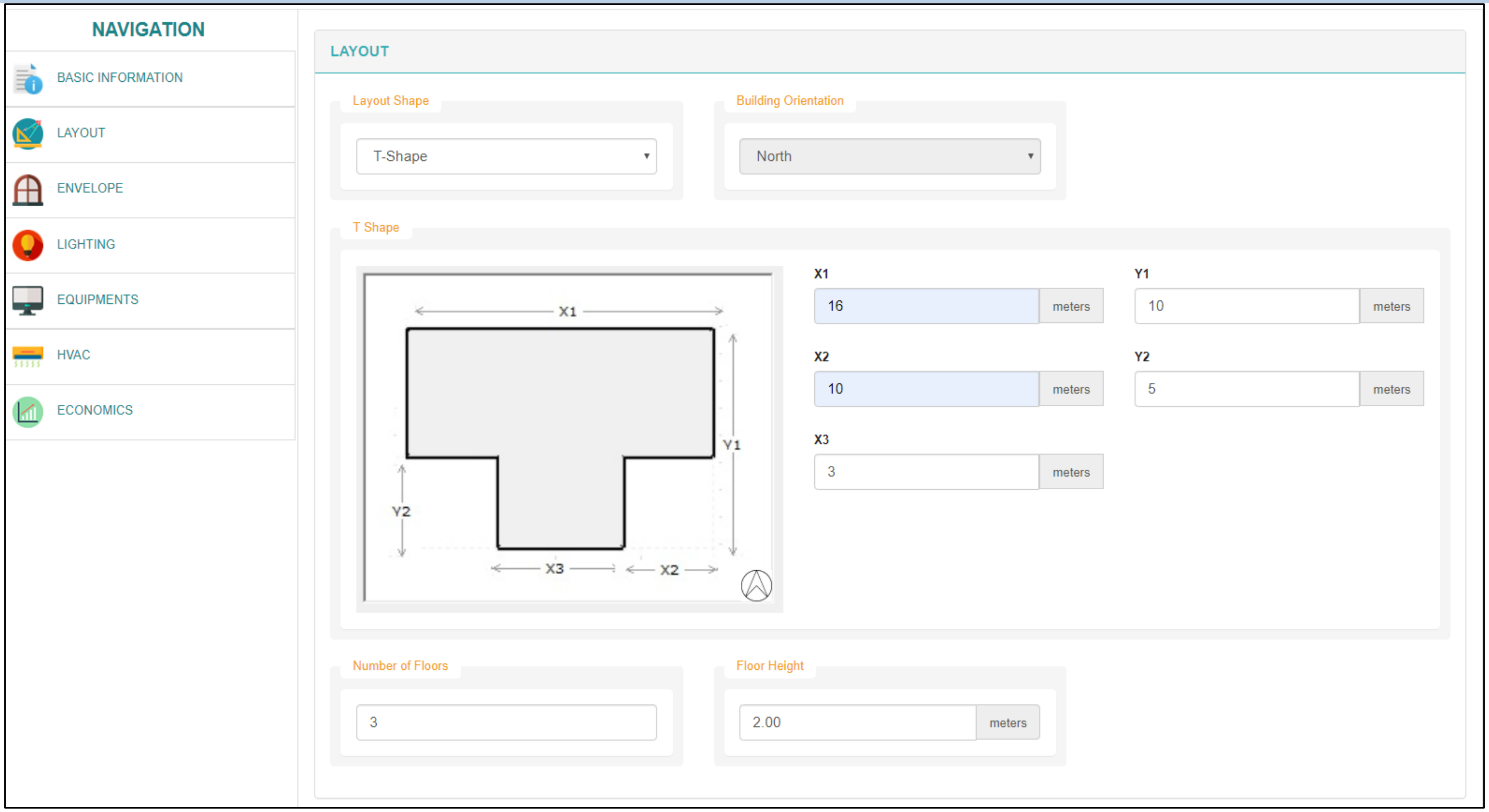
One click export of results to PDF file

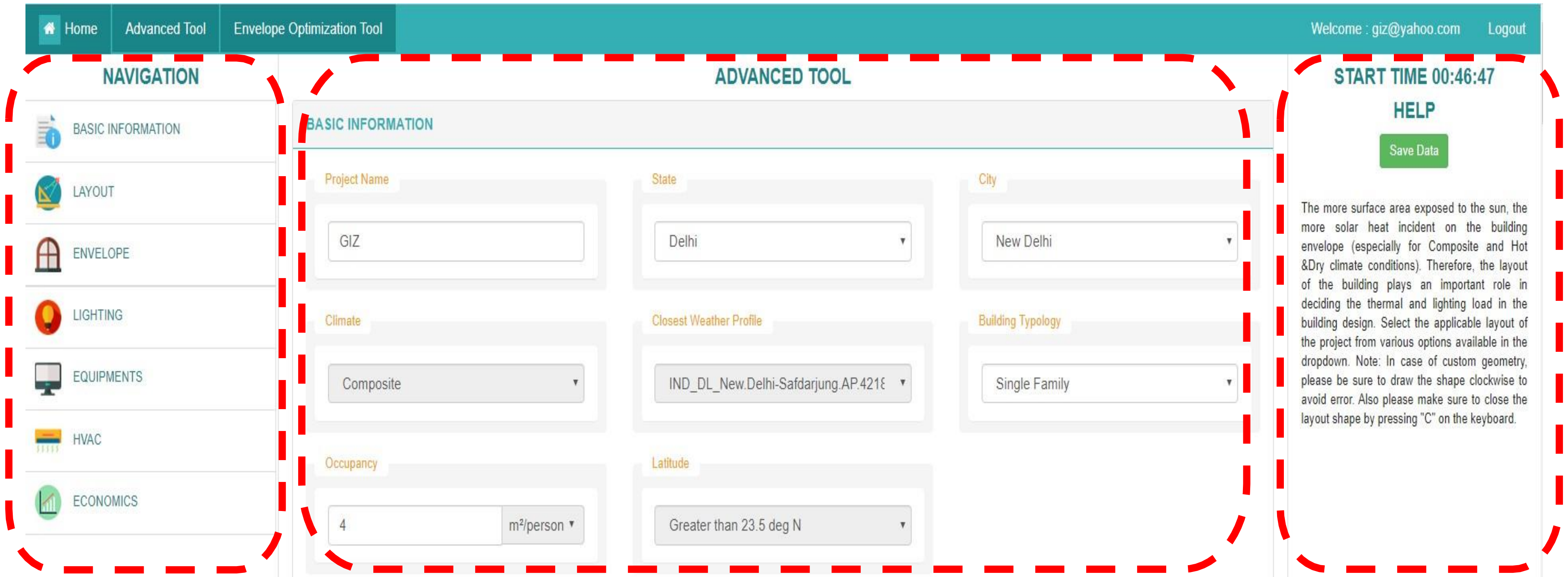
Ready reference on the effect on EPI of the design as compared to conventional (baseline) design

ECONIWAS 2.0 – MODULES AND BASIC INFORMATION

ADVANCED TOOL

Simulation based tool for the professionals (Architects, Engineers, MEP consultants, project developers, Industry professionals) who wish to perform detailed analysis of the project design features in terms of energy efficiency, economic feasibility and environmental impact.





Effective and responsible user form that takes essential inputs from the user to generate desired results

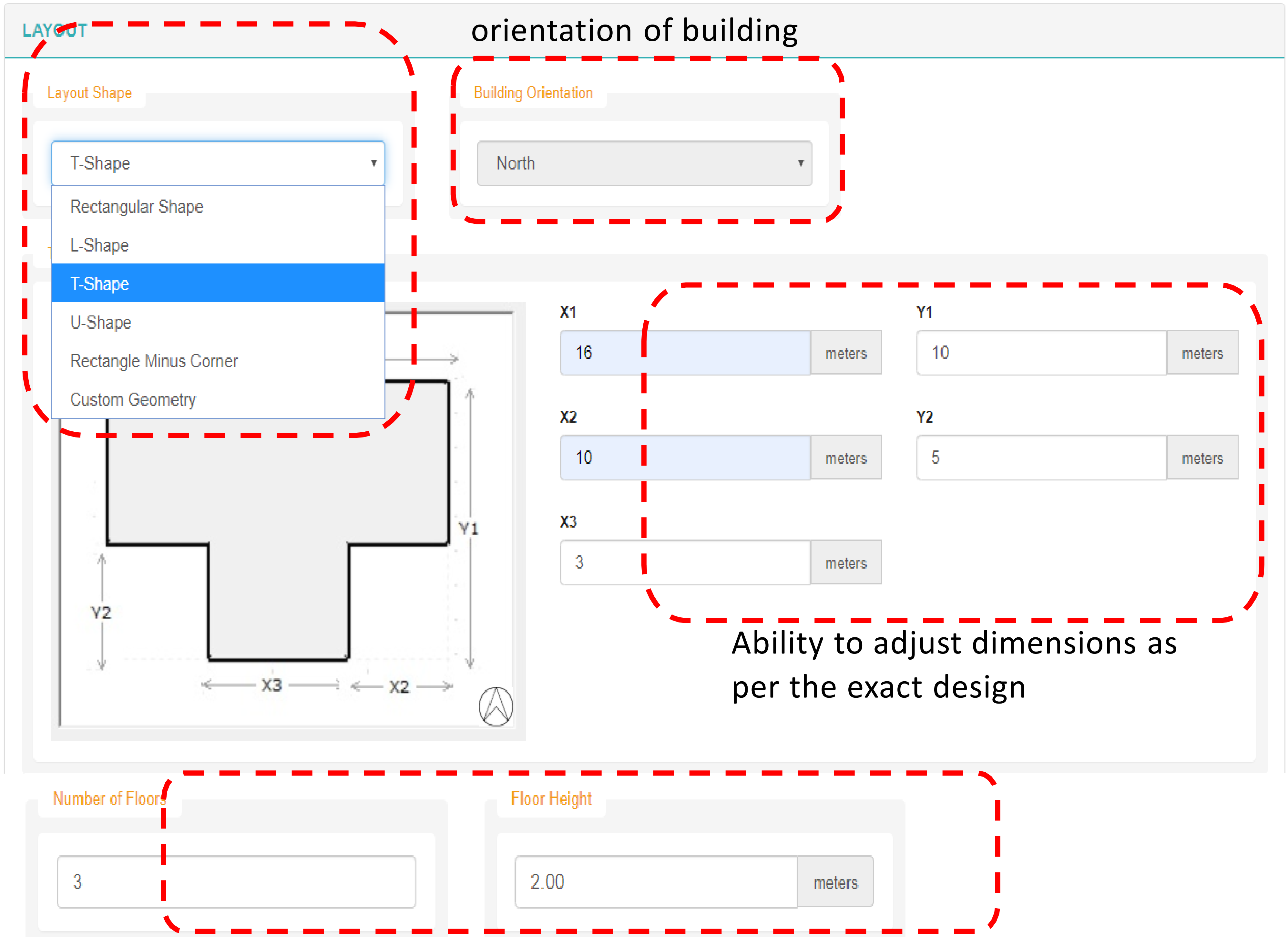
Easy to Navigate, tree view layout for quick navigations between various building parameters.

Self explanatory help panel for easy understanding of inputs for the users

ECONIWAS 2.0 – ADVANCECD TOOL – LAYOUT INFORMATION

Various layout options for the user to choose from, to match exact shape of the building design.

User can select desired orientation of building



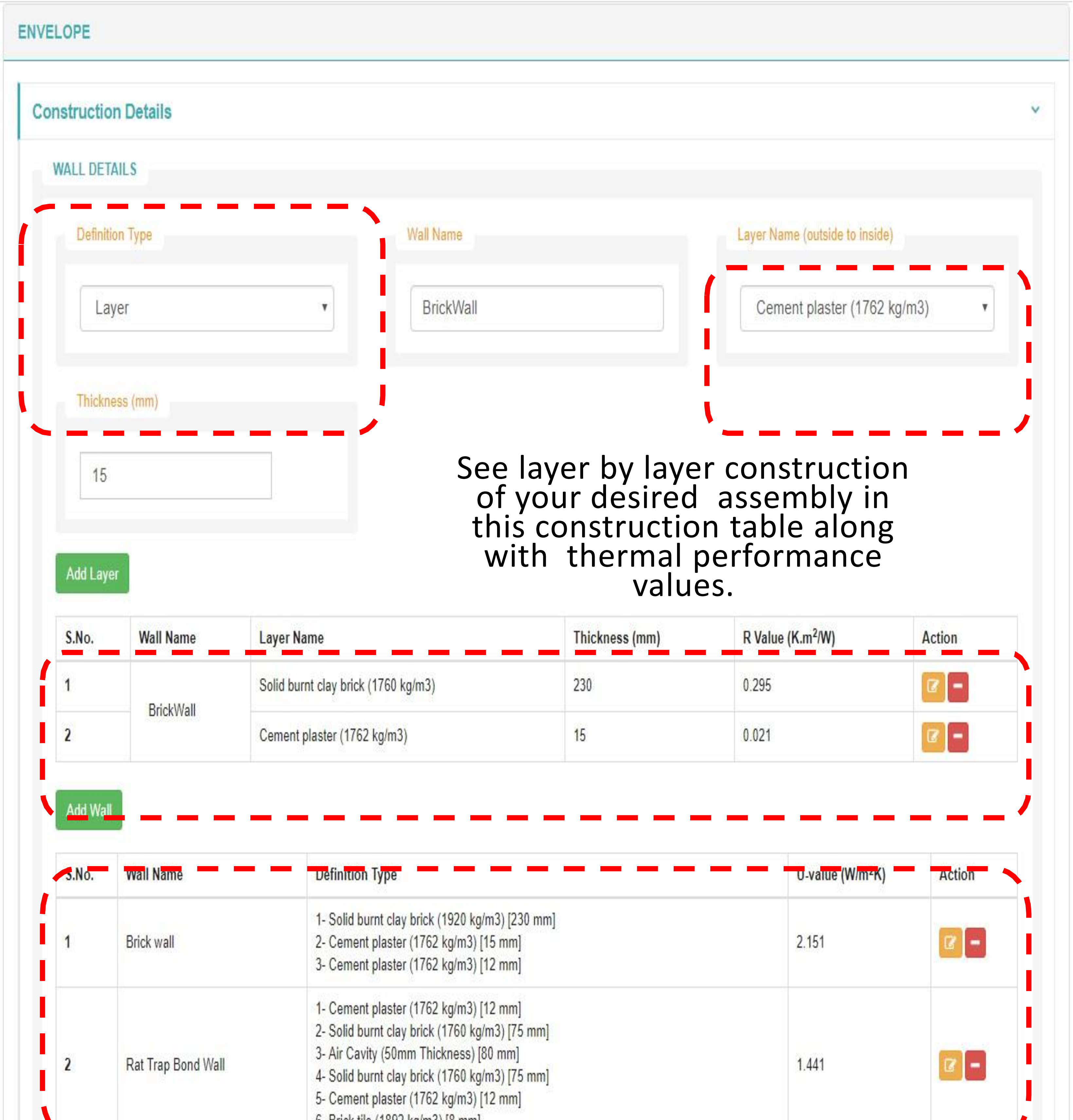
Ability to adjust dimensions as per the exact design

Accessibility to design multiple floors with user specified floor height

ECONIWAS 2.0 – ADVANCECD TOOL – ENVELOPE CONSTRUCTION INFORMATION

For Wall & Roof Construction Assembly Definition

Define Wall/Roof constructions through property (U-value) or layer definition method. The construction once created can be used multiple times.



S.No.	Wall Name	Layer Name	Thickness (mm)	R Value ($K.m^2/W$)	Action
1	BrickWall	Solid burnt clay brick (1760 kg/m3)	230	0.295	
2		Cement plaster (1762 kg/m3)	15	0.021	

S.No.	Wall Name	Definition Type	U-value (W/m^2K)	Action
1	Brick wall	1- Solid burnt clay brick (1920 kg/m3) [230 mm] 2- Cement plaster (1762 kg/m3) [15 mm] 3- Cement plaster (1762 kg/m3) [12 mm]	2.151	
2	Rat Trap Bond Wall	1- Cement plaster (1762 kg/m3) [12 mm] 2- Solid burnt clay brick (1760 kg/m3) [75 mm] 3- Air Cavity (50mm Thickness) [80 mm] 4- Solid burnt clay brick (1760 kg/m3) [75 mm] 5- Cement plaster (1762 kg/m3) [12 mm] 6- Brick tile (1892 kg/m3) [8 mm]	1.441	

See layer by layer construction of your desired assembly in this construction table along with thermal performance values.

Large number of construction Materials as per ENS are available in the list

All the assembled constructions are listed in this table for later use.

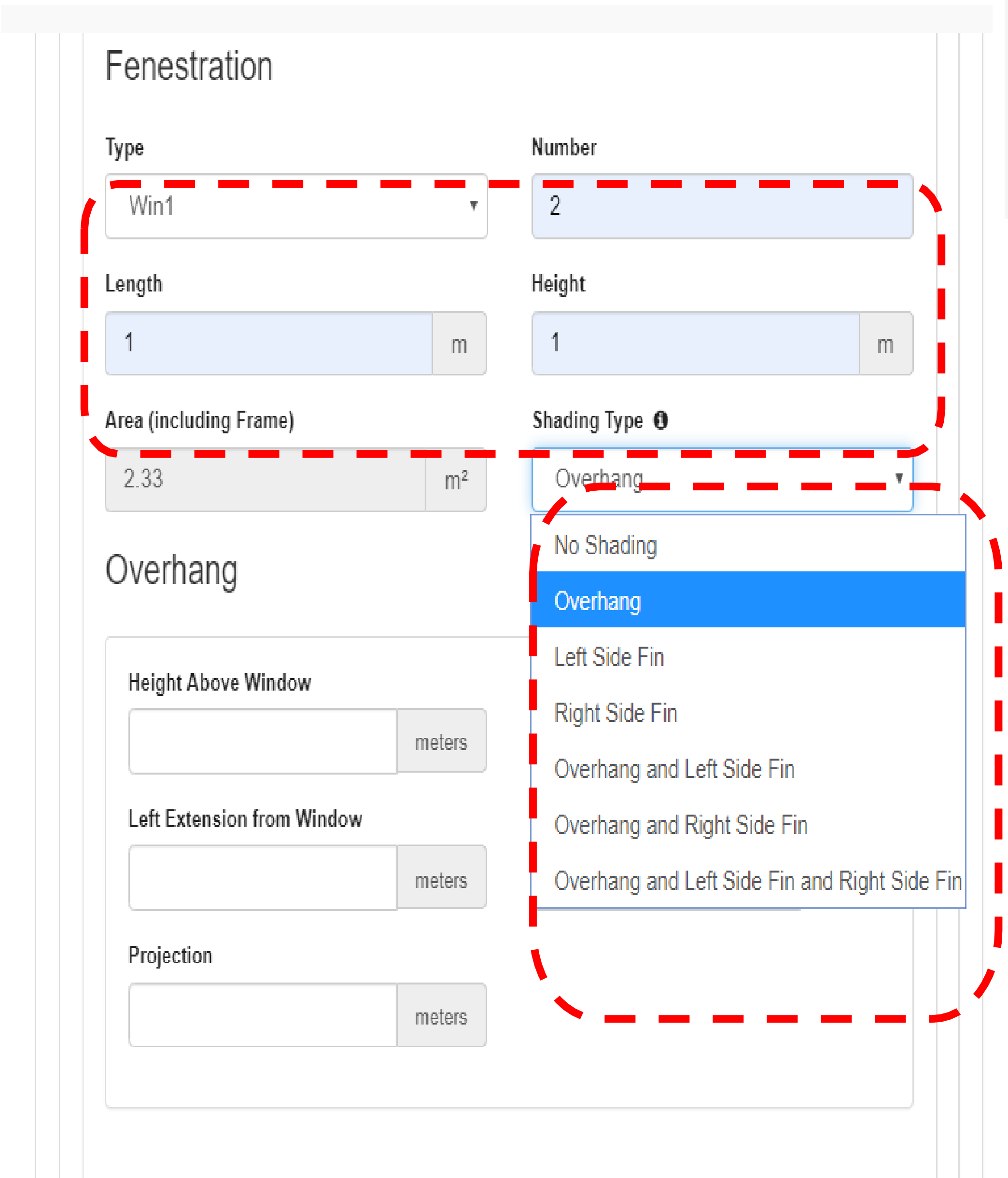
ECONIWAS 2.0 – ADVANCECD TOOL – ENVELOPE CONSTRUCTION INFORMATION

For Fenestration Definition

Define fenestration constructions through property U-value, SHGC & VLT, glazing area and opaque frame selection. The construction once created can be used multiple times.

S.No.	Fenestration Type	Name of the window	Fenestration Opening Type	U-value (W/m²K)	SHGC	VLT	Glazing (%)	Opaque Frame U-Value (W/m².K)	Action
1	Window	wind_1	Casement	1.4	0.4	0.47	50	1.90	
2	Window	wind_2	Casement	0.4	0.4	0.44	40	0.40	

All the window constructions are listed in this table for later use.



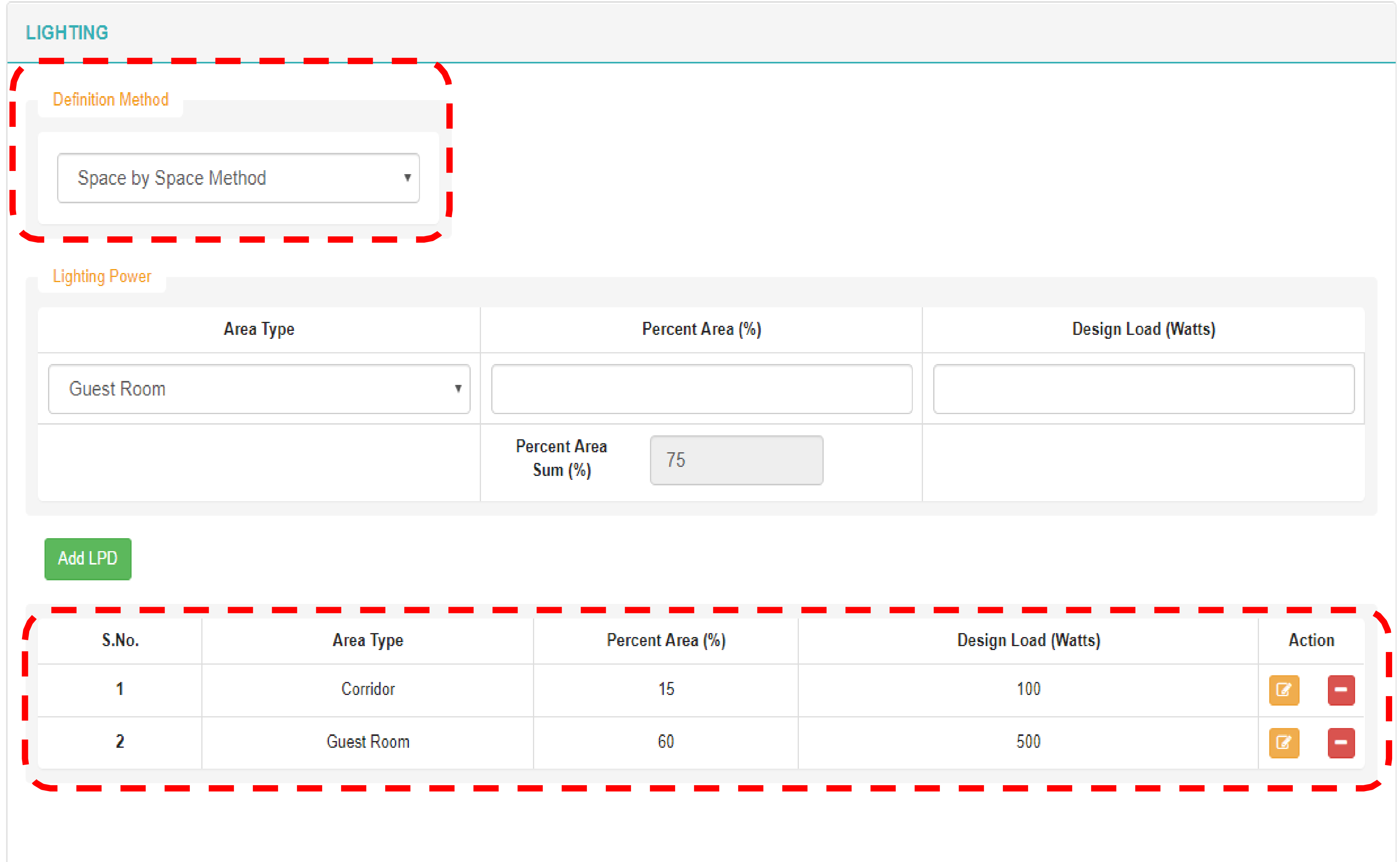
For Fenestration & Shading Dimension Definition

Select window type from predefined window constructions types to be installed on the selected wall of the building. Define dimension of windows and numbers

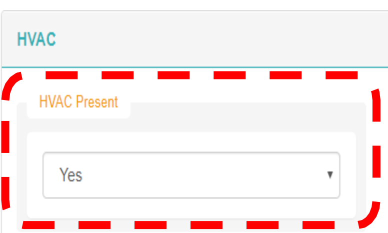
Options to install shading elements on the selected window. Select one and input dimensions.

ECONIWAS 2.0 – ADVANCECD TOOL – LIGHTING/EQUIPMENT & HVAC INFORMATION

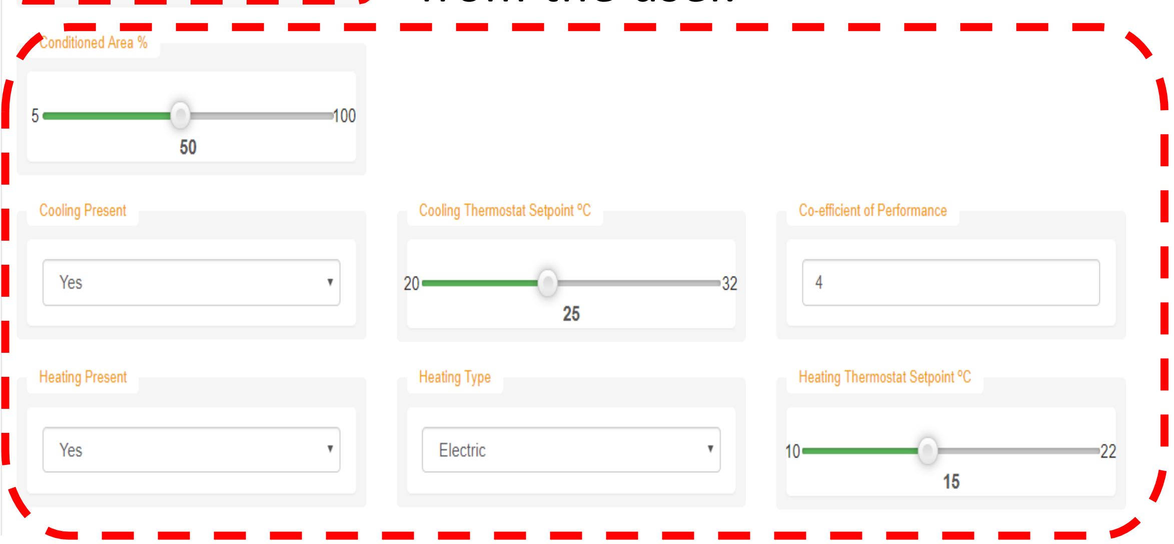
User can define the lighting/equipment power density using Building Area Method or Space Function Method as per ECBC



This table represents the design lighting/equipment load in different areas of the building.



In case the HVAC is present, some essential information about the efficiency of equipment and conditioned area is asked from the user.

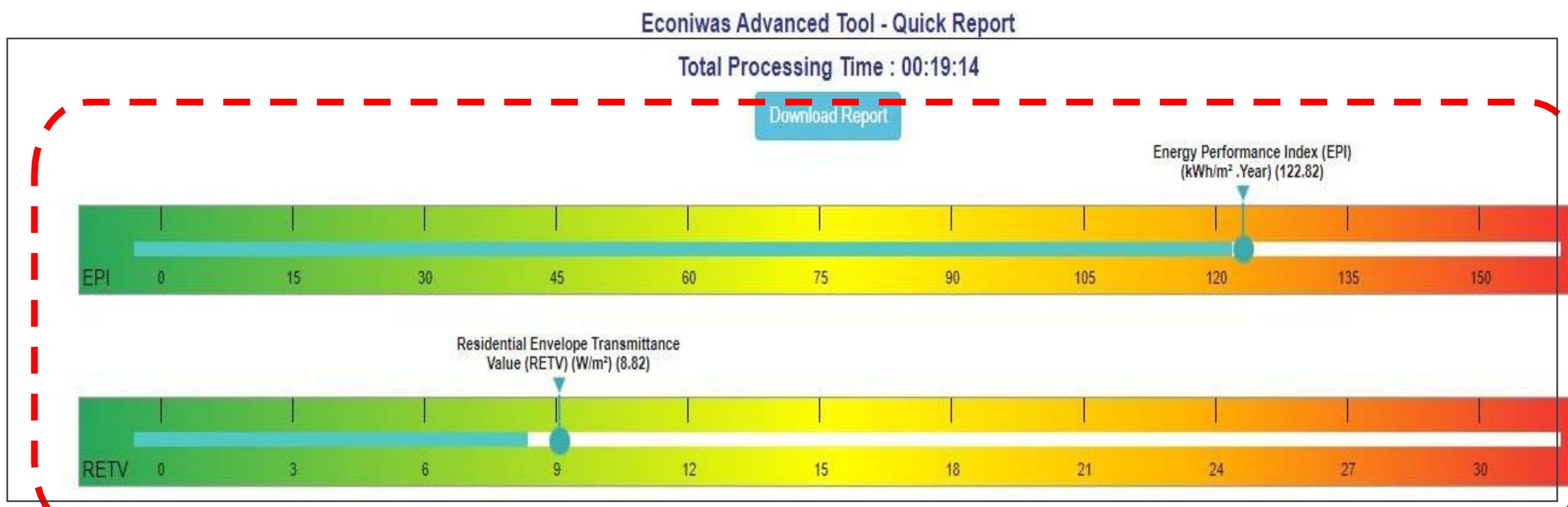


User has the option to choose whether the building is conditioned or naturally ventilated.

ECONIWAS 2.0 – ADVANCECD TOOL – RESULTS

On the submission of the form, the tool performs the energy simulation using energy plus server-side simulation platform to predict the EPI and RETV values of the designed building.

The user has the option to export the results in PDF format for later use, using the “Download Report” button on the results page.

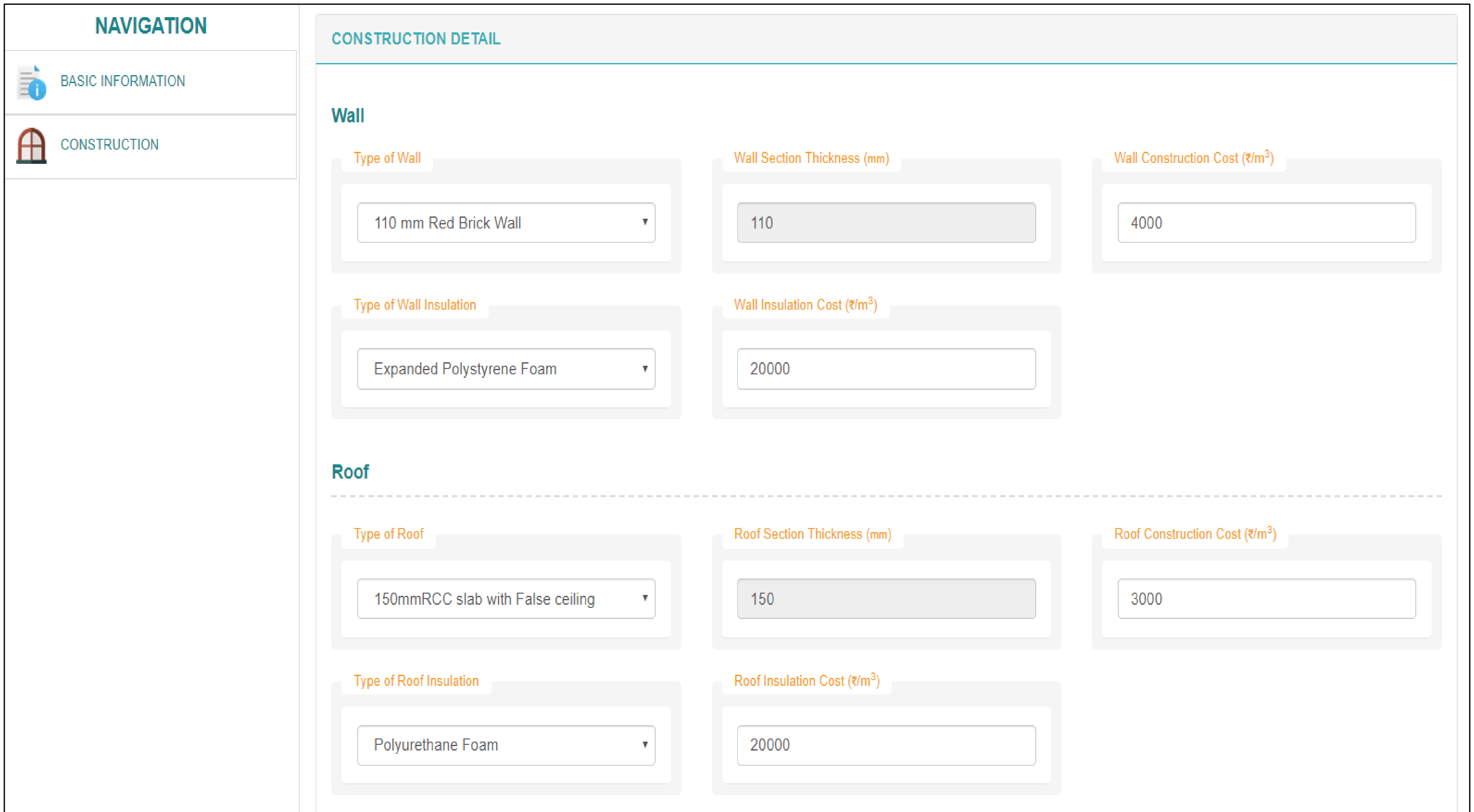


The tool also predicts the Annual CO2 generation, Annual Operational cost of the design and Annual life cycle cost of the project based on the inputs given by the user

ECONIWAS 2.0

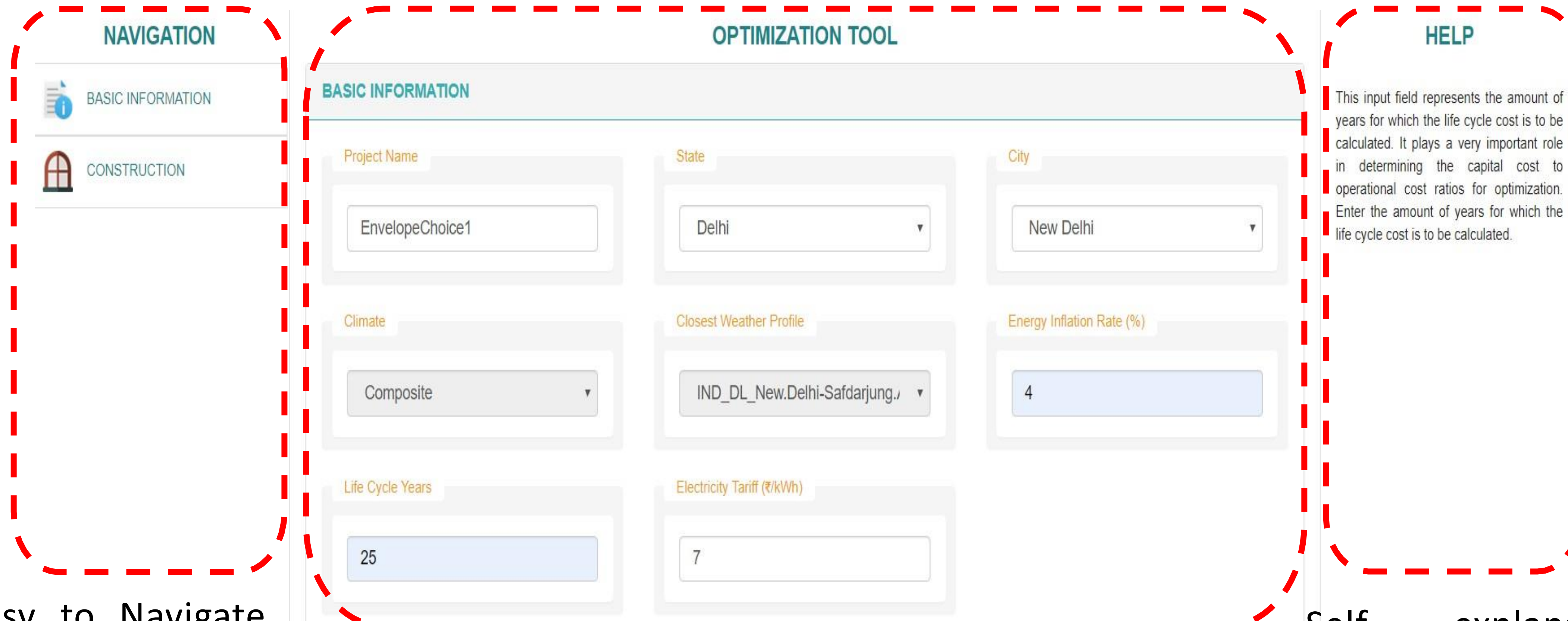
Envelope Optimization Tool

A quick envelope evaluation module to compute the most optimized set of U-values & SHGC for best wall, best roof and best window including thickness of selected insulation required on the selected base assemblies of wall and roof for the selected location based on life cycle cost of the building envelope.



ECONIWAS 2.0 – ENVELOPE OPTIMIZATION TOOL – BASIC INFORMATION

Effective and responsible user form that takes essential inputs from the user to generate desired results. Project location, energy inflation rate, tariff rate and life cycle years are few basic inputs which are required by the user.

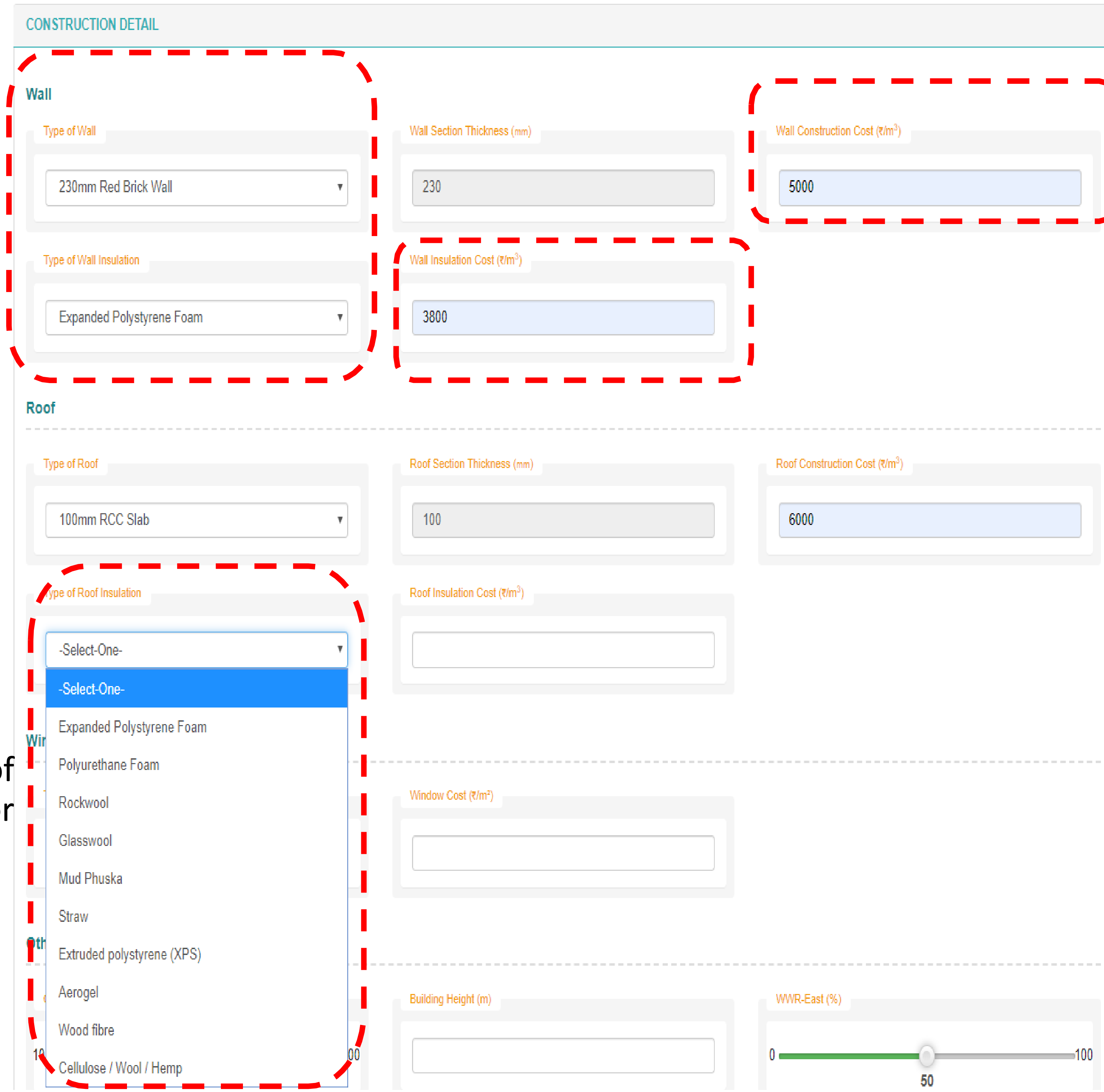


Easy to Navigate, tree view layout for quick navigations between various building parameters.

Self explanatory help panel for easy understanding of inputs for the users

ECONIWAS 2.0 – ENVELOPE OPTIMIZATION TOOL – BASIC INFORMATION

User is required to select the choice of base wall/roof assembly on which insulation of optimized thickness shall be installed. Similarly, selection of insulation material is required as input.



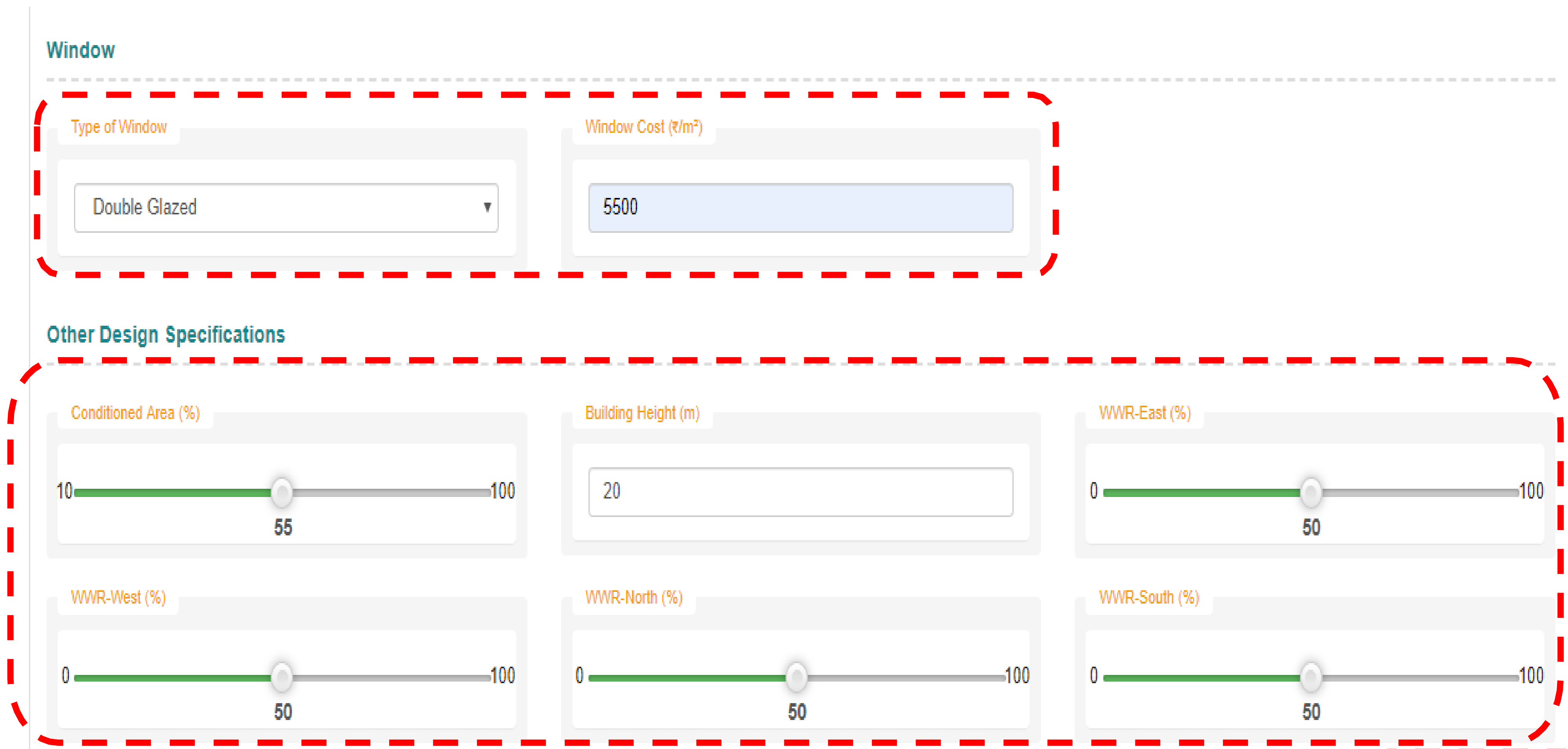
User is required to define the cost per cubic meter for base wall roof assembly and the selected insulation.

Large number of insulation options for user to choose from.

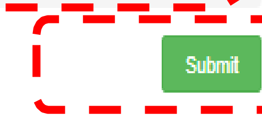
ECONIWAS 2.0 – ENVELOPE OPTIMIZATION TOOL – OTHER DESIGN INFORMATION

Similarly, selection of Window type and corresponding cost is required as input. Based on the window type, the optimization tool shall limit the U-value output.

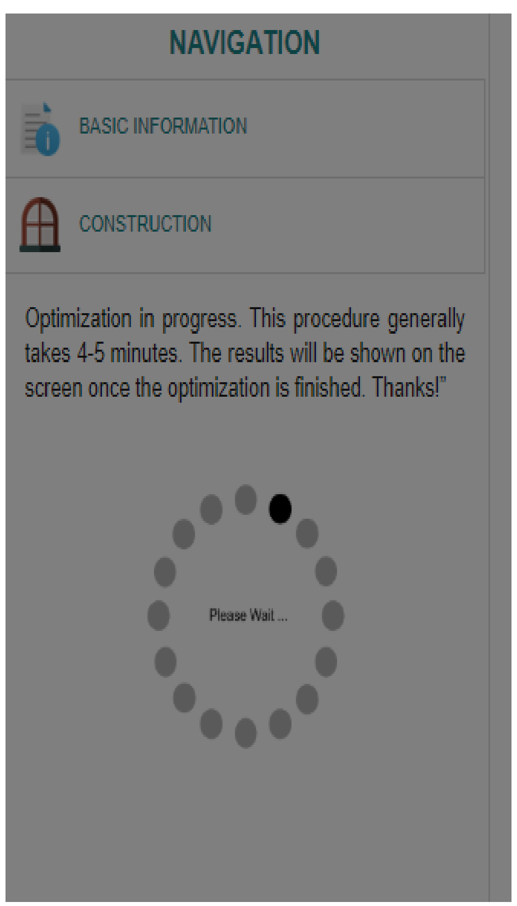
For example, if user selects SGU, the tool can predict U values close to 7 W/m2.K, whereas if user selects DGU, the tool will limit the prediction of U-value upto 4 W/m2.K



Apart from this, a few other relevant information on the envelope such as Building Height, Conditioned Area and WWR of each façade is required as input from the user



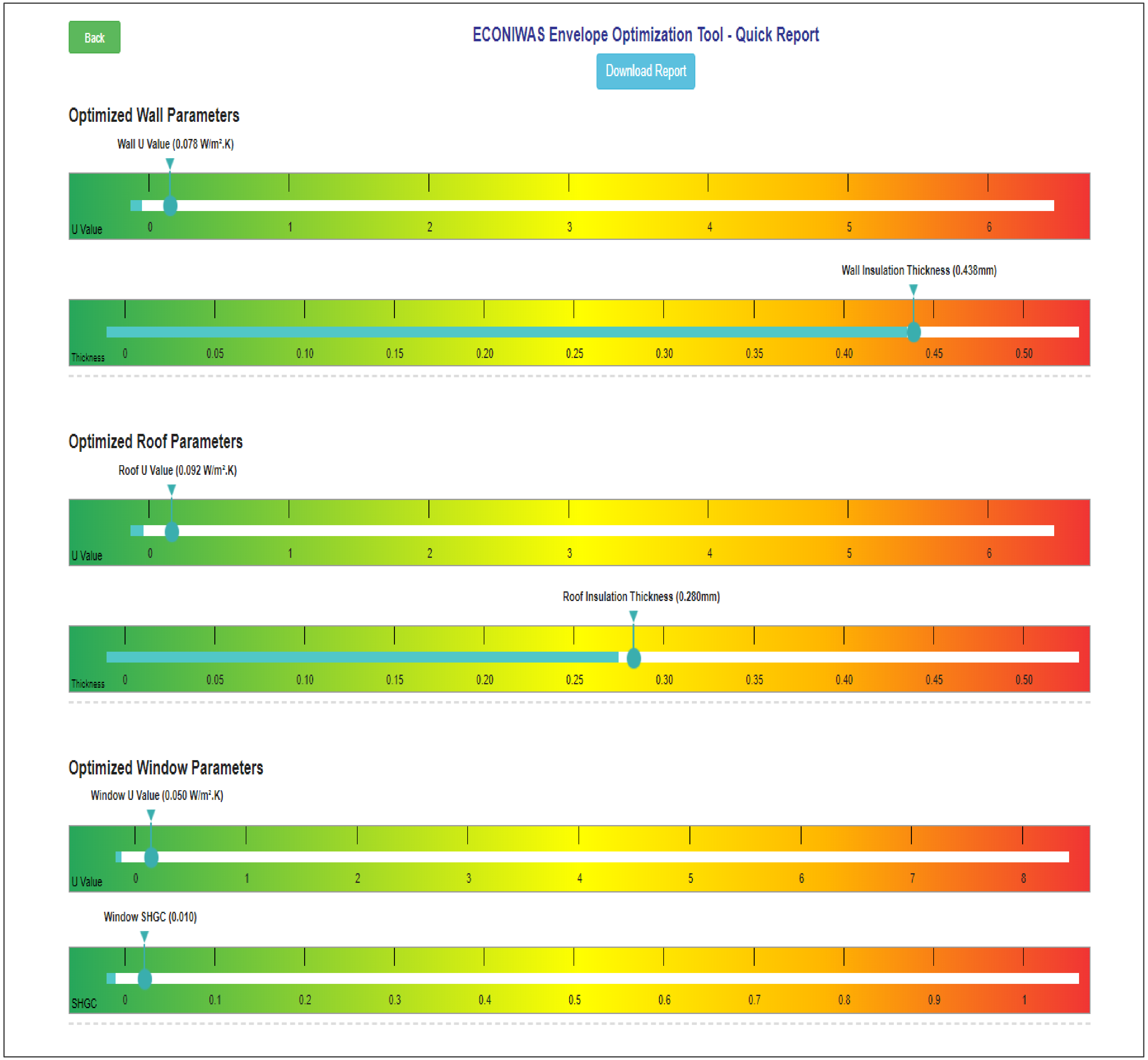
After filling all the required information, the user is required to click on the Submit button to start the optimization engine.



Generally, the optimization process takes 4-5 minutes to complete. The following message is shown in the tool during execution of optimization.

ECONIWAS 2.0 – ENVELOPE OPTIMIZATION TOOL – RESULTS

On the submission of the form, the tool performs the optimization using energy plus server-side simulation platform to predict the optimized U-value, SHGC for envelope components (wall, roof windows) as well as thickness of insulation for wall and roof assemblies. The user also has the option to export the results in PDF format for later use, using the “Download Report” button on the results page.



LEARNINGS

- Mainstreaming passive strategies in buildings for thermal comfort can significantly reduce cooling, ventilation and lighting requirements in buildings;

- Lesser dependency on mechanical cooling/ heating approaches will decrease formation of surface ozone, hence better air quality.

- Greater awareness of the benefits of sustainable building design will spur greater demand from all strata of society

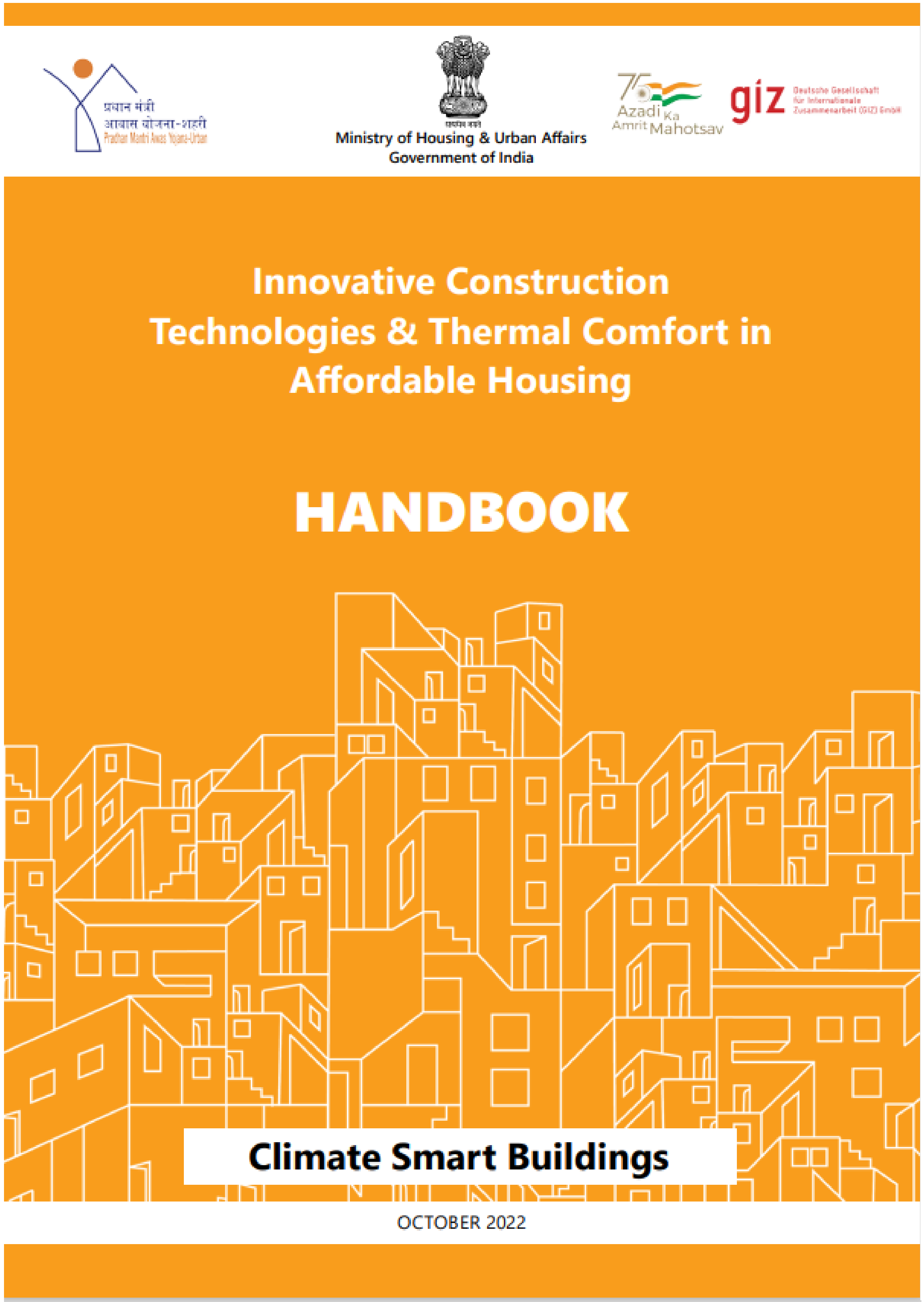
- Sensitivity in building practices will tend to decrease disparity in thermal comfort of different economic classes.

- **Make active strategies passive, and passive strategies active.**

- **70% of the buildings required in India by 2030 are yet to be built. Maintaining status quo is irrelevant, and there is a great opportunity for incorporating passive design strategies successfully across our built environment.**

Source: McKinsey

LEARNINGS


Ministry of Housing & Urban Affairs
Government of India

Innovative Construction Technologies & Thermal Comfort in Affordable Housing

HANDBOOK

Climate Smart Buildings

OCTOBER 2022

Ministry of Housing & Urban Affairs, Government of India
Nirman Bhawan, New Delhi - 110001

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Thank you.