Ministry of Housing and Urban Affairs
Government of India

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Innovative Construction Technologies & Thermal Comfort for Affordable Housing

RACHNA 2.0

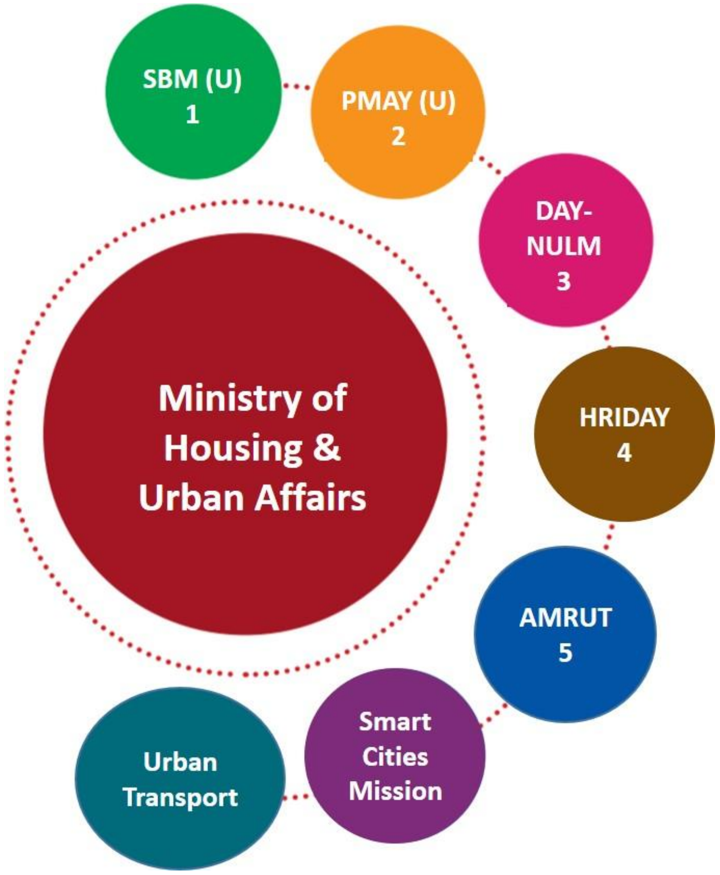
RESILIENT, AFFORDABLE AND COMFORTABLE HOUSING THROUGH NATIONAL ACTION

Prepared by

Climate Smart Building (CSB) Cell, North Cluster, LHP Lucknow

INTRODUCTION – MINISTRY OF HOUSING & URBAN AFFAIRS (MoHUA)

- **Ministry of Housing and Urban Affairs (MoHUA)** is the supreme authority of the Government of India to formulate and monitor all the programmes concerning the housing and urban development of the country.
- **The Ministry of Housing and Urban Affairs (MoHUA)** through its flagship mission **Pradhan Mantri Awas Yojna-Urban (PMAY-U)** ensures a pucca house to all eligible urban households.
- PMAY-U aims to achieve Urban Development through Transformation, Innovation and Sustainable Inclusions.



1. Swachh Bharat Mission- Urban, 2. Pradhan Mantri Awas Yojana- Urban, 3. Deendayal Antyodaya Yojana- National Urban Livelihood Mission,
4. Heritage Cities Development and Augmentation Yojana, 5. Atal Mission for Rejuvenation and Urban

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Pradhan Mantri Awas Yojana-Urban

GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA

Ministry of Housing and Urban Affairs
Government of India

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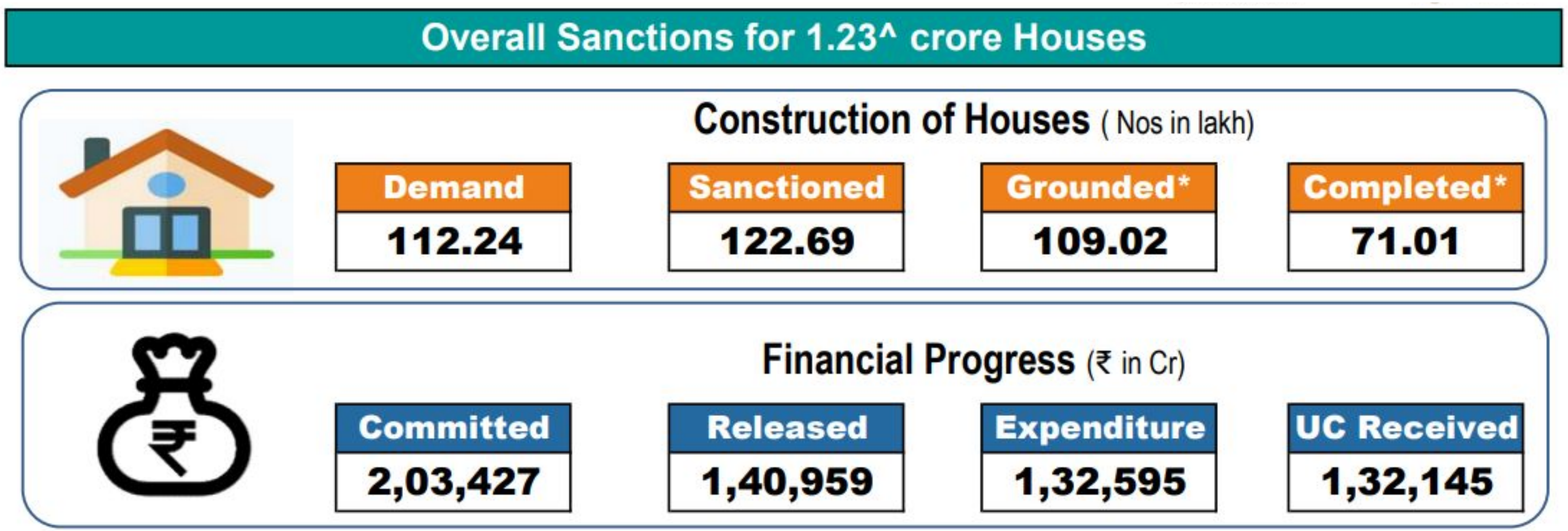
INTRODUCTION – MINISTRY OF HOUSING & URBAN AFFAIRS (MOHUA)-PMAY

- Due to Rapid increase in urbanization and believing it as an opportunity to reduce poverty.
- For addressing the huge housing demand in the Affordable Sector, Govt. of India launched **Pradhan Mantri Awas Yojana-Urban** in June 2015.

PMAY (U) Achievement (provisional), as on 28th February 2023



16 lakh houses are being constructed using New Technologies

Source: PMAY Website

INTRODUCTION- GLOBAL HOUSING TECHNOLOGY CHALLENGE (GHTC-INDIA)

- The Ministry of Housing and Urban Affairs, Government of India has conceptualized a Global Housing Technology Challenge - India (GHTC- India).
- To identify and mainstream a basket of innovative technologies from across the globe that are sustainable and disaster-resilient.
- Such technologies would be cost effective, speedier and ensure a higher quality of construction of houses, meeting diverse geo-climatic conditions and desired functional needs.
- A Technology Sub-Mission (TSM) has been set up.

COMPONENTS OF GLOBAL HOUSING TECHNOLOGY CHALLENGE (GHTC-INDIA)

Construction Technology India: Grand Expo-Cum-Conference

- Promotion of Innovative Construction Technology
- Platform to Facilitate Signing of MoUs and form Potential Partnerships.
- Technical Evaluation, Exchange of Knowledge, and business.
- Exhibition of Technologies

Proven Demonstrable Technologies

- Onboard States & Local Support Partners
- Six Light House Project Sites
- Induct Established Proven technologies across the Globe
- Identify Basket of Site-specific Technologies
- Different Technology for Each Site
- Live Laboratories for learning
- Technology to be Adopted in Curriculum and India System

Potential Future Technologies

- Setting up **ASHA- India** (Affordable Sustainable Housing Accelerators)
- Support Domestic Technologies by Product Development, Mentoring & Market Support
- Incubation Centres in IITs
- Organizing Periodic Accelerator Workshops

EVENTS OF GLOBAL HOUSING TECHNOLOGY CHALLENGE (GHTC-INDIA)

Construction Technology India (CTI) – 2019 Expo-cum-Conference, on 2nd to 3rd March 2019, Vigyan Bhawan, New Delhi.

Indian Housing Technology Mela (IHTM) on 5th to 7th October 2021 in Lucknow, Uttar Pradesh.

Indian Urban Housing Conclave (IUHC)-2022, on 19th to 21st October 2022, in Rajkot, Gujrat.

GHTC- SHORTLISTED TECHNOLOGIES

- 54 proven technologies were shortlisted suiting different climatic zone conditions in the CTI conference in 2019.

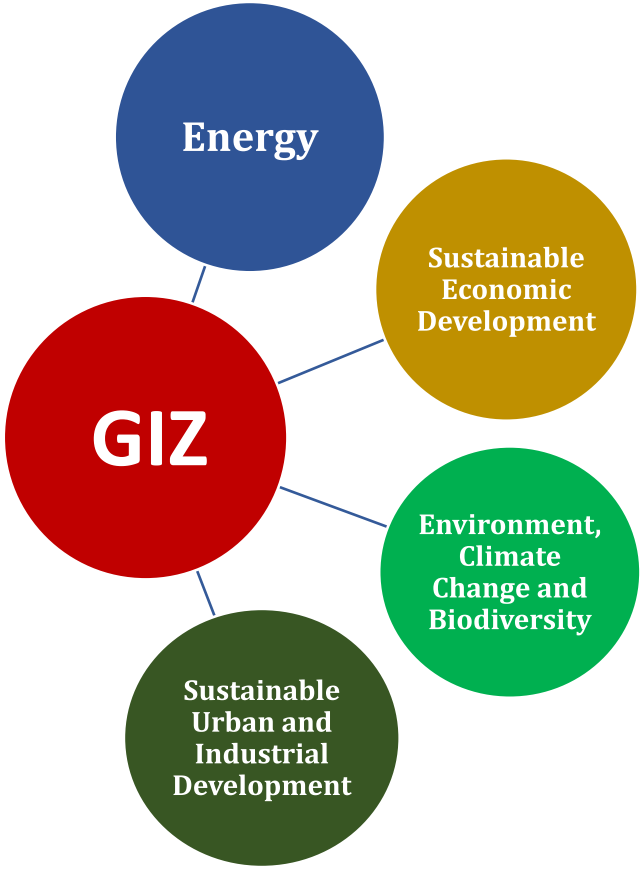
Broad Category	Technologies (Nos.)
Precast Concrete Construction System - 3D Precast volumetric	4
Precast Concrete Construction System – Precast components assembled at site	8
Light Gauge Steel Structural System & Pre-engineered Steel Structural System	16
Prefabricated Sandwich Panel System	9
Monolithic Concrete Construction	9
Stay In Place Formwork System	8
Total	54

INTRODUCTION – GIZ AND IGEN (INDO GERMAN ENERGY PROGRAM)

- GIZ is an international cooperation enterprise for sustainable development which operates worldwide, on a public benefit basis.

- For over 60 Years, **GIZ** has been working jointly with partners in India for sustainable economic, ecological, and social development.

- The Government of the Republic of India and the Federal Republic of Germany under the Indo-German Technical Cooperation, agreed to jointly promote the “Indo-German Energy Programme” **(IGEN)** with the aim to foster sustainability in the built environment through GIZ.



INTRODUCTION – CLIMATE SMART BUILDINGS PROGRAMME

The Ministry of Housing and Urban Affairs (MoHUA) aims to enhance climate resilience and thermal comfort in the affordable housing segment through GIZ under Indo German Energy programme (IGEN)'s programme, **Climate Smart Buildings (CSB)**.

Aim:

- Adopting sustainable and low-impact design.
- Adoption of best available Materials and construction technologies.
- Use of innovative technologies to provide desired thermal comfort for mass replication.

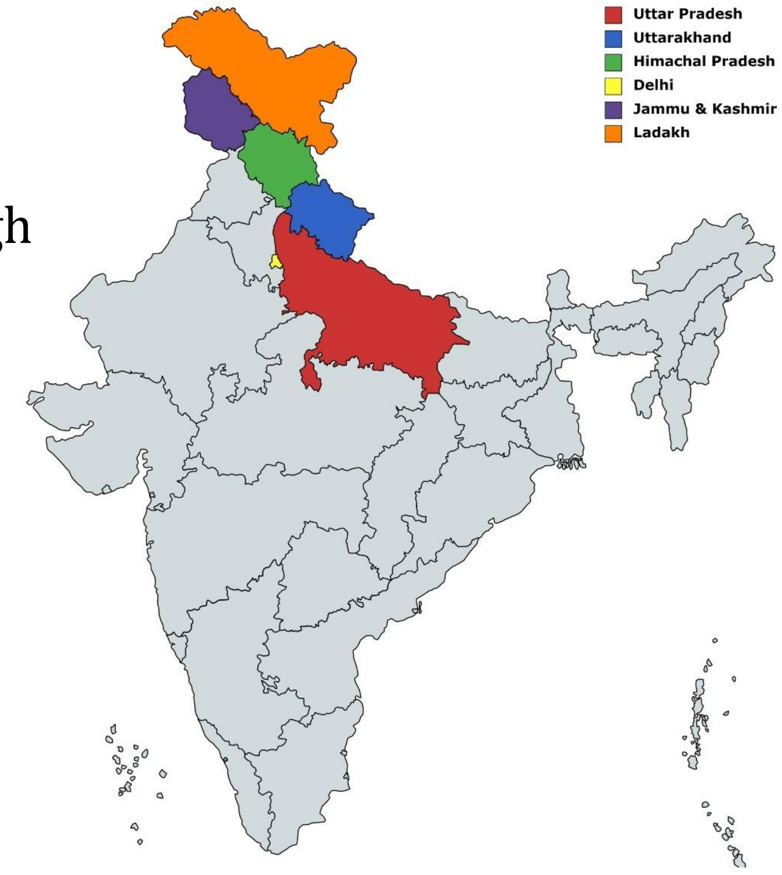
INTRODUCTION: CLIMATE SMART BUILDINGS CELL-NORTH CLUSTER

- Climate Smart Buildings Cluster cells are established in each of the six Light House Project states where pilot affordable housing projects are being built utilizing innovative construction technologies.

Goal:

To improve climate resilience and thermal comfort in buildings through

- Passive Measures
- Locally sustainable Materials
- Low embodied energy materials
- Best available technology



OBJECTIVES: CLIMATE SMART BUILDINGS CELL, NORTH CLUSTER

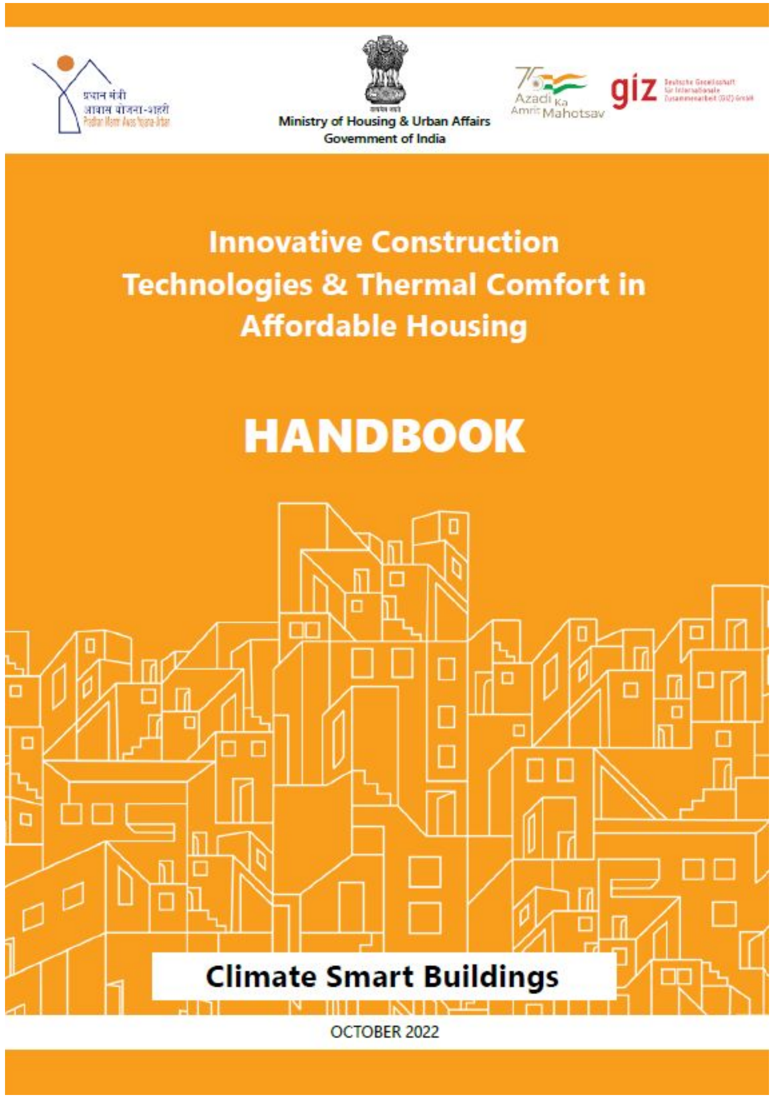
In the direction to achieve the goal of sustainability and thermal comfort in affordable housing, CSB Cell is working with following objectives:

- **WP1:** Facilitate implementation and monitoring of Light House Project Lucknow (LHPs)
- **WP 2:** Technical assistance to enhance thermal comfort in upcoming Demonstration Housing Projects (DHPs) and ARHCs (Affordable rental housing complexes) and other Public/Private housing projects in West Cluster
- **WP 3:** Inclusion of climate resilience and thermal comfort requirements in building byelaws and Local Government framework in West Cluster
- **WP 4:** Capacity development of Govt officials and private stakeholders on thermal comfort in the North Cluster

Handbook: Innovative Construction Technologies & Thermal Comfort in Affordable Housing

A Handbook for training programs on innovative construction technologies & Thermal comfort in Affordable housing was curated and launched by the **Hon'ble Prime Minister** at the Indian Urban Housing Conclave in Rajkot on 19th October 2022.

To disseminate the knowledge in this handbook, Ministry of Housing and Urban Affairs is launching a seconds set of training i.e. **RACHNA2.0,** from Dec 2022 till Mar 2023.



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Handbook: Innovative Construction Technologies & Thermal Comfort in Affordable Housing

CONTENTS

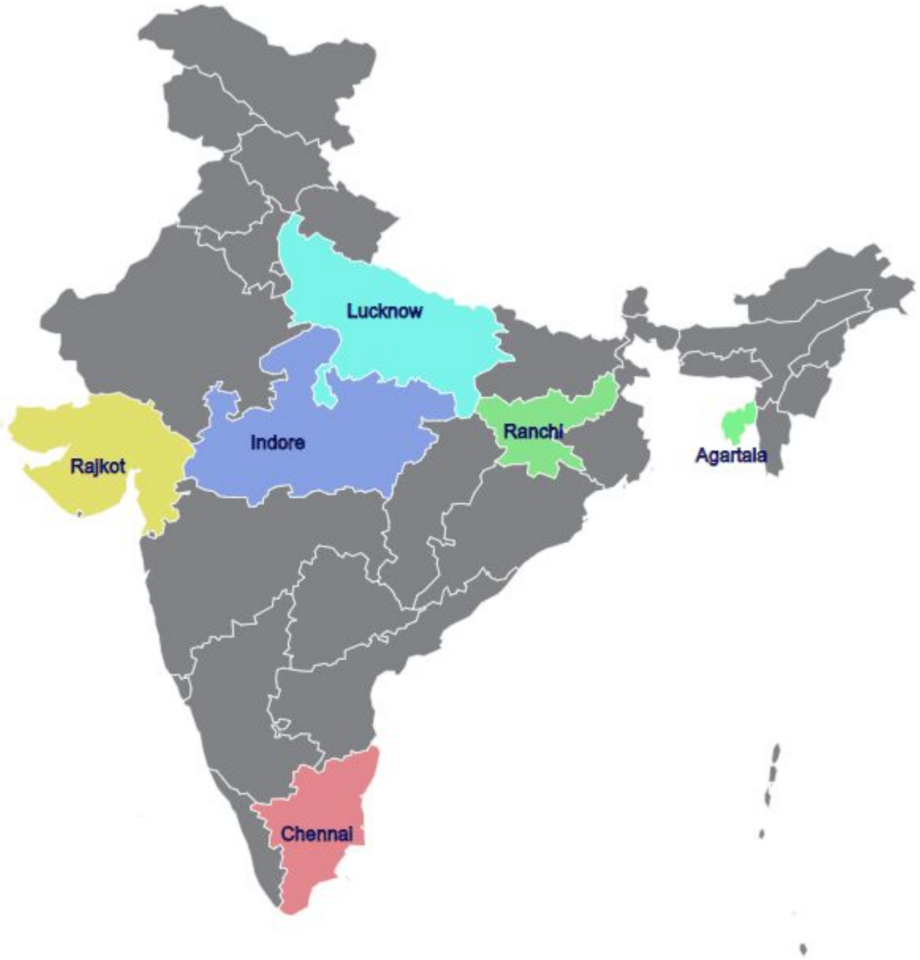
SESSION-1

Innovative Construction Technologies of Light House Technologies, LHP Study and Observations.

1. LHPs Construction Technologies
2. Thermal Comfort Analysis and Recommendations on LHPs and Assisted Demo Projects.
3. Life Cycle Cost Analysis and its Impact in Carbon Emission.
4. Q&A on New & Innovative technologies and Thermal Comfort.

CONCEPT OF LIGHT HOUSE PROJECTS (LHPS)

- Ministry of Housing and Urban Affairs Under **PMAY(U)**, set up a **Technology Sub-Mission (TSM**) to provide:
    - Alternative sustainable technological solutions.
    - Better, Faster & cost-effective construction methodologies.
    - Houses suiting to geo-climatic and hazard conditions of the country.
- **Light House Projects** have been conceptualized as part of **Global Housing Technology Challenge – India (GHTC-India)**
- Construction of six **LHPs** with allied infrastructure and six categories of globally proven innovative technologies were



CONCEPT OF LIGHT HOUSE PROJECTS (LHPS)

- The fundamental concept of the Light-House Projects is to encourage large-scale participation of the people of India for mainstreaming the proven technologies identified globally by the principles.

THE LIGHT-HOUSE PROJECTS (LHP) IN INDIA

Hon'ble Prime Minister Shri Narendra Modi laid the foundation stone of six Light House Projects (LHPs) each consisting of approx. 1000 houses in January 2021, in six cities :

Precast Concrete Construction System – Precast Components Assembled at Site

- Chennai, Tamilnadu
- No. of Houses: 1152

Monolithic Concrete Construction using Tunnel Formwork

- Rajkot, Gujarat
- No. of Houses: 1144

Prefabricated Sandwich Panel System

- Indore, Madhya Pradesh
- No. of Houses: 1024

Precast Concrete Construction System – 3D Volumetric

- Ranchi, Jharkhand
- No of Houses: 1008

Light Gauge Steel Structural System & Pre-engineered Steel Structural SystemAgartala, Tripura

- Agartala, Tripura
- No of Houses: 1000

PVC Stay in Place Formwork System

- Lucknow, Uttar Pradesh
- No of Houses: 1040

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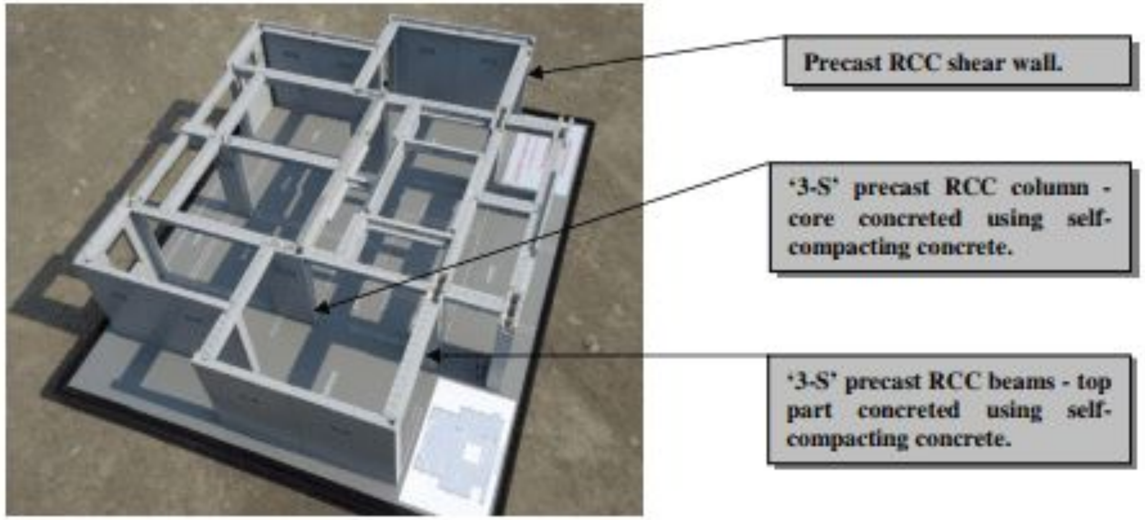
LHP CHENNAI-INAUGRATION (26TH MAY 2022)

LHP CHENNAI-PRECAST CONCRETE CONSTRUCTION SYSTEM ASSEMBLED AT SITE

- Precast dense reinforced cement concrete hollow core columns and RCC shear walls is being used as structure .
- AAC blocks in partition walls are being used.
- Dowel bars, continuity reinforcement placed at connections.
- Self-compacting concrete is being used in hollow cores of columns.




Plinth with dowels


Precast Column Erection


Precast Slab work


AAC Block work

LHP RAJKOT- INAUGRATION (19TH October 2022)








LHP RAJKOT- MONOLITHIC CONCRETE CONSTRUCTION USING TUNNEL FORMWORK

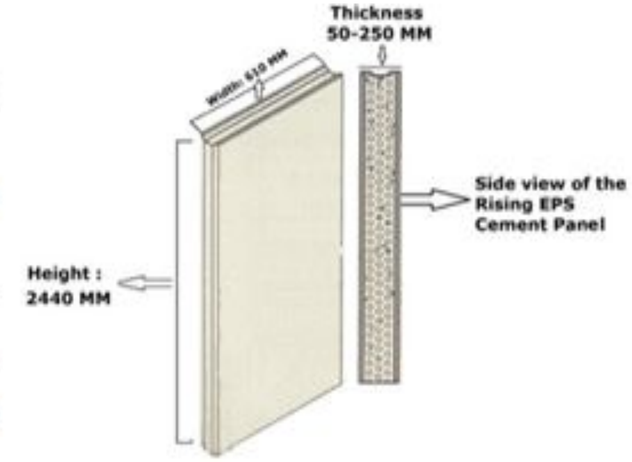
- Customized engineering formwork replacing conventional steel or plywood shuttering systems.
- Mechanized system for cellular structures.
- Two half shells which are placed together to form a room or cell.
- Walls and slab are cast in a single day.
- The formwork is stripped the next day for subsequent phase.

Tunnel formwork panel slab and wall casting

Building Using Tunnel Formwork

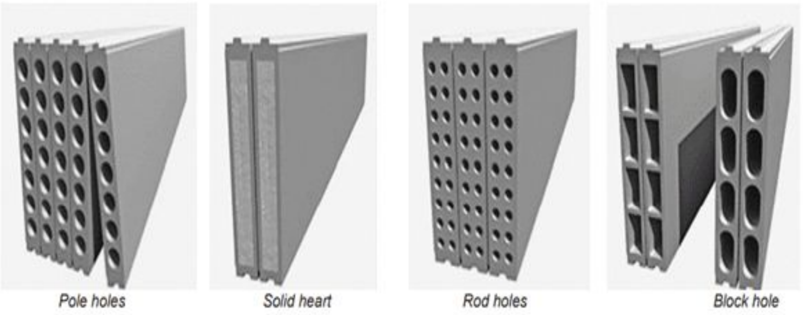
LHP INDORE-PREFABRICATED SANDWICH PANEL SYSTEM

- Lightweight composite wall, floor and roof sandwich panels made of thin fi cement or calcium silicate board as face covered boards.
- Core material is EPS granule balls, adhesive, cement, sand, fly ash and ot bonding materials in mortar form.
- The core material in slurry state is pushed under pressure into pre-set moulds.
- Once set, it shall be moved for curing and ready for use with steel support structure



Prefabricated EPS Sandwich Panel

Steel Structure Prefabricated EPS Panel



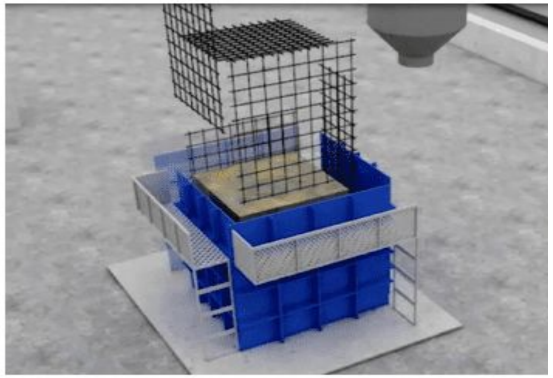
Types of Prefabricated Sandwich Panels

LHP RANCHI- PRECAST CONCRETE CONSTRUCTION SYSTEM – 3D VOLUMETRIC

- Components like room, Bathroom, Kitchen etc. are cast monolithically in Plant or Casting yard in a controlled condition.
- Magic Pods (Precast Components) are transported, erected & installed using cranes .
- Prestressed slabs are installed as flooring elements.
- Consecutive floors are built in similar manner to complete the structure.

Transportation of Magic Pods

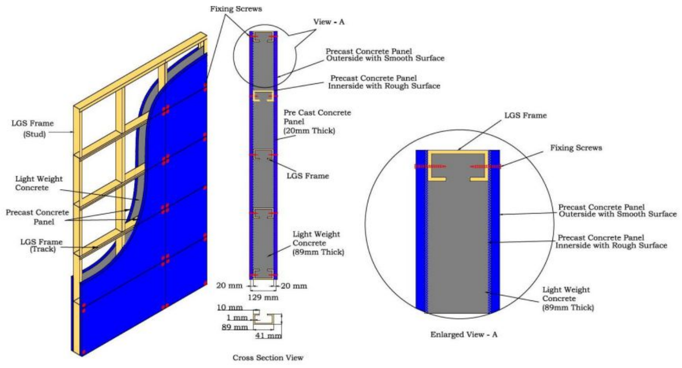
Construction and installation



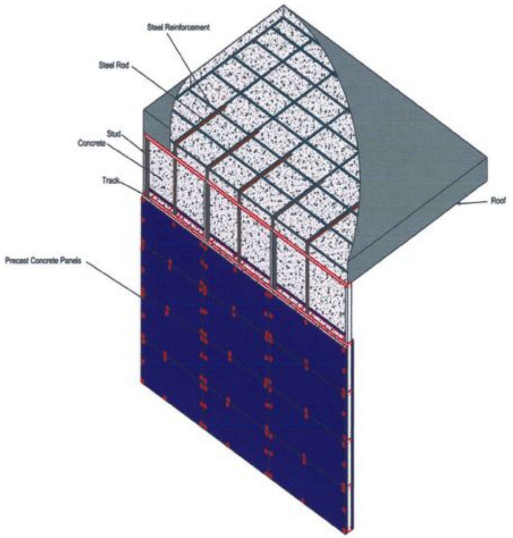
Pre Casting of building modules

LHP AGARTALA- LIGHT GAUGE STEEL FRAMED STRUCTURE WITH INFILL CONCRETE PANELS (LGSFS-ICP)

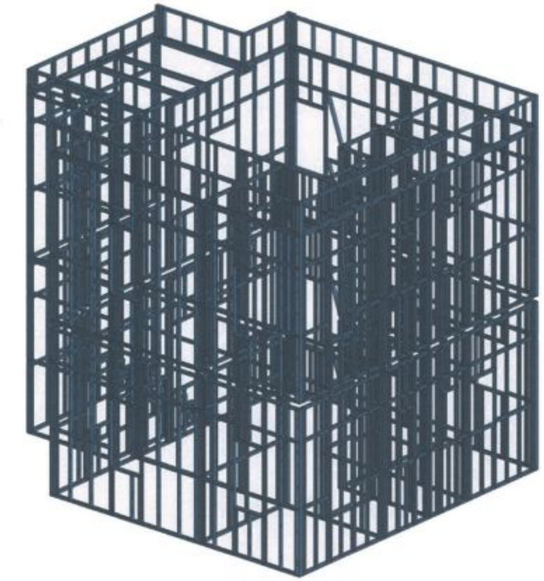
- Light Gauge Steel Framed Structure with Infill Concrete Panels (LGSFS-ICP) Technology.
- Factory made Light Gauge Steel Framed Structure (LGSFS), light weight concrete and precast panels are being used.



Structural Details of LGSFS-Infill Concrete Wall



Precast concrete panels



Light Gauge Steel Frame Structure

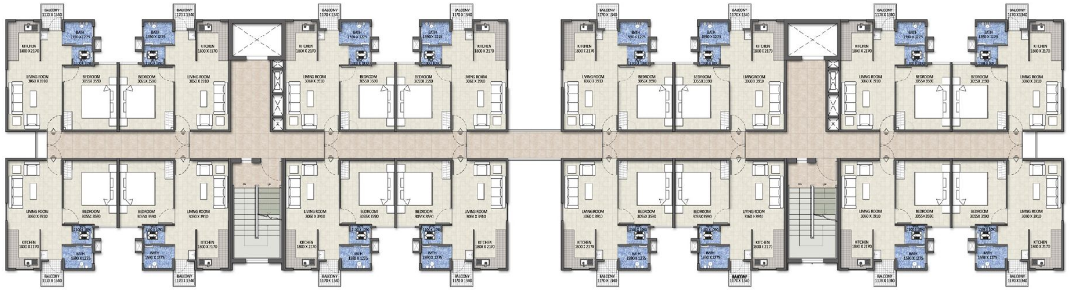
Assembly of LGS Frames and Construction of Wall

LHP LUCKNOW- PROJECT OVERVIEW

Project Brief	
Location of Project	Avadh Vihar, Lucknow, U.P.
No. of DUs	1,040 (S+13)
Plot area	20,036 sq.mt.
Carpet area of each DU	34.51 sq.mt.
Total built up area	48,702 sq.mt.
Technology being used	Stay In Place Formwork System with pre-engineered steel structural system
Other provisions	Community Centre, Shops
Broad Specifications Broad Specifications	
Foundation	RCC raft foundation
Structural Frame	Pre-engineered steel structural frame
Walling	Stay In Place PVC Formwork System
Floor Slabs/Roofing	Cast in-situ deck slab

LHP LUCKNOW- PROJECT PLAN

Project Layout Plan



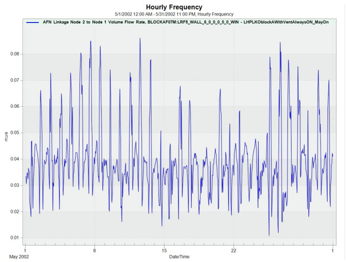
Block Plan

Site Plan

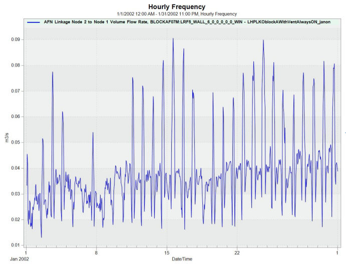
CONSTRUCTION TECHNOLOGY: LHP LUCKNOW

- **Hot Rolled Pre-Engineered Building (PEB)** sections act as a structural framework of the building whereas SIP (Stay-in-Place) formwork works as a partition wall.
- **0.9mm Deck Sheet** used as slab support component over which concrete is casted for enhancing strength. It reduces casting time, propping, shuttering and centering support.
- **Self-Compacting Concrete** is being poured in SIP formwork as an infill to make it more rigid and thermally sound.
- **Polyvinyl Chloride(PVC)** based polymer components serve as a permanent stay-in-place formwork with infilled **concrete** for building walls.

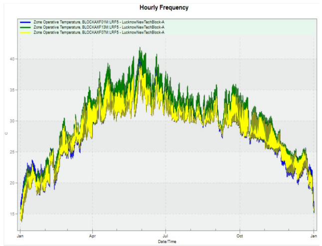
THERMAL PERFORMANCE OF LHP LUCKNOW



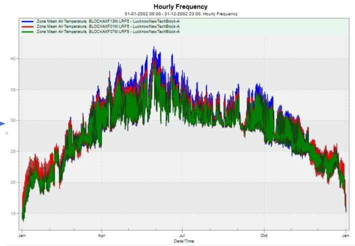
Summer Peak ACH- 6.3



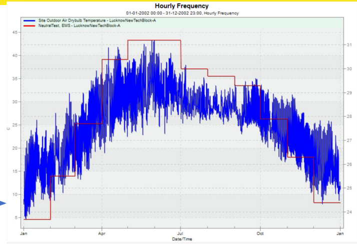
Winter Peak ACH- 6.7



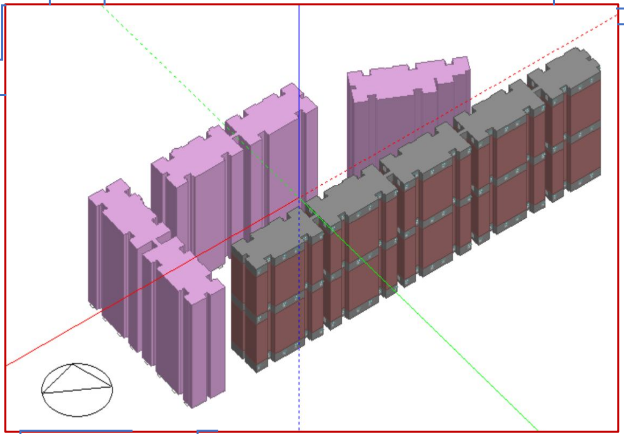
Summer Peak Zone Operative Temperature-41.92^{0}C

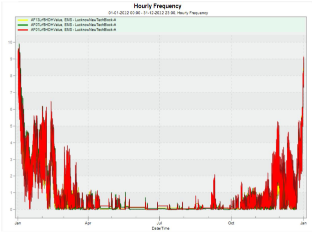


Summer Peak Zone Mean Air Temperature 42.2^{0}C

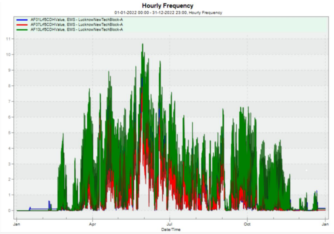


Summer Peak Out Site Dry Bulb Temperature 42.97^{0}C

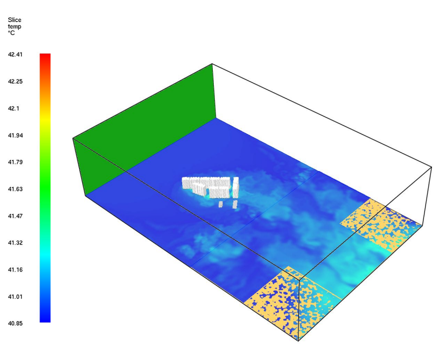




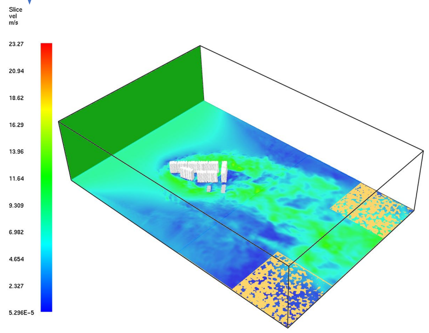
Winter Peak Heating Discomfort Hours-9.83



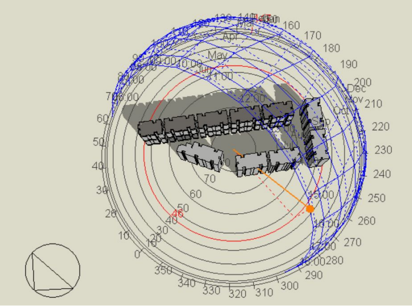
Summer Peak Cooling Discomfort Hours-10.8

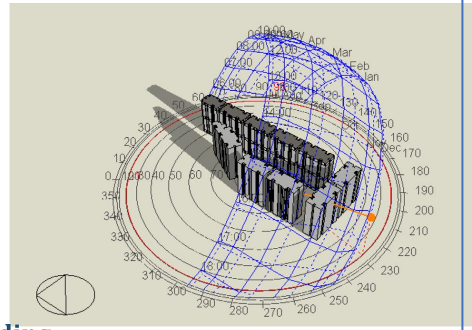


Local Temperature Profile

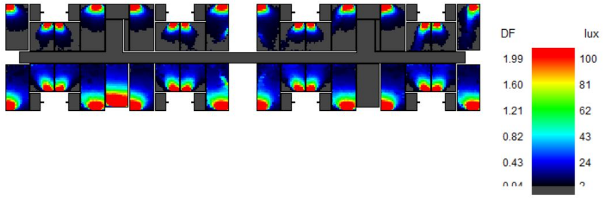


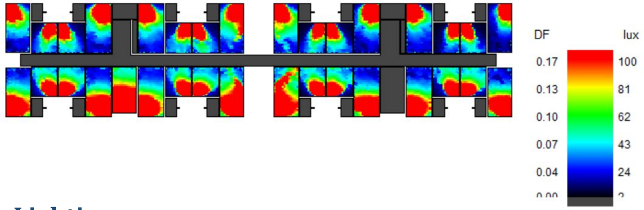
Local Wind Profile





Shading





Day Lighting

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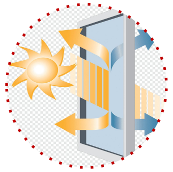
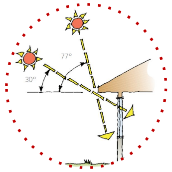
THERMAL COMFORT ANALYSIS-LUKERGANJ, PRAYAGRAJ

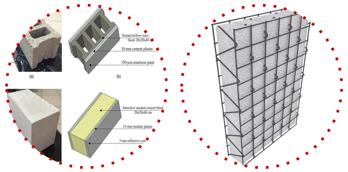
Assisted Demo Project Lukerganj, Prayagraj Uttar Pradesh



Low-E Coated Glass

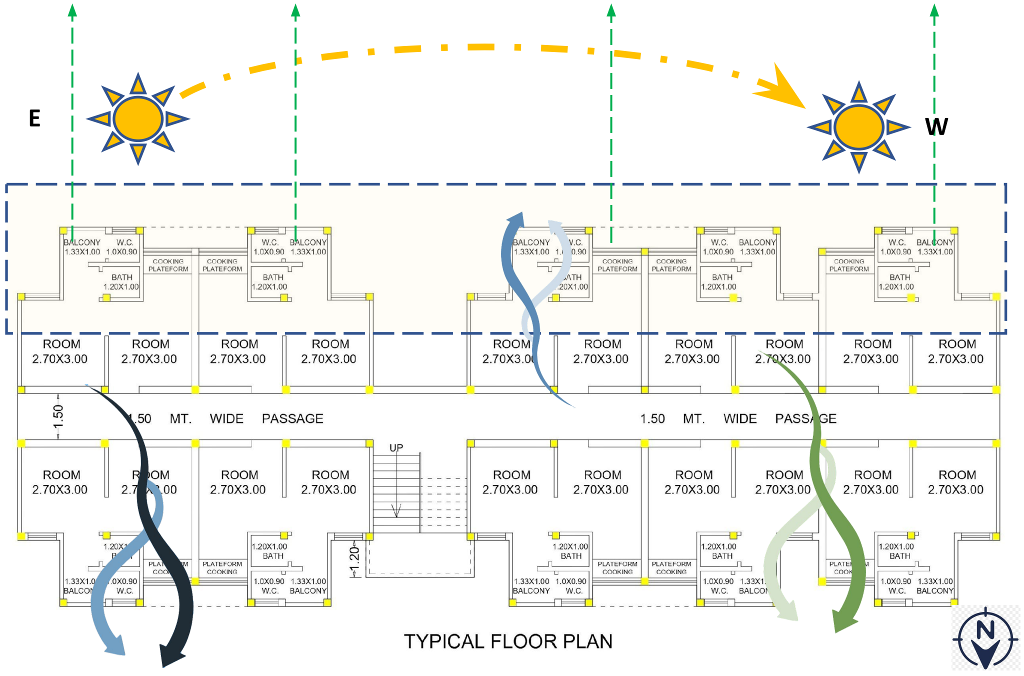


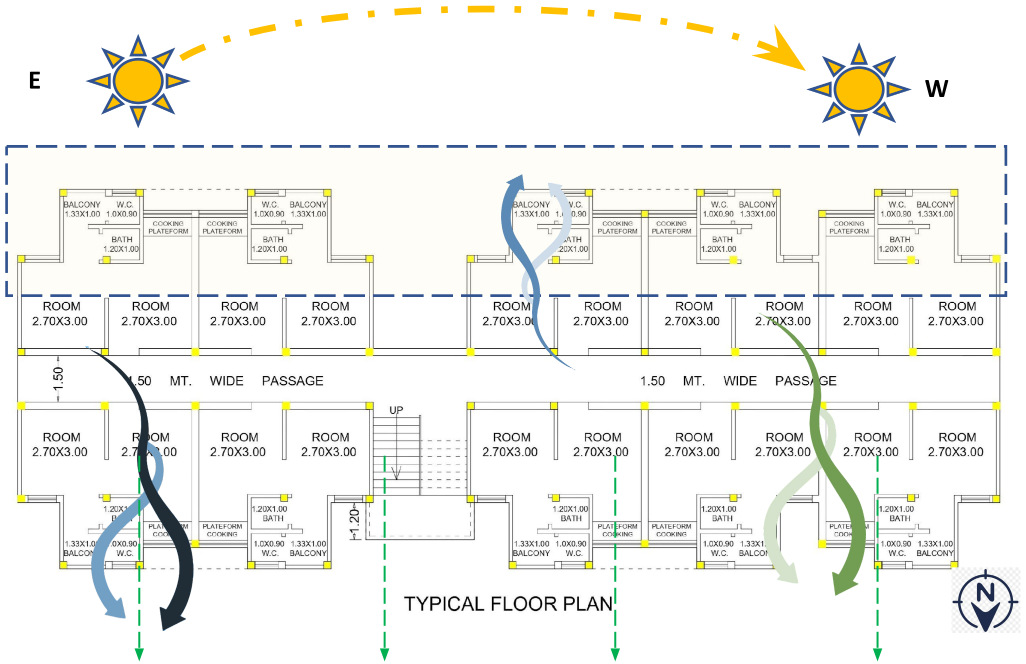
Shading to Avoid Direct Sun Rays

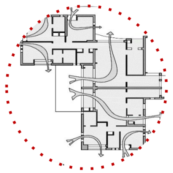


AAC Block/EPS Panel in Envelope Wall

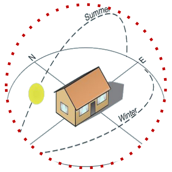
EPS Insulation on Roof



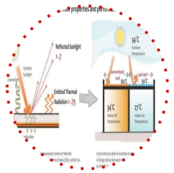




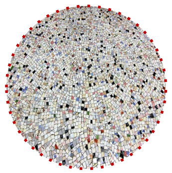
Ventilation With Proper WFRop



Orientation As Per Site Constraints



High SRI Coating Over Roof & Walls



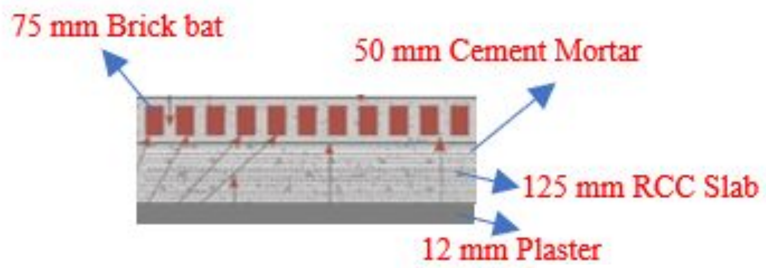
China Mosaic Tiles on Roof

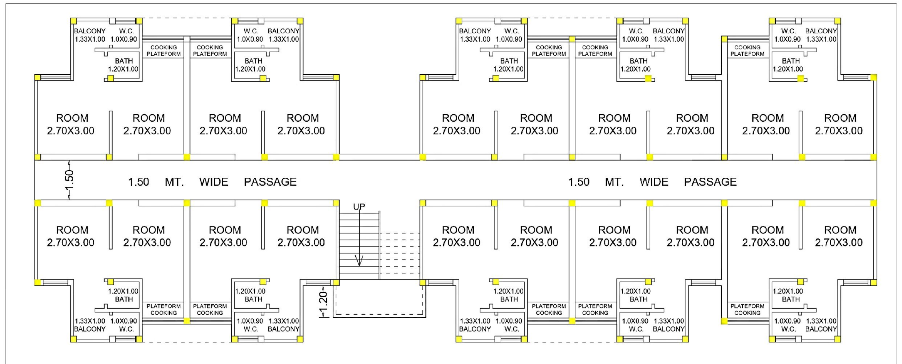
RECOMMENDATIONS TO ENHANCE THERMAL COMFORT (BASE CASE)

Existing Project Details

- Total Plot Area: 1731 m^2
- No. of DUs: 76 (G+3)
  (Block-1: 40, Block-2: 36)
- Covered Area: 634.8 m^2

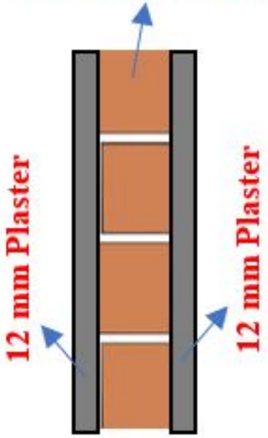
Roof Assembly (U-Value: 1.908 W/m^2K)





TYPICAL FLOOR PLAN

- ***Wall Assembly:***
- ***Brick wall (U-Value: 3.012 W/m^2K)***
- *WFRop: 19.57*
- *VLT (%): 85%*
- ***RETV: 18.28 W/m^2***



	Mandatory Requirement	Total Points	Calculated Value	Point Achieved
RETV(W/m^2) (Residential Envelope Transmittance Value)	NA	80	18.28	0
U-Value Roof($W/m^2.K$) (Thermal Transmittance-Roof)	NA	7	1.91	0
WFRop (Window to Floor Area Ratio)	Achieved		19.57	A
VLT(%) (Visible Light Transmittance)	Achieved		85.0	NA

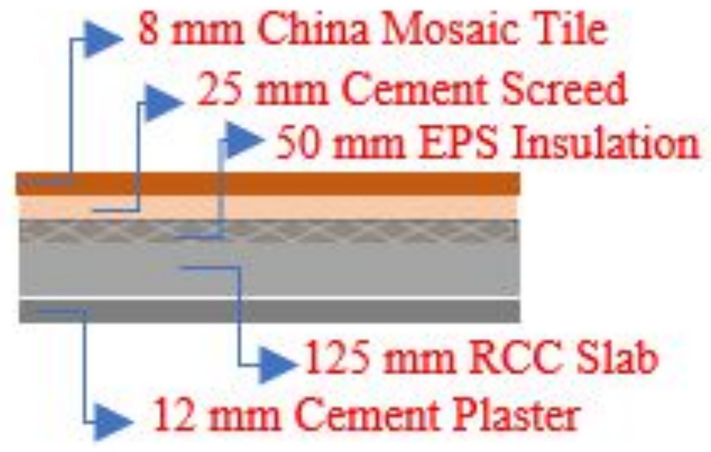
RECOMMENDATIONS TO ENHANCE THERMAL COMFORT (CASE-1)

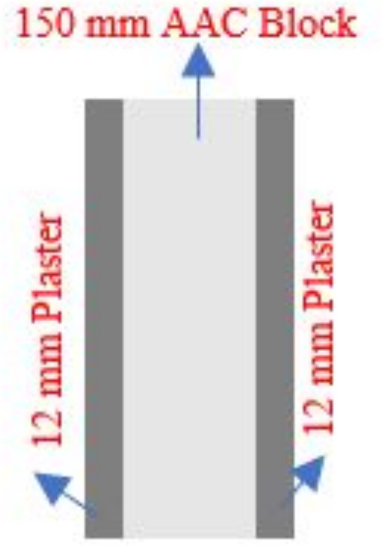
Wall Assembly: AAC Block Wall

- **(U-Value: 0.981 W/m^2K)**
  - WFRop: 19.57 ENS Compliant
  - VLT (%): 85% ENS Compliant
  - **RETV: 10.76 W/m^2** (ENS Compliant)

Roof Assembly

(U-Value: 0.602 W/m^2K)





	Mandatory Requirement	Total Points	Calculated Value	Point Achieved
RETV(W/m^2) (Residential Envelope Transmittance Value)	NA	80	10.76	56
U-Value Roof($W/m^2.K$) (Thermal Transmittance-Roof)	NA	7	0.6	6
WFRop (Window to Floor Area Ratio)	Achieved		19.57	[illegible]
VLT(%) (Visible Light Transmittance)	Achieved		85.0	NA

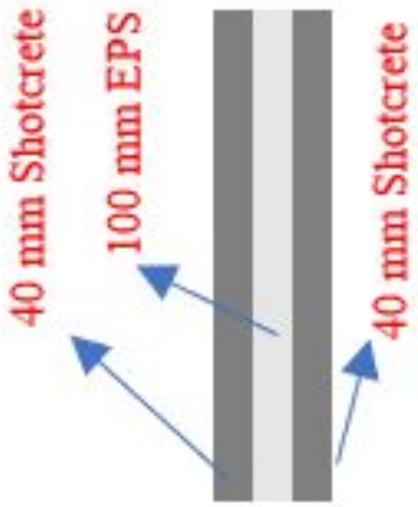
प्रधान मंत्री आवास योजना-शहरी Pradhan Mantri Awas Yojana-Urban | GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA | Ministry of Housing and Urban Affairs Government of India | आज़ादी का अमृत महोत्सव | bmtpc | giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

RECOMMENDATIONS TO ENHANCE THERMAL COMFORT (CASE-2)

Wall Assembly:

EPS Core Panel Wall (U-Value: 0.651 W/m^2K)

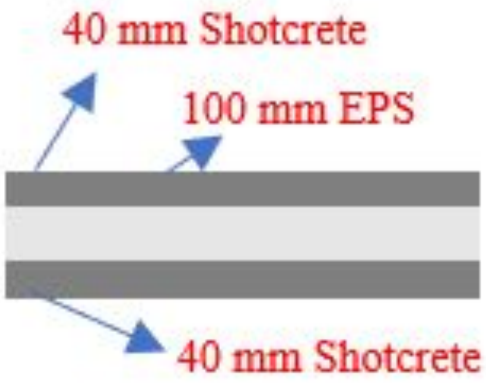
- WFRop: 19.57 ENS Compliant
- VLT (%): 85% ENS Compliant
- **RETV: 7.76 W/m^2** (ENS Compliant)



Roof Assembly

EPS Core Panel

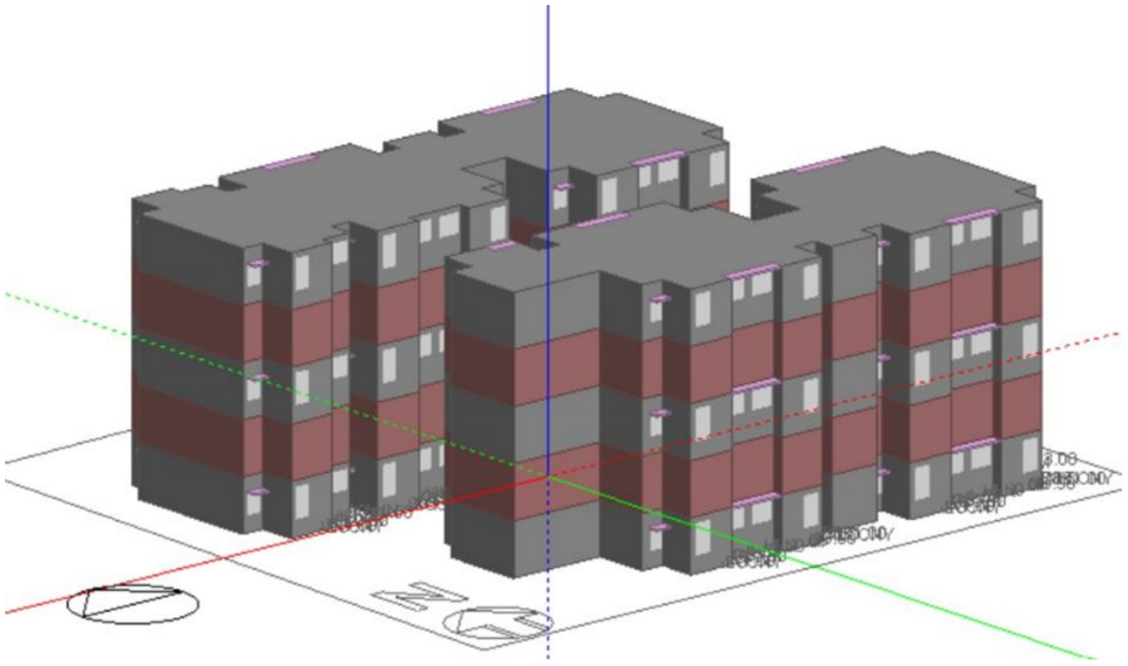
(U-Value: 0.346 W/m^2K)



	Mandatory Requirement	Total Points	Calculated Value	Point Achieved
RETV(W/m^2) (Residential Envelope Transmittance Value)	NA	80	7.67	71
U-Value Roof($W/m^2.K$) (Thermal Transmittance-Roof)	NA	7	0.35	7
WFRop (Window to Floor Area Ratio)	Achieved		19.57	[illegible]
VLT(%) (Visible Light Transmittance)	Achieved		85.0	NA

COMPLIANCE Eco-Niwas Samhita 2018

THERMAL COMFORT ANALYSIS AND RECOMMENDATIONS



3-D model for thermal comfort analysis

Demo Project-Lukerganj, Prayagraj				
KPI	**Unit**	**Base Case**	**Case-1**	**Case-2**
RETV	W/m2	18.28	10.76	7.67
Reduction in Heat Transmittance Through Building Envelope	% Reduction w.r.t. base case	-	41%	58%
Embodied Energy Savings	% Savings w.r.t base case	-	55%	22.8%
Annual Discomfort Hours	Hrs.	3704	3380	3064
Annual Discomfort Hours	% Reduction w.r.t base case	-	8.74%	17.27%
Degree Discomfort Hours	^{0}C.Hrs.	19661	17760	16251
Peak Temperature difference (Summer)	^{0}C	3.75	4.49	5.73
Cost	Rs/DU	539099	552699	579879
Passive Features	Orientation, Shading etc..	E-W	E-W	E-W

SESSION-2

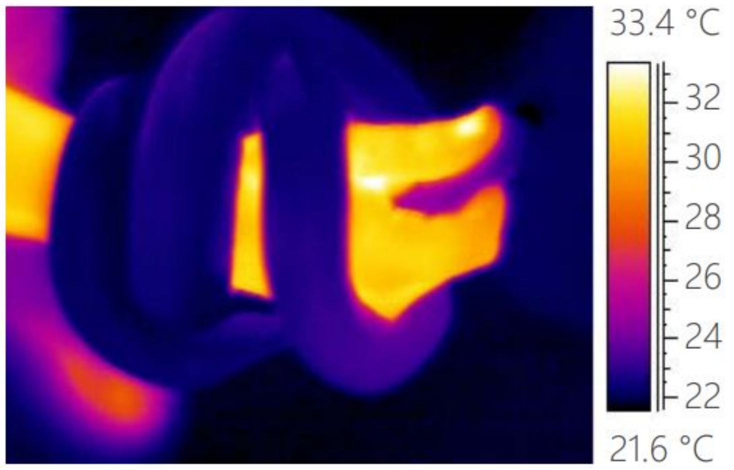
Importance of Thermal Comfort

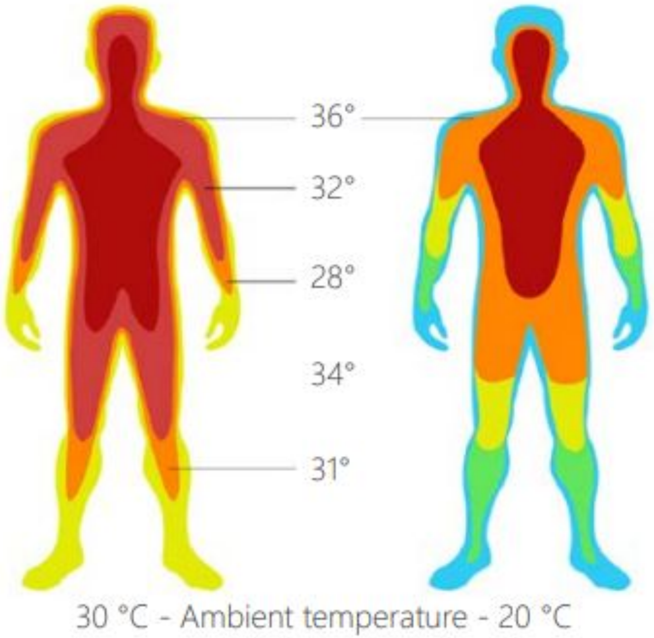
1. *Thermal comfort and cooling demand*
2. *Factors affecting thermal comfort and cooling demand*
3. *Contemporary approaches*
4. *Thermal comfort metrics*

THERMAL COMFORT & ITS IMPORTANCE

Thermal comfort is "the state of mind that expresses satisfaction within the thermal environment" and generally assessed subjectively (ASHRAE, 2004).

- In case of humans, the core body temperature lies in a narrow range around 37° C (ASHRAE, 2021).
- To maintain the body core temperature during varying external temperatures, the human body is constantly acclimatizing itself to its external environmental conditions through exchange of heat between the body and surrounding environment.
- Both core body temperature and skin surface temperature are relevant in understanding thermal comfort.

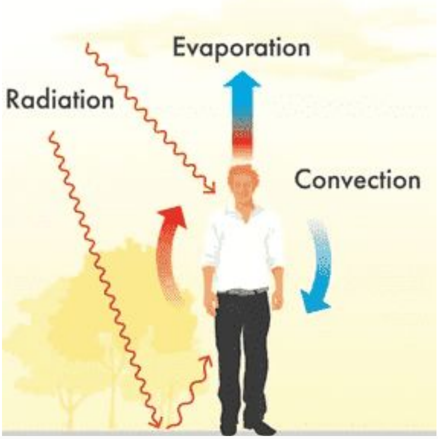




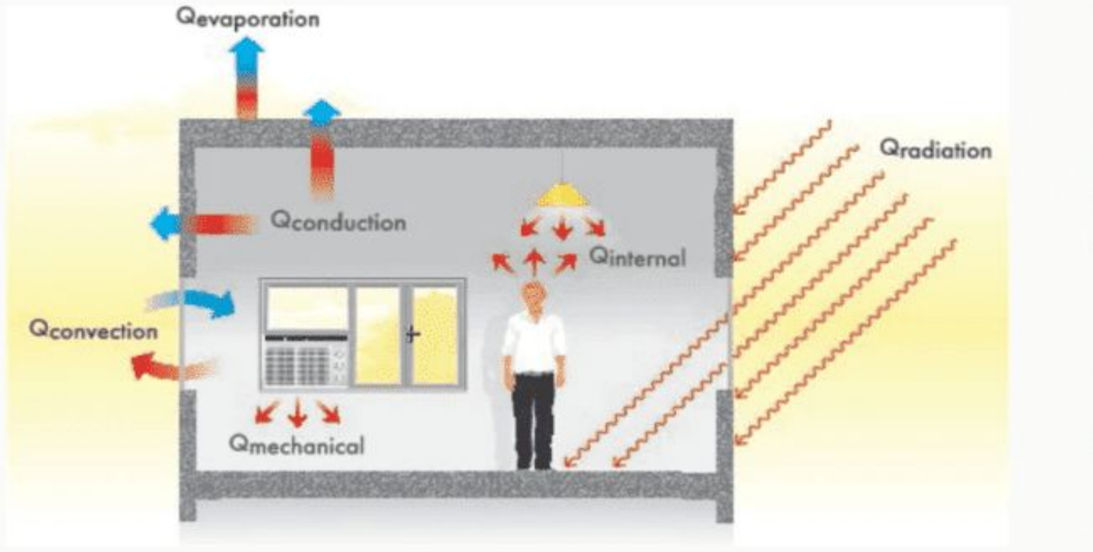
TRANSFER OF HEAT FROM HUMAN BODY

Mode of Heat Transfer

What affects the **<u>Thermal indoor environment?</u>**



- The heat exchange between the human body and its environment occurs mainly in three ways
  - Conduction
  - Convection
  - Radiation
- Thermal indoor environment is affected by both internal and external sources.



Thermal comfort refers to the percieved feeling on the human body as the result of the effect of heat and cold sources in the environment.

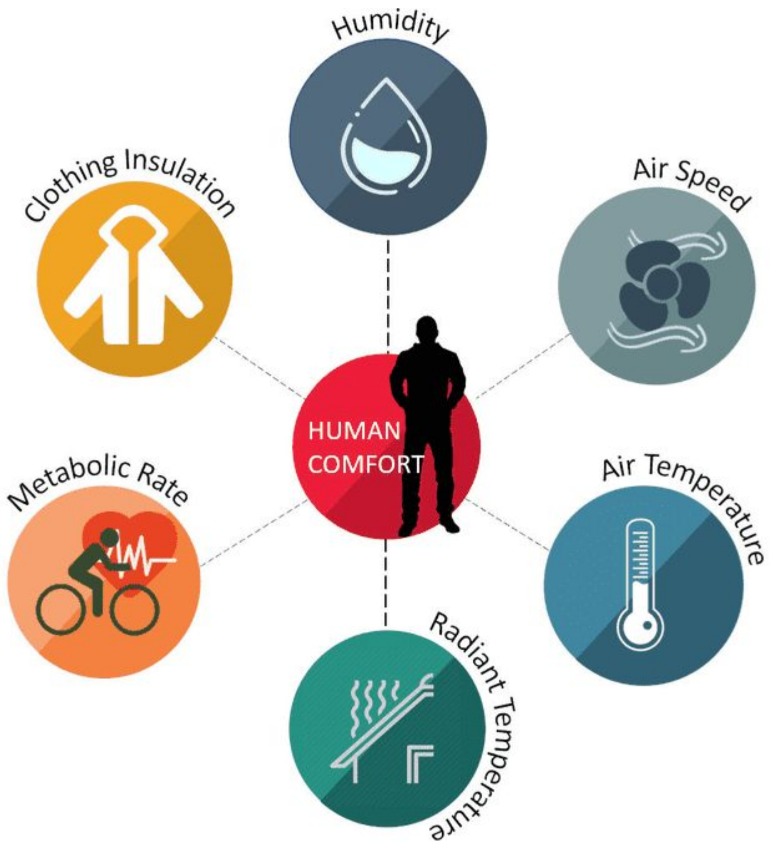
FACTORS AFFECTING THERMAL COMFORT

Environmental Parameters/Factors

- Air Temperature
- Mean Radiant Temperature
- Air Velocity
- Humidity

Personal Parameters/Factors

- Clothing Level
- Physical Activity



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

Skin surface temperature at various locations of the body in cold, neutral, and hot indoor environment.

ENVIRONMENTAL FACTORS AFFECTING THERMAL COMFORT

PHYSICAL FACTORS

AIR TEMPERATURE

The temperature of the air surrounding a body

The ideal temperature for sedentary work is usually between **20ºC and 26ºC**

RADIANT TEMPERATURE

The heat that radiates from a warm object

Heat can be generated by equipment, which raises the temperature in a specific region.

AIR VELOCITY

The speed of air moving across the worker

It's best if the air flow rate is between **0.1 and 0.2 m/s.**

HUMIDITY

The amount of evaporated water in the air

Air-conditioning can easily attain ideal relative humidity values of **40 percent to 70 percent.**

PERSONAL FACTORS AFFECTING THERMAL COMFORT

CLOTHING LEVEL

Layers of insulating clothing keep a person warm or cause overheating by preventing heat loss. The better the insulating ability of a garment, the thicker it is in general. Air movement and relative humidity can reduce the insulating effectiveness of clothing, depending on the type of material it is constructed of.

METABOLIC RATE

The rate at which chemical energy is converted into heat and mechanical effort by metabolic activities within an organism, commonly measured in units of total body surface area. People have different metabolic rates that can fluctuate due to activity level and environmental conditions.

CLOTHING LEVELS & INSULATION

CLOTHING	Clo
T-shirts, shorts, Light socks, Sandals	0.30
Shirt, Trousers socks, Shoes	0.70
Jacket, Blouse, Long skirt, stockings	1.00
Trousers, Vest, Jacket Coat, Socks Shoes	1.50

METABOLIC RATE FOR HUMAN ACTIVITY AND OCCUPANCY

Table 3.1
Metabolic Rate *M* for Various Activities

1 M = 1 met = 58.2 W/m² =18.4 Btu/h.ft²

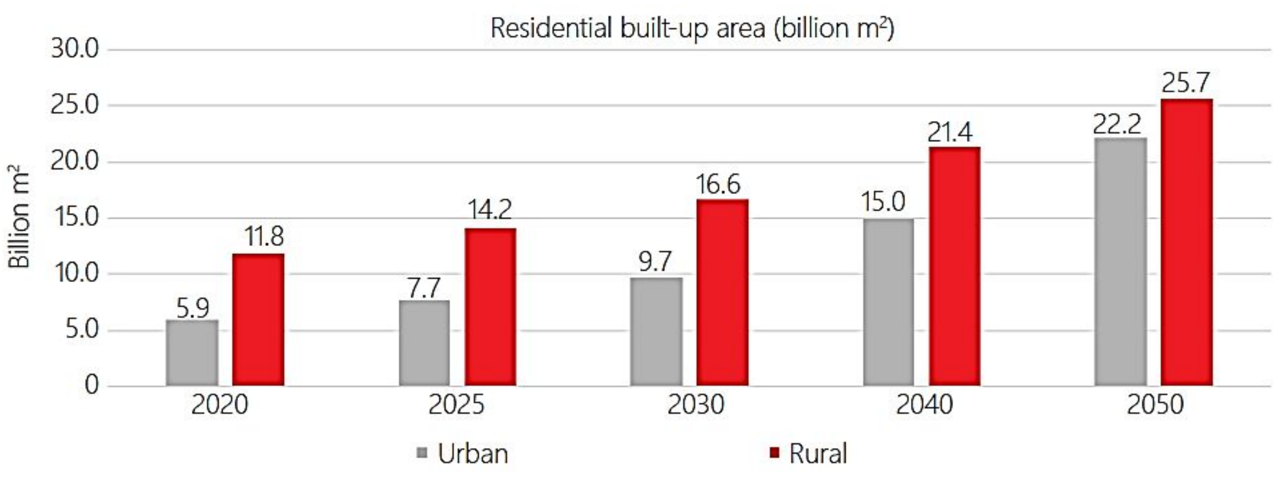
Activity	met	W/m^2	$Btu/(h \cdot ft^2)$
Sleeping	0.7	40	13
Reclining	0.8	45	15
Seated, quiet	1.0	60	18
Standing, relaxed	1.2	70	22
Walking (0.9 m/s, 3.2 km/hr, 2.0 mph)	2.0	115	37
Walking (1.8 m/s, 6.8 km/h, 4.2 mph)	3.8	220	70
Office- reading, seated	1.0	55	18
Office, walking about	1.7	100	31
House cleaning	2.0-3.4	115-200	37-63
Pick and shovel work	4.0-4.8	235-280	74-88
Dancing, social	2.4-4.4	140-255	44-81
Heavy machine work	4.0	235	74

Source: Courtesy of ASHRAE, *Standard 55-2013: Thermal Environmental Conditions for Human Occupancy*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 2010. With permission.

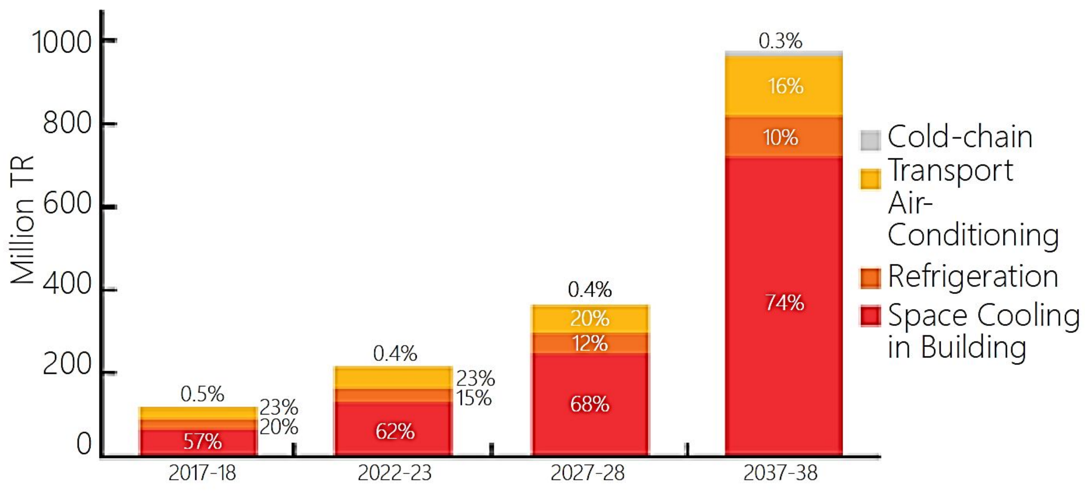
- Thermal comfort is maintained by heat mass transfer.
- Human body generates heat about 100w under sedentary condition with body area 1.5 to 2 sqm.
- More layer of clothing = more insulation = less heat loss

Ministry of Housing and Urban Affairs
Government of India

FACTORS AFFECTING THERMAL COMFORT & COOLING DEMAND



Projected increase in residential built-up area in urban and rural India. Source: ICAP



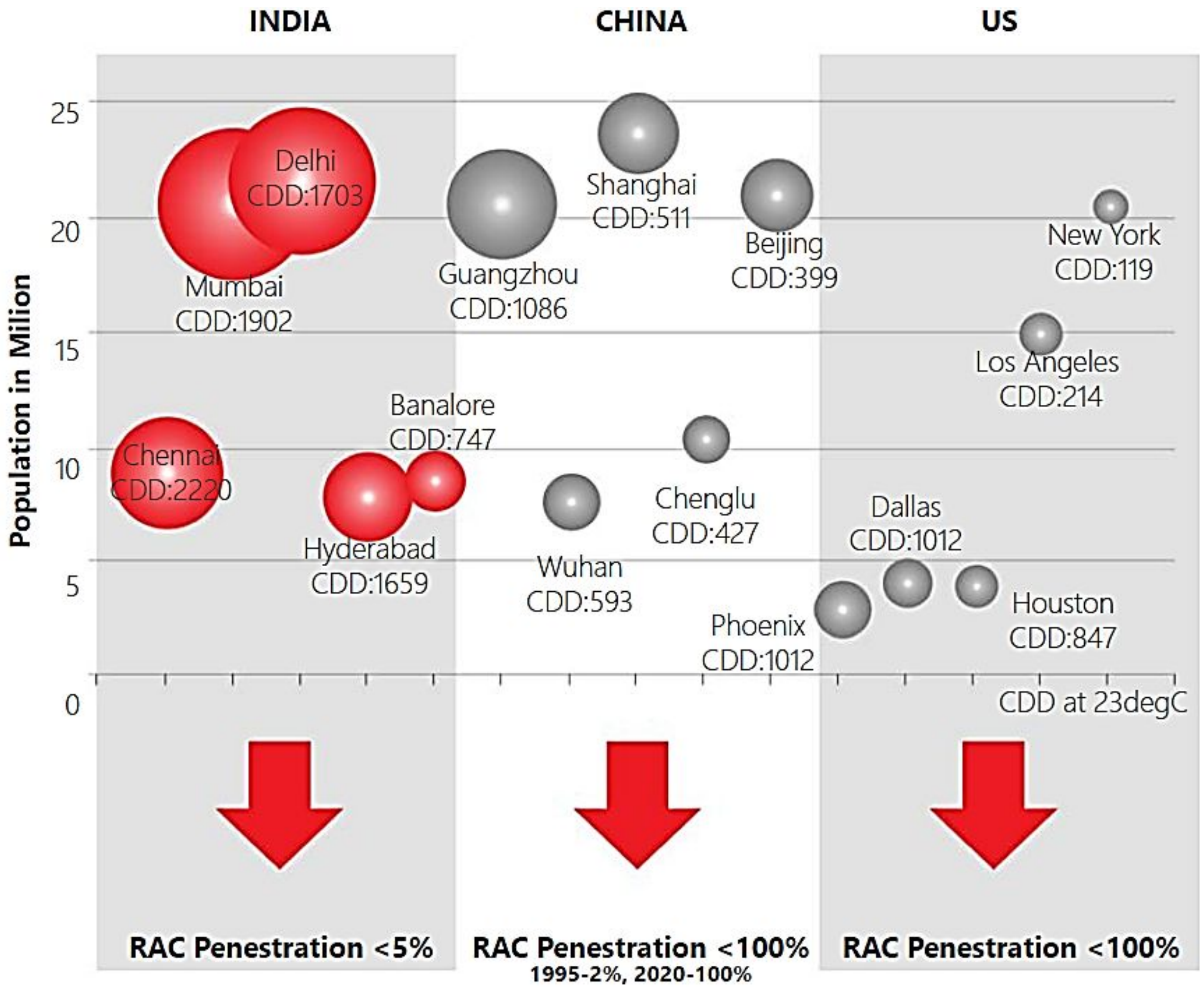
Sector-wise growth in cooling demand. Source: ICAP

The India Cooling Action Plan sets the following goals to promote sustainable cooling and thermal comfort for all.

1. 20-25% reduction of cooling demand across various sectors by 2037-2038
2. 25-40% reduction in cooling energy requirements by 2037-2038.
3. 25-30% reduction in refrigerant demand by 2037-2038.
4. Training and certification of 1,00,000 service technicians by 2022-2023
5. Recognizing "cooling and related areas" as a thrust area of research

FACTORS AFFECTING THERMAL COMFORT & COOLING DEMAND

- Major Indian cities have high population and cooling degree days.
- Cooling demand to combat uncomfortable conditions is also high.
- When residential buildings are designed in a non-sustainable manner.
- The reliance on active cooling that uses devices such as air-conditioners increases to achieve thermal comfort.



Cooling demand in India, China, and USA
Source: Sustainable and Smart Space Cooling Coalition (2017).

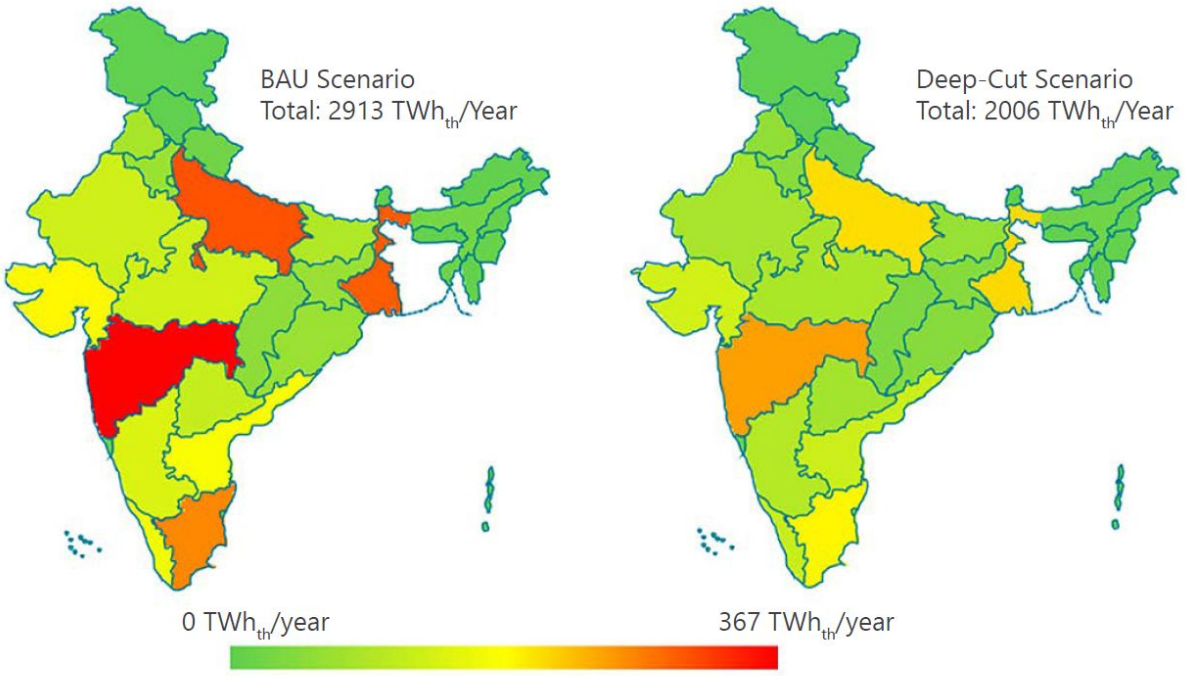
CONTEMPORARAY APPROACHES

BAU vs Deep Cut Scenario

- BAU refers to what is actually prevailing.
- 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.

Target values for metrics like

- Residential Envelope Transmittance Value (RETV) of envelope
- U-value of roof for both existing and new buildings are set for different time periods in the deep cut scenario



Urban residential space cooling energy requirement map of India, 2050
Source: Developing Cost-Effective And Low-Carbon Options To Meet India's Space Cooling Demand In Urban Residential Buildings Through 2050

CONTEMPORARAY APPROACHES

Impact of Building envelope

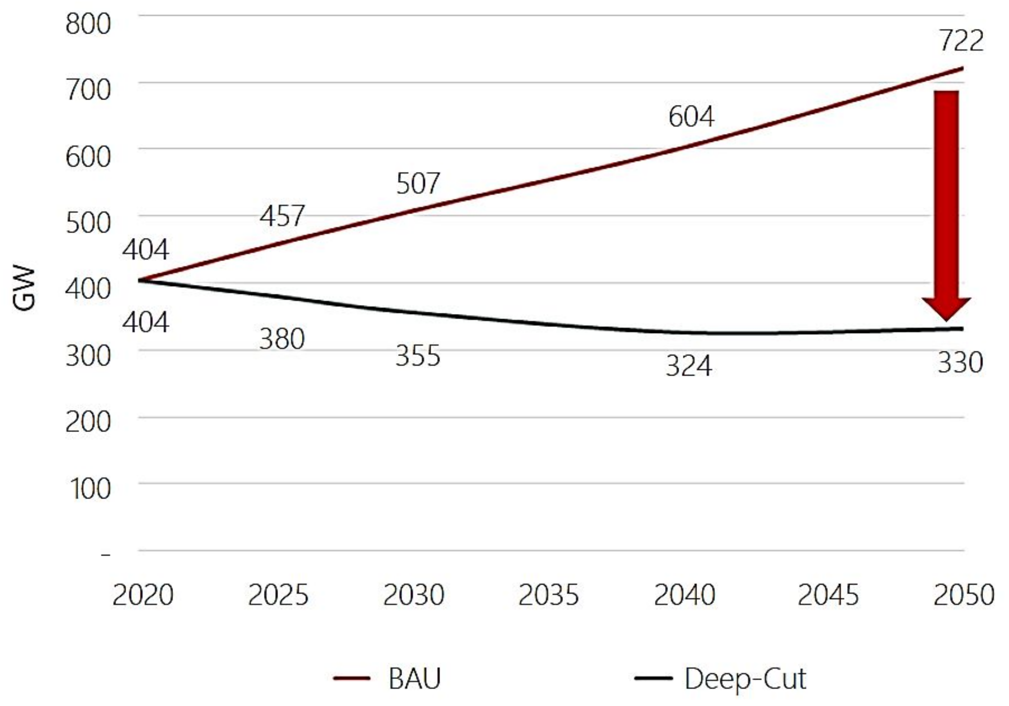
The envelope of a building undergoes retrofitting at much greater intervals. This translates into higher energy and environmental costs for decades.

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).

Two-fold benefit of optimised building envelope

1. Reduces cooling loads on other building systems

2. Reduces associated economic impacts such as HVAC sizing, etc.



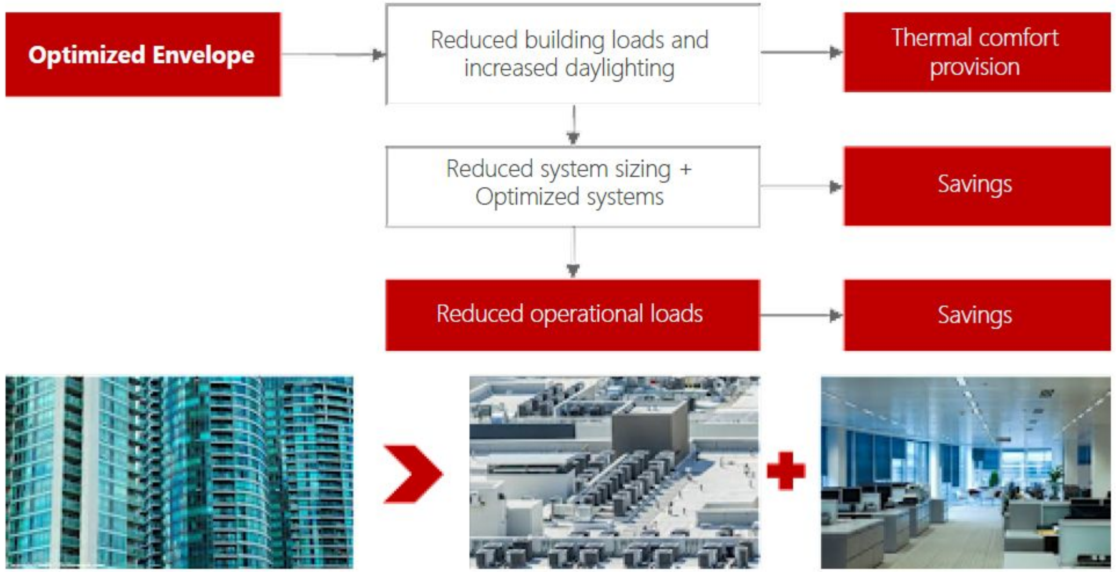
Peak Load for Cooling systems (GW)
Source: Developing Cost-Effective and Low-Carbon Options to Meet India's Space Cooling Demand In Urban Residential Buildings Through 2050

CONTEMPORARAY APPROACHES

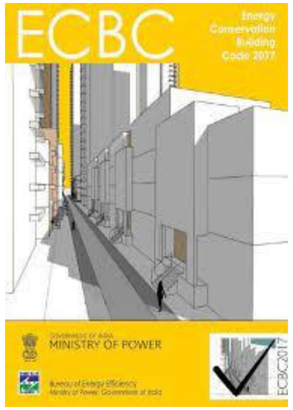
Provisions in code

To achieve the needful reduction in cooling demand, national guidelines, codes, and tools have been developed for implementation.

- ECBC 2007 & 2017(Revised Edition) to set the minimum energy performance for commercial buildings in India.
- Eco-Niwas Samhita (Part-1) was launched in 2018 to include minimum performance requirements for residential building envelope.
- Eco Niwas Samhita (Part-2) launched in 2021 with inclusion of building systems in addition to envelopes.



Reduced operational energy loads and economic benefits with thermal comfort provision in codes like ECBC, ENS 20181 & 2021 from optimized building envelope and electro mechanical systems



THERMAL COMFORT METRICS

- Heat transfer through roofs can be considered similar to walling material in terms of thermal conductivity and relevance of R-value.
- However, to reduce radiative heat gains, surface of roof exposed to the outdoors can be treated with coatings that increase solar reflectance.

Parameter	Metric	Building envelope element
Thermal Conductivity	R value – U value	Walls • Internal • **External**
Thermal Mass	Specific heat capacity	
Thermal Conductivity (Frames and Glass)	R value – U value	**Fenestration** • **Windows** • Skylights • Doors
Solar Gains	Solar Heat Gain Coefficient	
Visible Light Transmittance	VLT	
Thermal Conductivity	R value – U value	**Roofs** Floors Foundations
Thermal Emissivity	Solar Reflectance	

Relevant metrics for building envelope elements in terms of heat transfer
Source: Rawal, R., 2021. Heat Transfer And Your Building Envelope, Solar Decathlon India

SESSION-3

Building Physics & Fundamental of Thermal Comfort

1. *Concept of energy and heat*
2. *Factors influencing heat transfer and laws of thermodynamics*
3. *Heat balance and adaptive thermal comfort method*
4. *Local thermal discomfort*

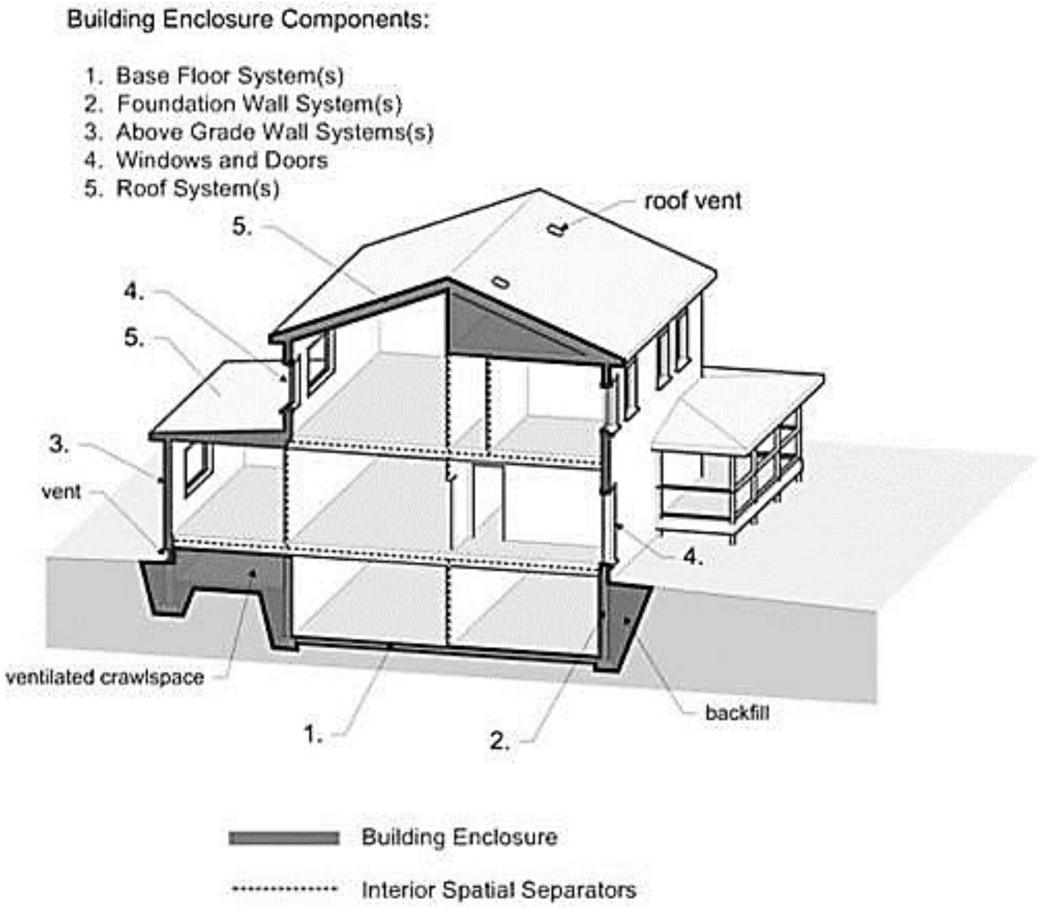
BUILDING PHYSICS (BUILDING)

Building physics includes the study of the interactions between heat, moisture and air movement between indoor and outdoor environments

What is a *BUILDING*?

Your ***Environmental Separator***.

- A building provides shelter - shelter from the elements as well as from other dangers and the outdoor environment.
- Its' function is to separate the inside from the outside
- A building creates an interior environment that is different from the exterior environment – it is an

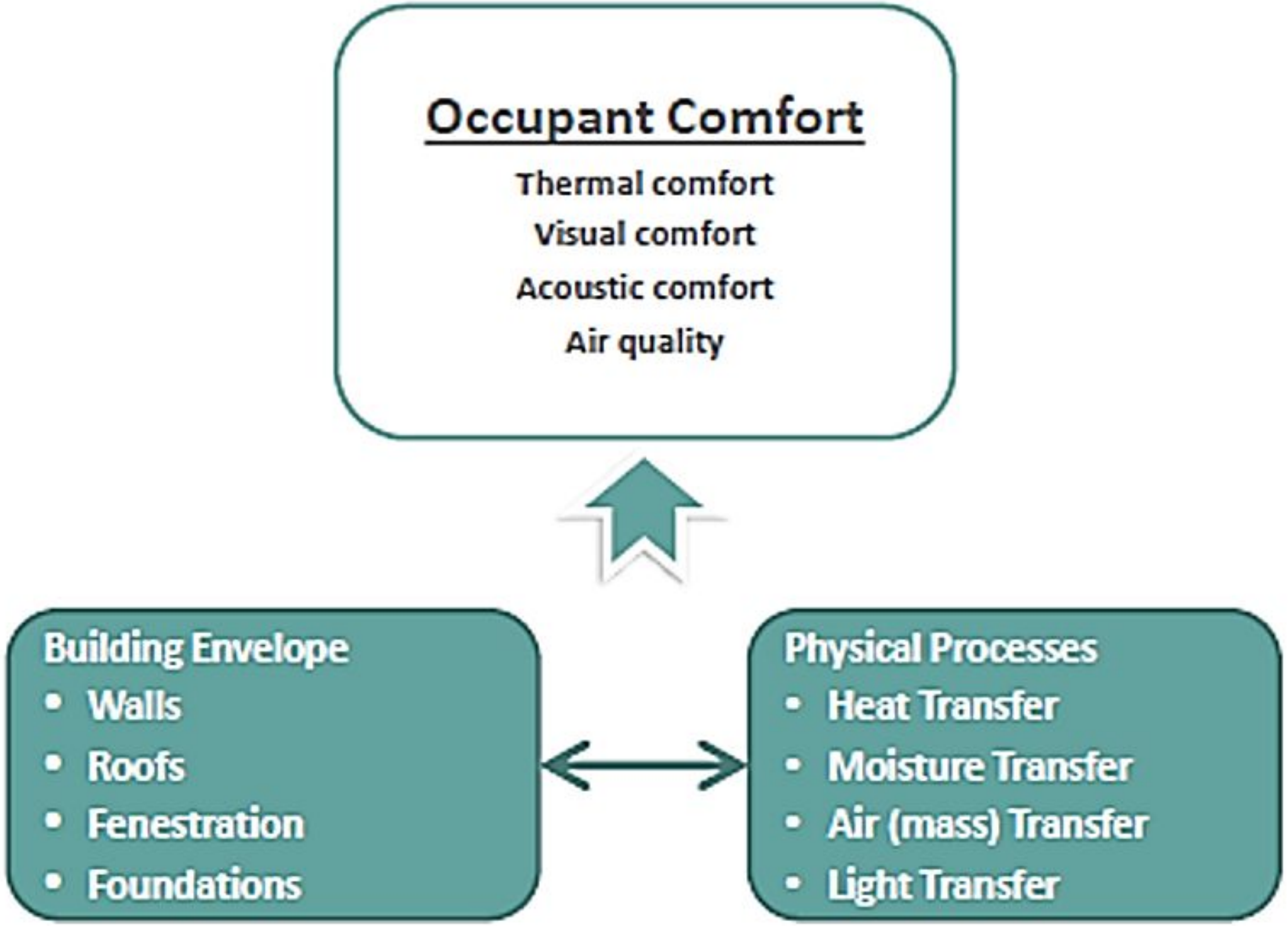


BUILDING PHYSICS (PURPOSE OF BUILDING)

Purpose of *Buildings*?

Buildings are designed for *People* and for *Specific tasks.*

- ✔ The building needs to keep people *Comfortable, Efficient, and Healthy*.
- ✔ *Energy Efficient Design* seeks to create buildings that keep people comfortable while minimizing Energy Consumption.



Occupant comfort, Physical processes, and Elements of building Relationship

BUILDING PHYSICS (CONCEPT OF ENERGY & HEAT)

2nd Law of *Thermodynamics*

“In an isolated system, a process can occur only if it increases the total entropy of the system”.

-Rudolph Clausius

- *Energy moves from higher state to lower state –(the second law of thermodynamics)*
- *Heat moves from warm to cold (thermal gradient)*
- *Moisture moves from more to less (concentration gradient)*

✔ ***Heat*** moves from warmer to cooler.

✔ ***Air*** moves from higher pressure to lower pressure

✔ ***Moisture*** moves from wetter to drier.

BUILDING PHYSICS (HEAT TRANSFER IN BUILDINGS)

Heat Transfer Calculations in Buildings

Conduction- Transfer of energy due to internal vibrations of envelop building material.

Convection- Transfer due to air infiltration from door windows.

Radiation- Transfer of heat through windows and transparent surfaces in form of electromagnetic waves.

Note:

- ✔ *ECBC/ENS regulates the U-Factor and SHGC for materials and glazing units.*
- ✔ *Solar incident radiation depends on the weather condition and solar altitude angle.*

$$Q_{Conduction} = U \cdot A \cdot (\theta_i - \theta_s)$$

Q = Heat transfer through conduction
U or U-factor = Overall heat transfer co-efficient (W/(m2·K)
A = Surface area
delta T = Temperature difference across surface; $T_{in}(\theta_i) - T_{out}(\theta_s)$ (K)

$$Q_{Convection} = h_{cv} \cdot A \cdot (\theta_s - \theta_f)$$

Q_c = Heat transfer through convection
h_{cv} = Heat Transfer Coefficient
θ_s=Temperature of the surface
θ_f=Temperature of the fluid

$$Q_{Radiation} = SHGC \cdot A \cdot E_t$$

Where:
SHGC = solar heat gain coefficient
E_t = incident solar radiation
A = area of transparent element

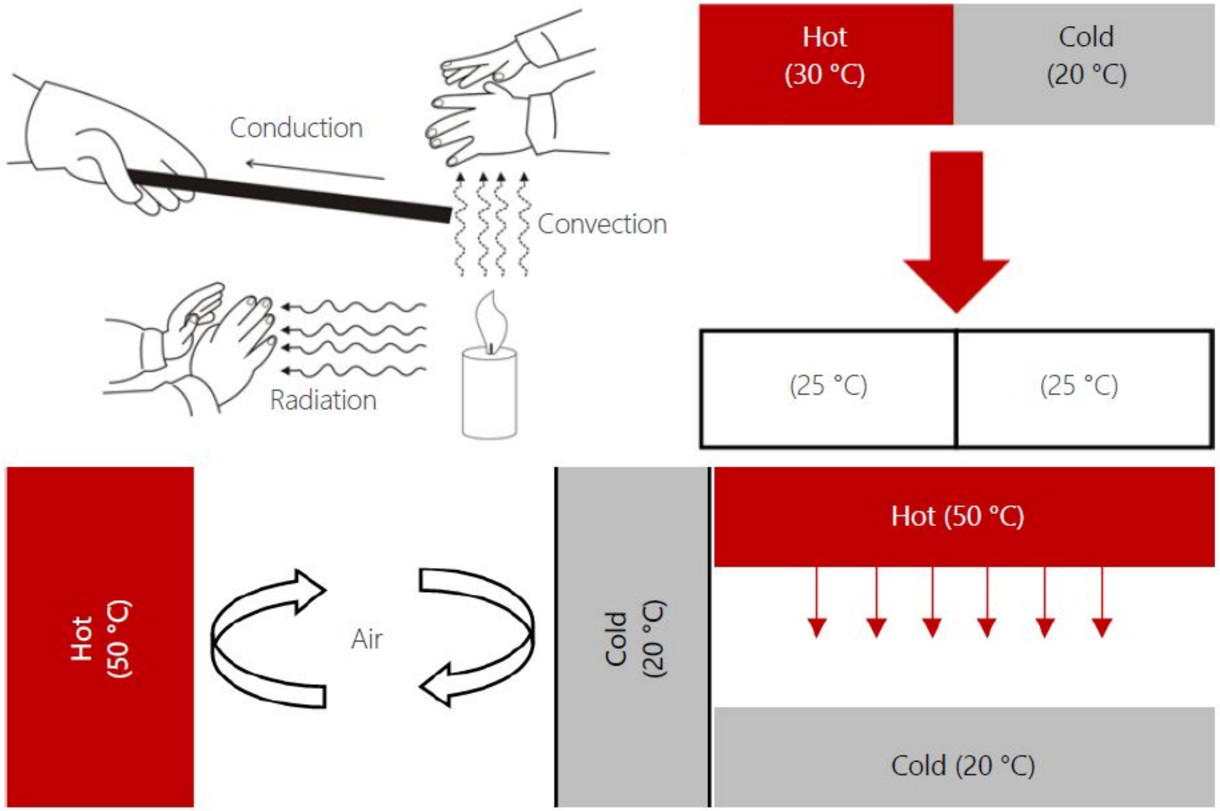
BUILDING PHYSICS

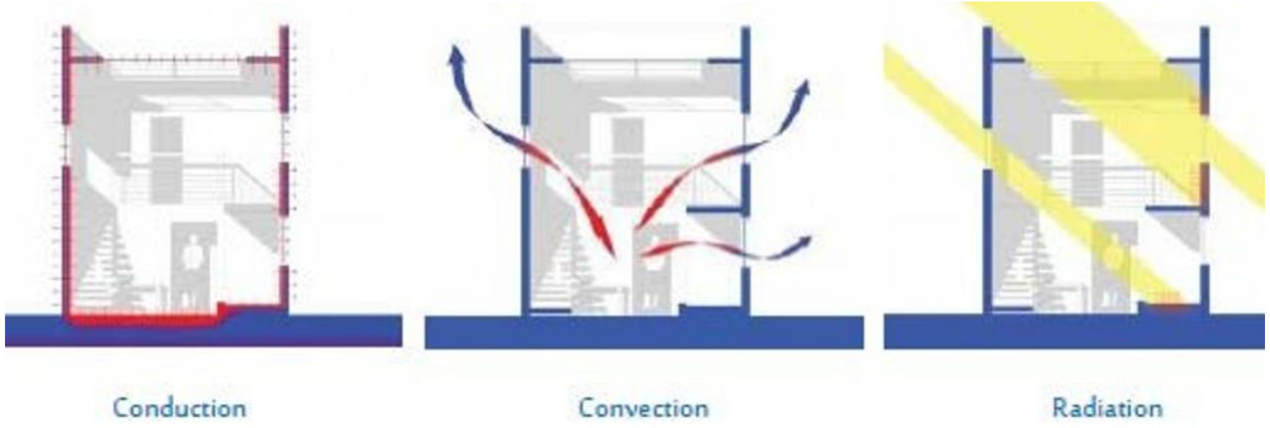
Heat Transfer in Buildings

Conduction- Transfer of heat through direct contact

Convection- Transfer due to movements of gases, liquid, and vapor.

Radiation- Transfer of heat through electromagnetic waves.





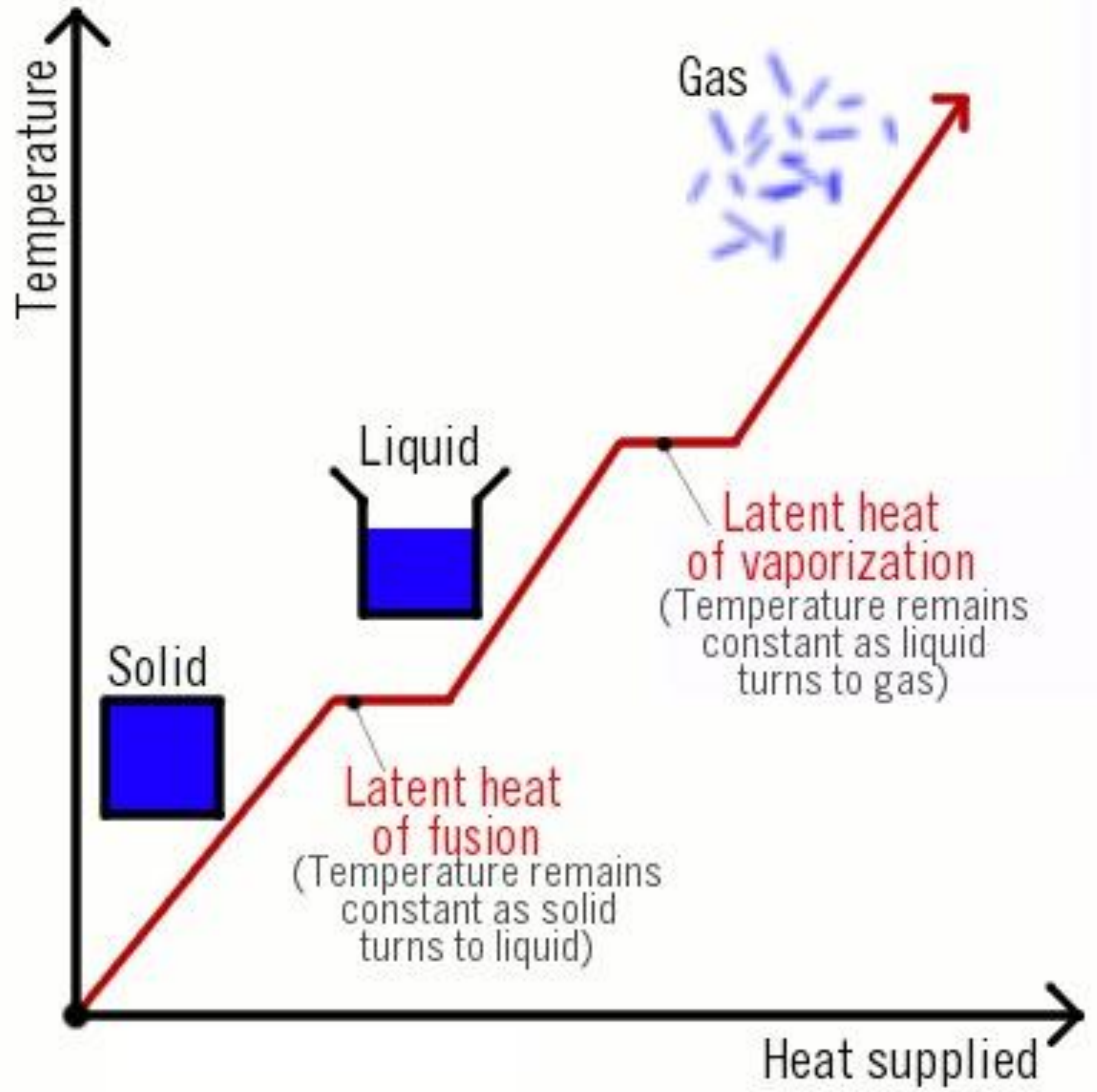
Clockwise- Forms of heat transfer; Conduction; Radiation; Convection
Source- https://thefactfactor.com/facts/pure_science/physics/conduction/9868/; Rawal, R., 2021. Heat Transfer and Your Building Envelope, Solar Decathlon India

BUILDING PHYSICS (SENSISBLE & LATENT HEAT)

Sensible Heat **–** When the temperature of an object falls/rises, the heat removed/added is called 'sensible heat'. Sensible heat results in a change in temperature.

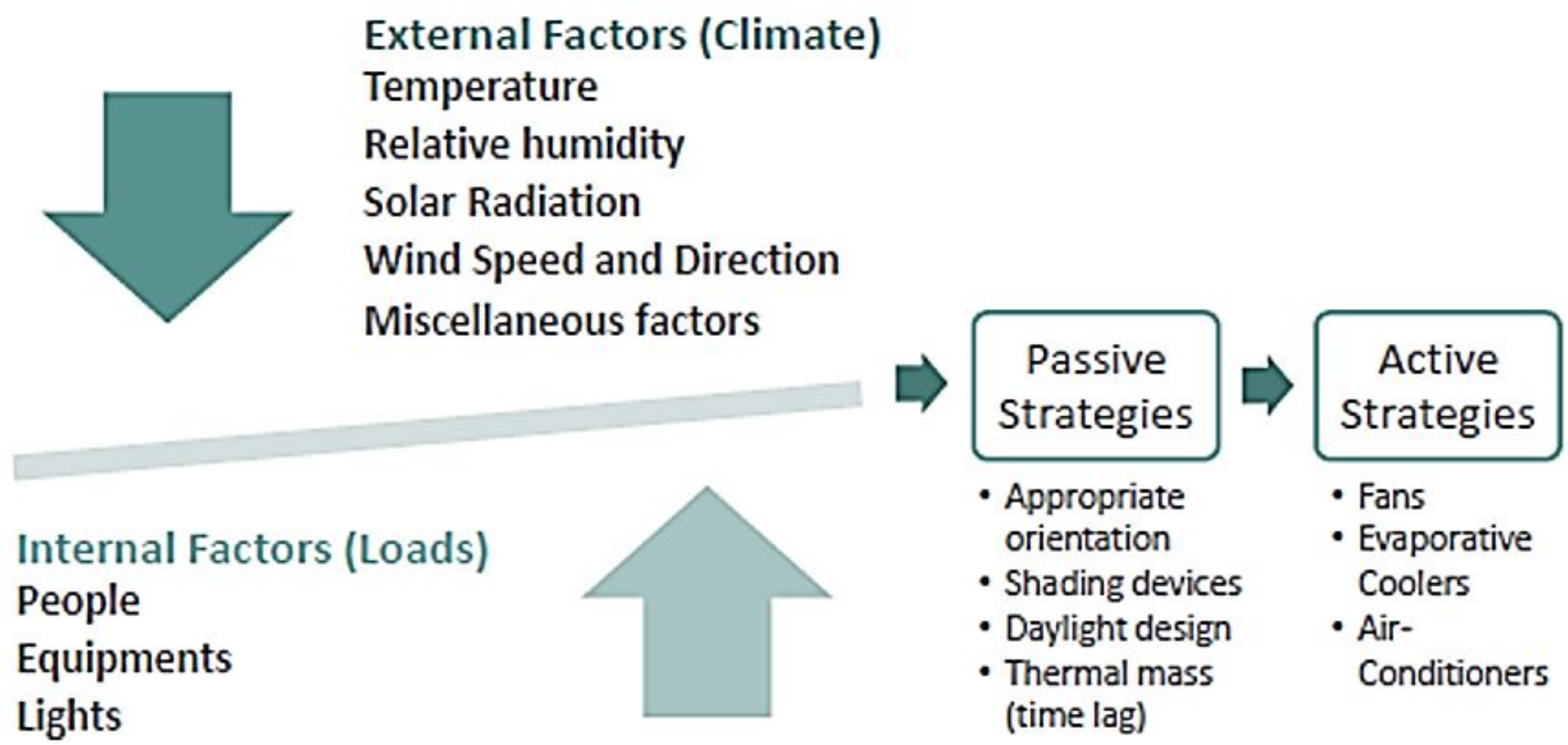
Latent Heat- Latent heat is the heat added/removed to an object in order for it to change its state. It affects the moisture content which results in a change of temperature.

Total flow of heat is the algebraic sum of sensible and latent heat within space.



BUILDING PHYSICS &THERMAL COMFORT

Use of Building Physics to Optimize Energy use for Thermal Comfort



External Factors.(Climatic)

- ✔ Temperature
- ✔ Relative Humidity
- ✔ Solar Radiation
- ✔ Wind Speed and Direction
- ✔ Miscellaneous Factors

Internal Factors.(Loads)

- ✔ People
- ✔ Equipment
- ✔ Lights

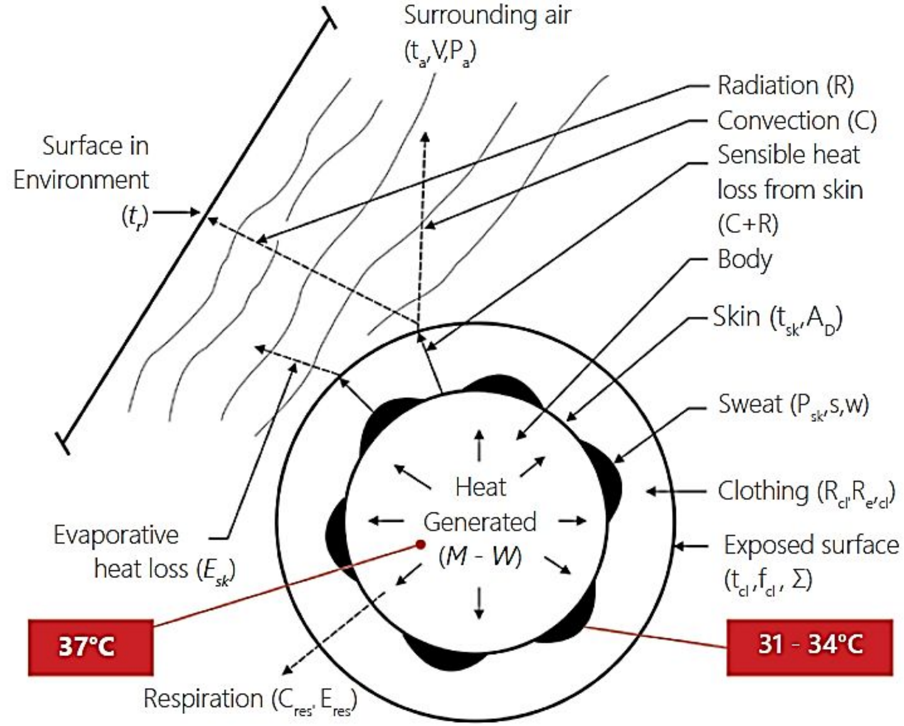
HEAT BALANCE AND ADAPTIVE THERMAL COMFORT

Heat Balance Method

The heat balance method presents a physics based mathematical model that establishes thermal comfort when heat loss from the body is exactly equal to heat produced within the body.

The heat balance method approaches thermal comfort from a biological perspective.

- **If heat generation rate > heat loss rate, individual will feel warm/ hot**
- **If heat generation rate < heat loss rate, individual will feel cool/ cold**
- **For thermal comfort, heat generation rate = heat loss rate**



Comfort Theory - Heat Balance Method
Source: Fantozzi, F., & Lamberti, G. (2019). Determination of thermal comfort in indoor sport facilities located in Moderate Environments: An overview. Atmosphere, 10(12), 769. https://doi.org/10.3390/ atmos10120769

HEAT BALANCE AND ADAPTIVE THERMAL COMFORT

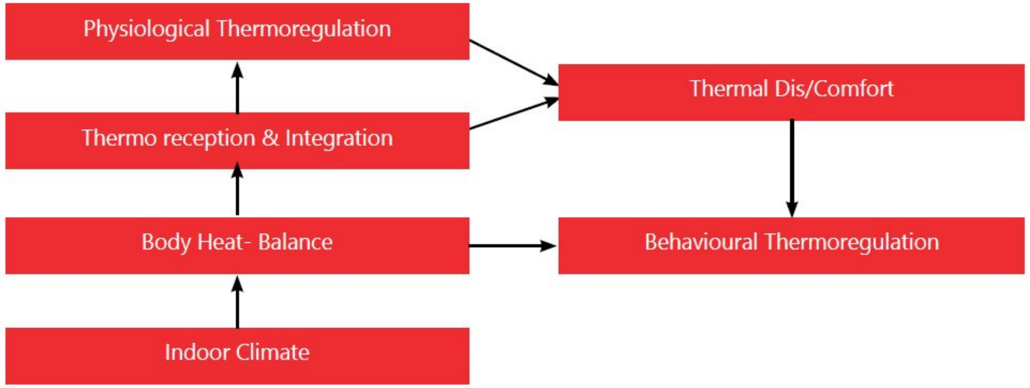
Adaptive Thermal Comfort Method

Adaptive thermal comfort model takes into consideration all three-

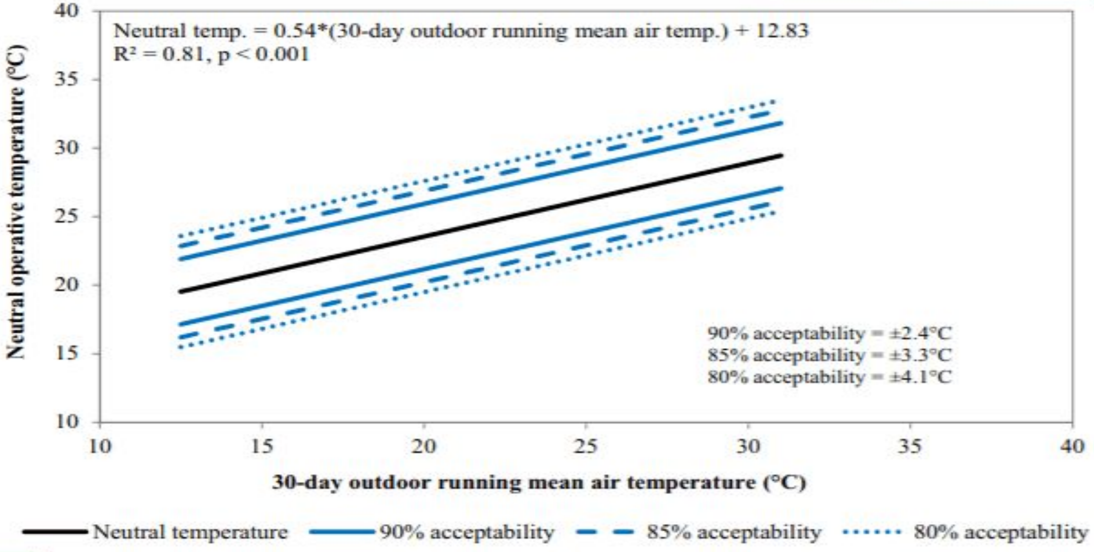
- **Physiological,**
- **Psychological,**
- **Behavioural**

aspects of occupants and their influence on perception of thermal comfort.

It prescribes indoor setpoint temperature to address 90% acceptability of thermal environment among occupants.



Comfort Theory: Adaptive Thermal Comfort Method



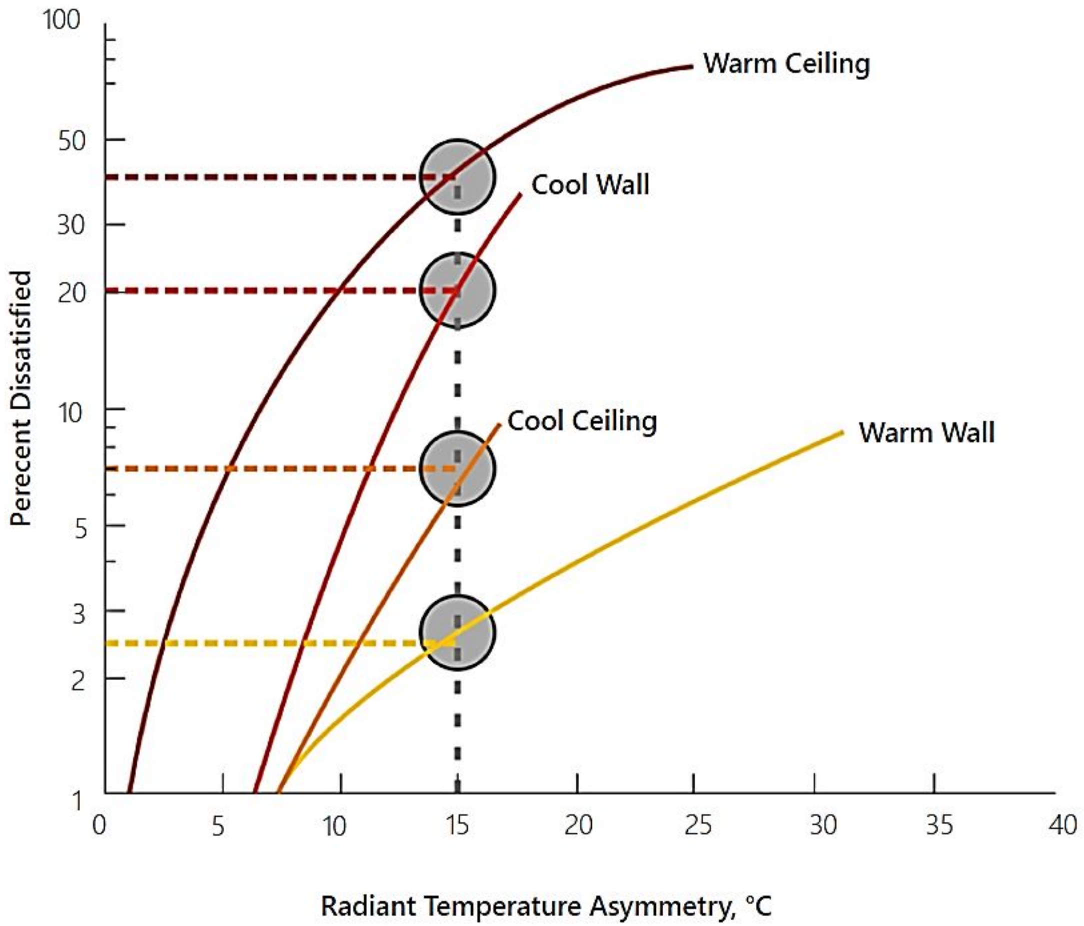
IMAC model for naturally ventilated buildings.

LOCAL THERMAL DISCOMFORT

Local Thermal Dis-Comfort

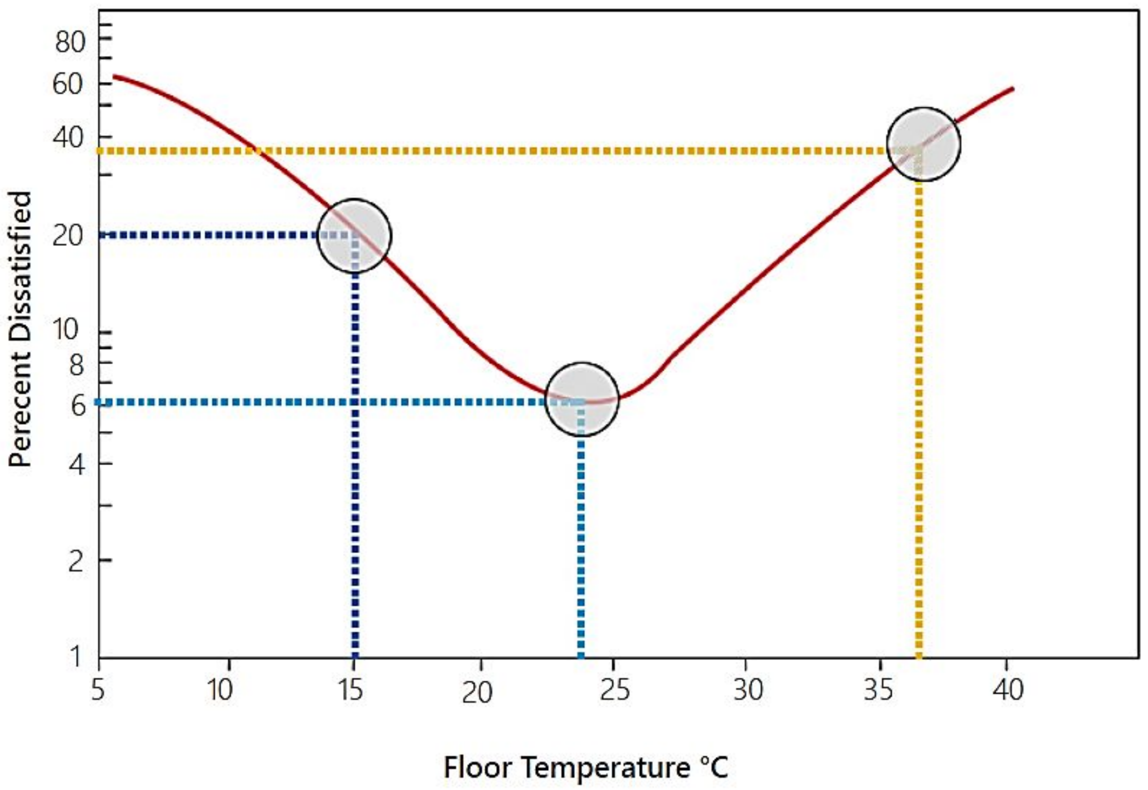
Studies have identified that it is possible for occupants to feel uncomfortable even if they feel thermally neutral overall. This usually happens when one or more parts of their body are either too warm or too cold.

- Local thermal discomfort is also a reason why it is highly unlikely for indoor spaces to achieve 100% thermal acceptability.
- To accommodate this, most standards like ASHRAE/IMAC specify conditions to ensure 80% acceptability of the thermal environment amongst occupants.

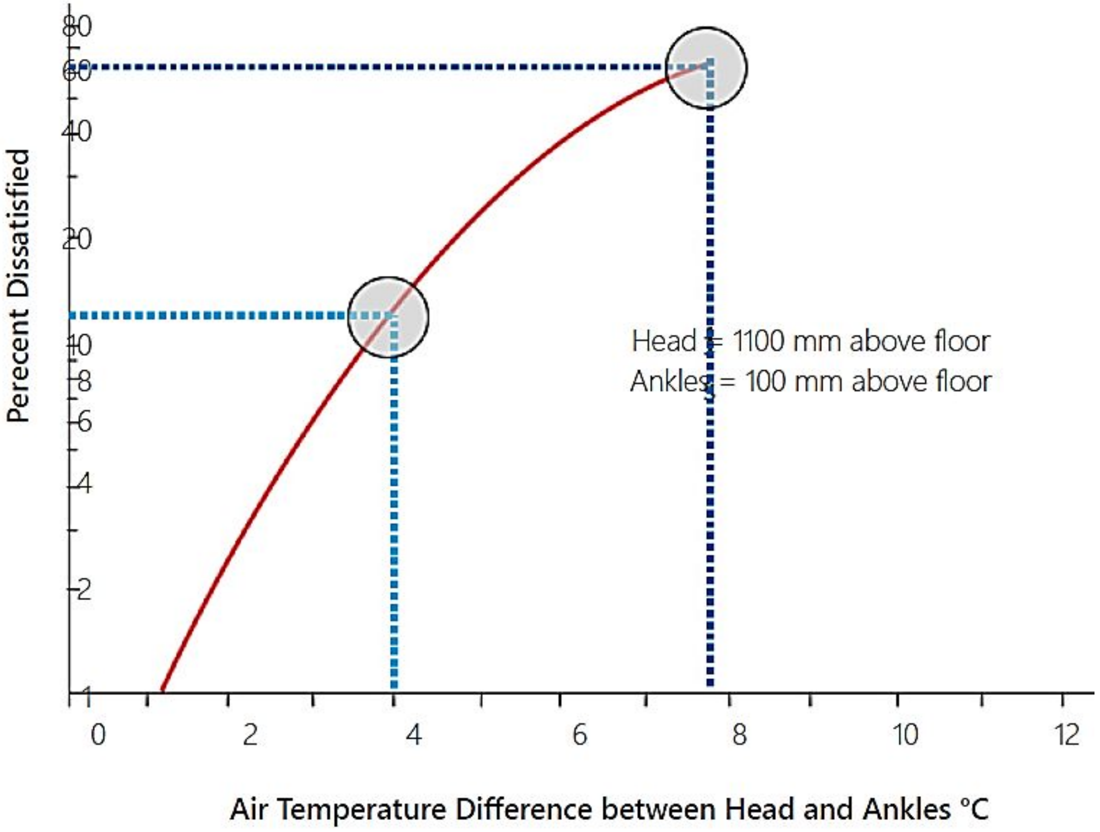


Occupant dissatisfaction levels due to radiant temperature asymmetry in walls and roof.
Source: Abushakra Bass, Akers Larry, Baxter Van, Hayte Sheila & Paranjpey Ramesh (2017). ASHRAE Fundamentals SI edition.

LOCAL THERMAL DISCOMFORT



Occupant dissatisfaction levels due to radiant temperature asymmetry in floor.
Source: Abushakra Bass, Akers Larry, Baxter Van, Hayte Sheila & Paranjpey Ramesh (2017). ASHRAE Fundamentals SI edition.



Percentage of Seated People Dissatisfied as Function of Air Temperature Difference Between Head and Ankles
Source: Abushakra Bass, Akers Larry, Baxter Van, Hayte Sheila & Paranjpey Ramesh (2017). ASHRAE Fundamentals SI edition.

SESSION-4

Passive Strategies & Building Materials

1. *Affordable housing & passive design strategies*
2. *Innovative building materials (wall, glazing & roof)*
3. *Case studies*

AFFORDABLE HOUSING & PASSIVE STRATEGIES

Strategies for various modes of heat transfer

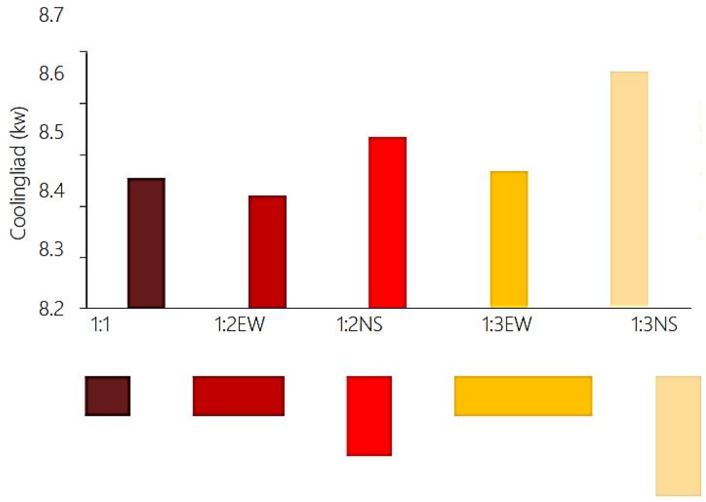
Passive design strategies may tackle either one or a combination of these modes of heat transfer.

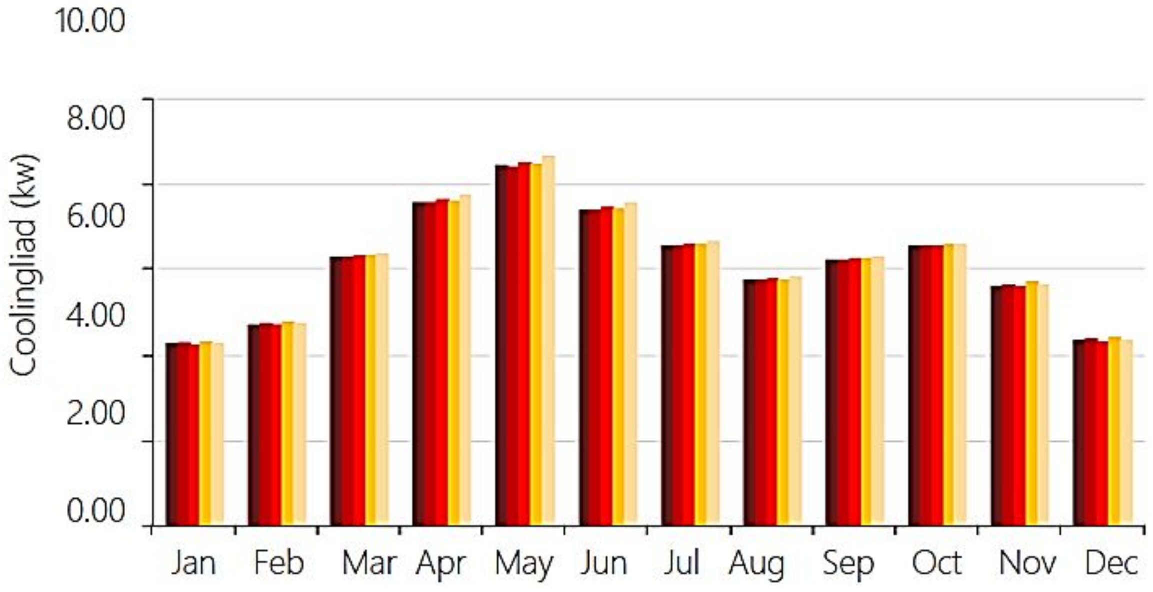
- Orientation, and massing of the building act as passive design strategies by influencing the quantity and quality of radiation reaching the envelope surface.
- Similarly, shading devices obstruct the amount of radiation entering the buildings through windows.
- Fixed or movable shading devices can be chosen depending on the trajectory of sun and direction of the façade.

Mode of heat transfer	Passive Design strategies applicable
Conduction	Materials and Construction
Convection	Space Volume, Building form- (Roof form, plan)
Radiation	Orientation Shading/ Brise Soleil, jail etc

Passive design strategies categorized based on modes of heat transfer

AFFORDABLE HOUSING & PASSIVE STRATEGIES



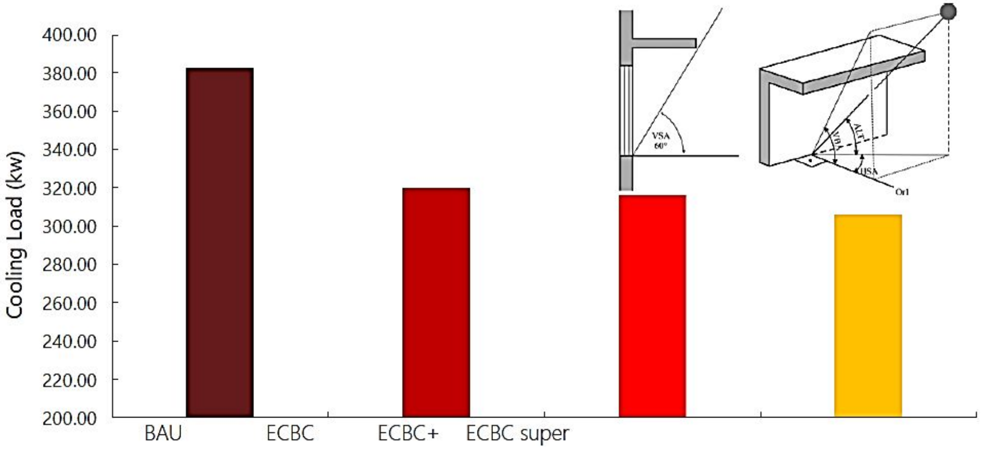


Form & orientation of the building

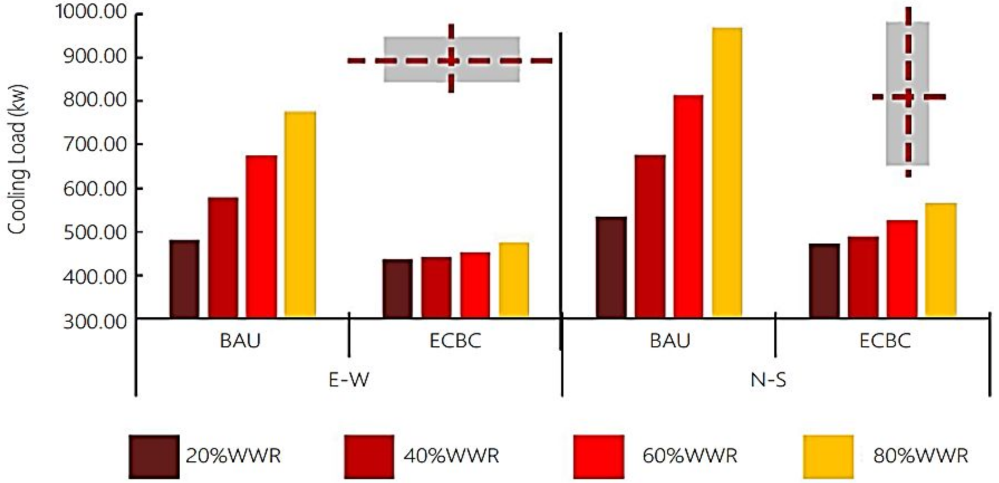
- Daylight penetration and fenestration design have implications on heat gain/loss through the building envelope.
- Careful orientation of fenestration can help achieve thermal and visual comfort
- Daylight harvesting from the north and south facade should be maximized with proper orientation of the building.

Top: peak cooling load for various forms and orientations; Bottom: variations in peak cooling load for each month for all sample cases.

AFFORDABLE HOUSING & PASSIVE STRATEGIES



Cooling loads for BAU, ECBC, ECBC+, and ECBC super buildings having 600mm shading over windows

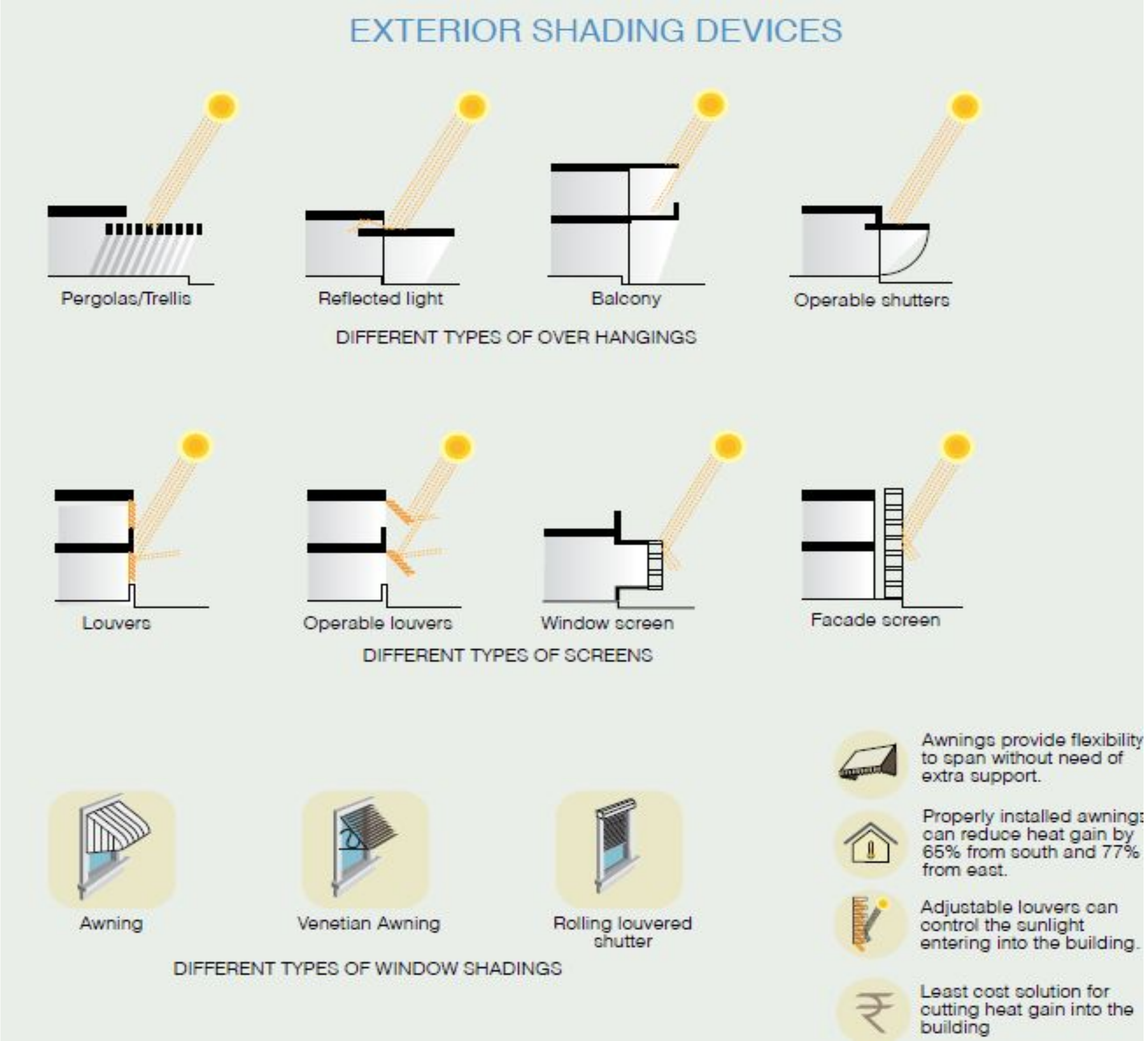


Comparative analysis of various WWR levels in East-West and North-South orientations for business-as-usual and ECBC compliant buildings

Shading & WWR

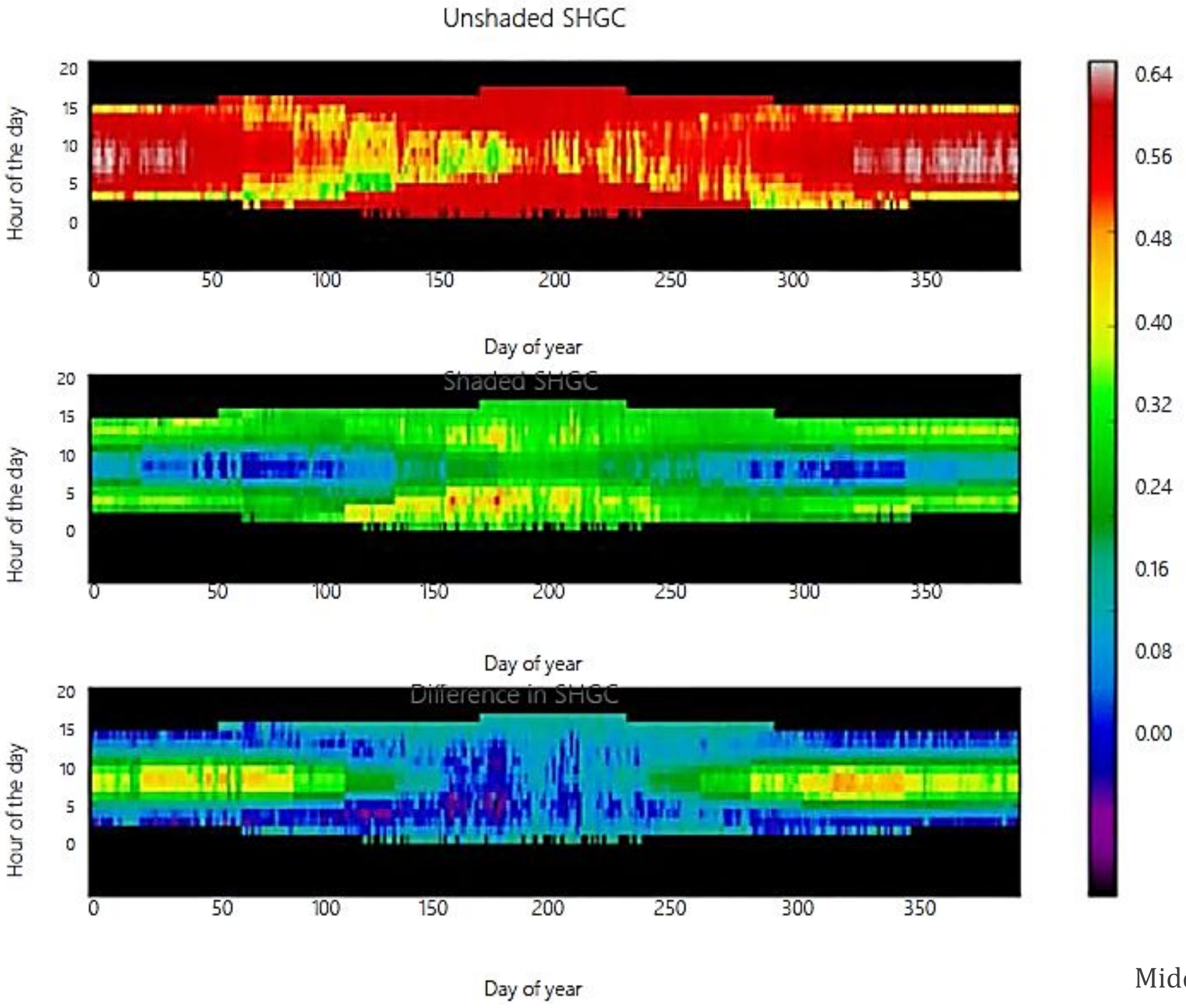
- Reduce heat gain and cooling energy use of the building.
- Dynamic movable external shading systems, vertical shading elements like fins are more useful in cutting radiations when the sun is at a lower altitude i.e., in East and West facades
- Greater WWR escalates the cooling load significantly in BAU cases. However, compliance with ECBC code results in reduced cooling load across the four WWR cases.

AFFORDABLE HOUSING & PASSIVE STRATEGIES



- Exterior shading devices can be provided in a variety of materials and designs, including sunshades, awnings, louvers, bamboo screens, jaali, and green cover through vines.
- These can be implemented with minimal cost implications and have the most favourable cost-benefit relation with respect to thermal comfort.
- To prevent summer overheating and glare, a good shading device strategy should be used with glazed openings.

AFFORDABLE HOUSING & PASSIVE STRATEGIES



- SHGC value of glass while maintaining desirable VLT and U-value. Hence, combination of multiple passive design measures can contribute to RETV value of 15 W/Sqm.

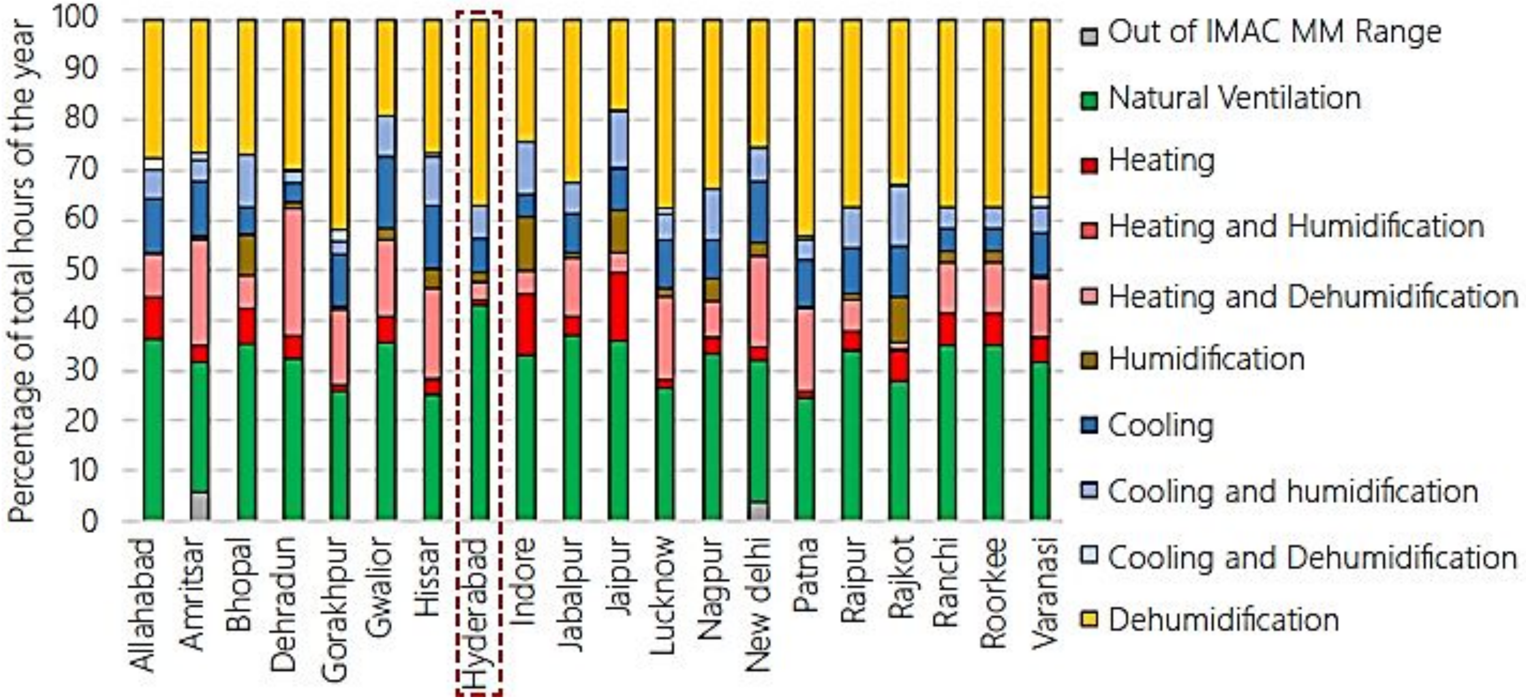
Top- SHGC values of an unshaded window throughout the year;
Middle- SHGC values of the same windows in case of shading present throughout the year;
Bottom- Difference in SHGC values of the first two graphs.

AFFORDABLE HOUSING & PASSIVE STRATEGIES

Natural ventilation

Natural ventilation is defined as provision of fresh air and removal of stale air using the naturally occurring forces of wind.

It can be observed in figure that natural ventilation as a standalone strategy can provide comfort for around 35% of the total hours of the year in hot-dry, warm-humid, and composite climates.

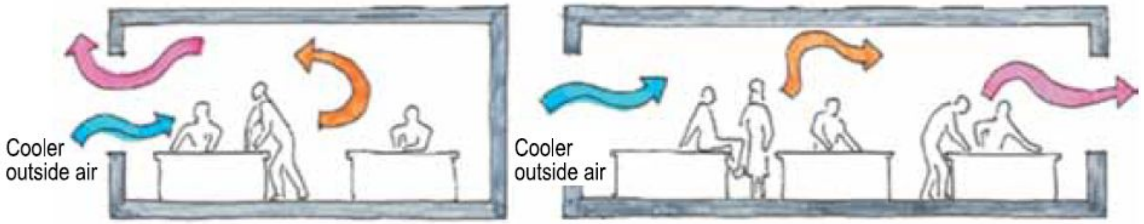


Percentage of comfort hours in a year for different building operation modes listed in IMAC-MM. Source: M., Shulka, Y., Rawal, R., Loveday, D., de Faria, L., Angelopoulos, C. (2020). Low Energy Cooling and Ventilation in Indian Residences Design Guide. CEPT Research & Development Foundation & Loughborough University. http://carbse.org/reports-and-articles/

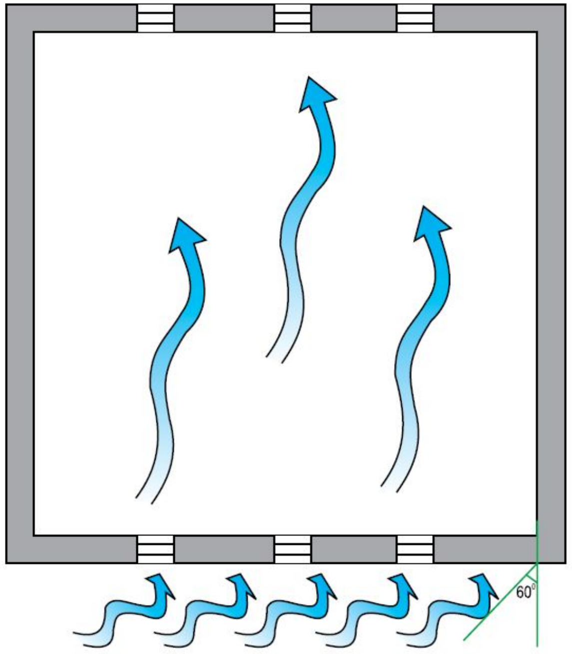
AFFORDABLE HOUSING & PASSIVE STRATEGIES

Natural ventilation

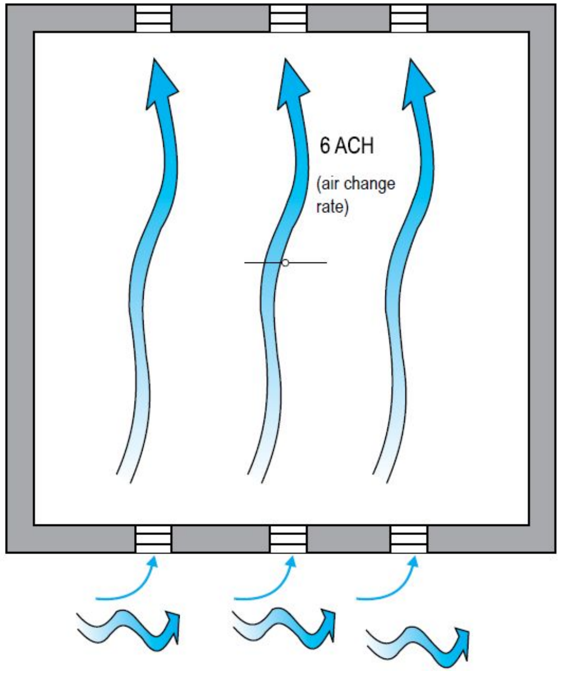
It is shown that the ACH improved from 6 ACH per hour to 14 ACH per hour with the use of the deflectors.



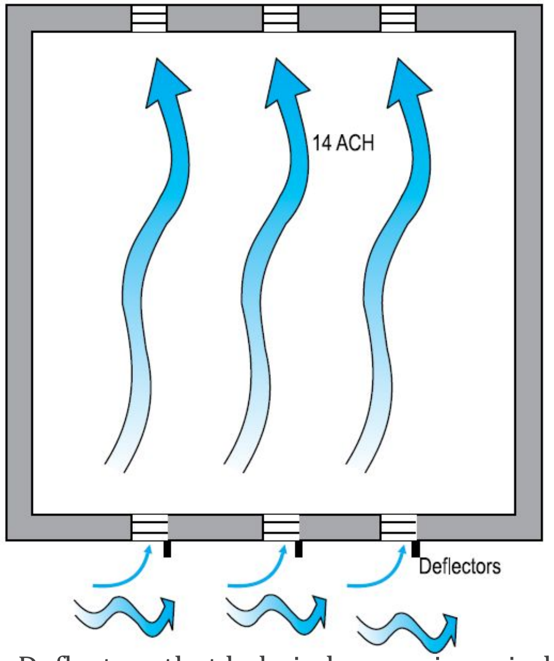
Principles of single-sided ventilation and cross-ventilation



Wind blowing at an angle of 60° from the perpendicular axis of the façade



Wind blowing parallel to the façade



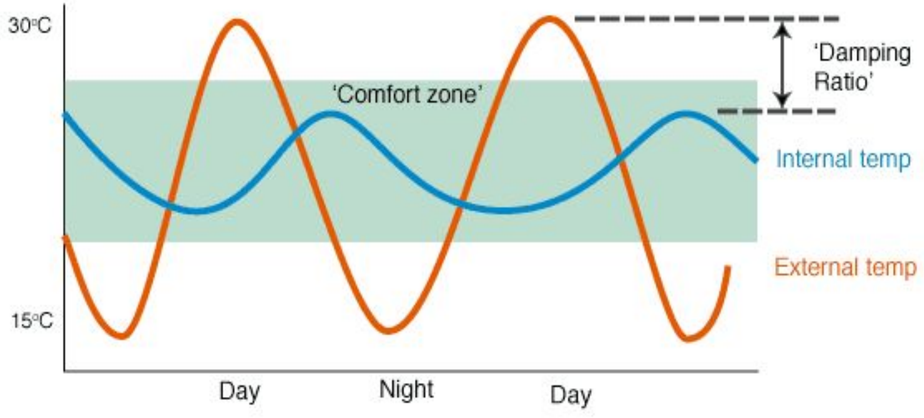
Deflectors that help in harnessing wind for natural ventilation

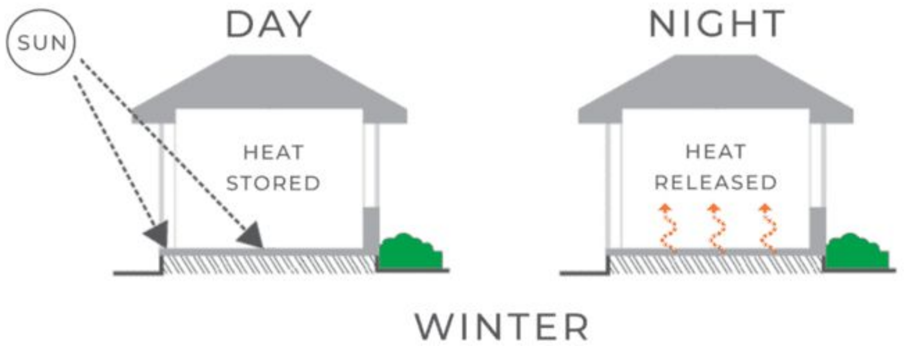
Source: Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka

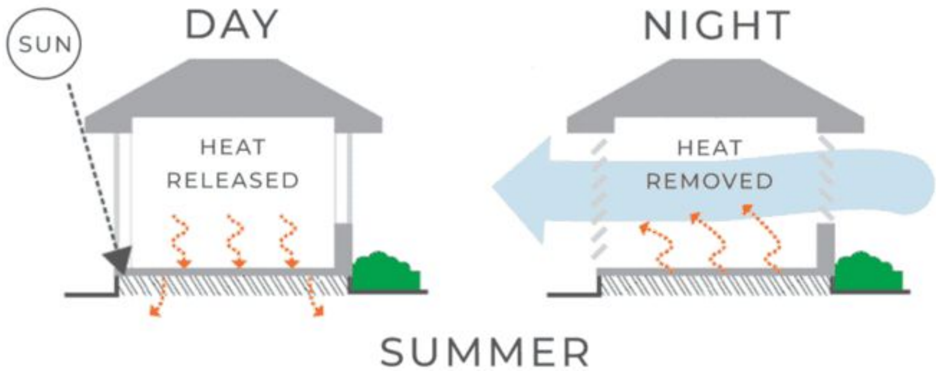
AFFORDABLE HOUSING & PASSIVE STRATEGIES

'Thermal mass' describes a material's capacity to absorb, store and release heat. A common analogy is thermal mass as a kind of thermal battery.

- **Denser thermal mass materials are more effective passive solar materials. Thus, denser the material the better it stores and releases heat.**
- **Do not substitute thermal mass for insulation. It should be used in conjunction with insulation.**



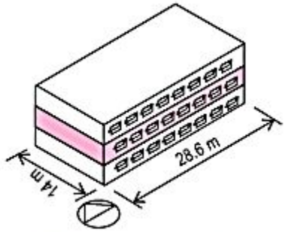
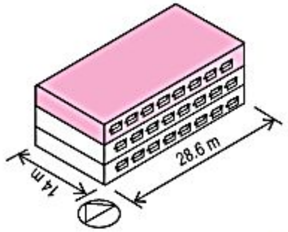




AFFORDABLE HOUSING & PASSIVE STRATEGIES

To understand the quantum of heat gain through various components of the envelope, the top and intermediate floors of the N–S oriented rectangular building with no windows on the east and west was simulated.

1. **For the intermediate floor, the heat gained through windows is much higher compared to the heat gained through walls.**
2. **For the top floor, it is seen that the heat gain from the roof is highest, while the heat gain from windows is also significant.**

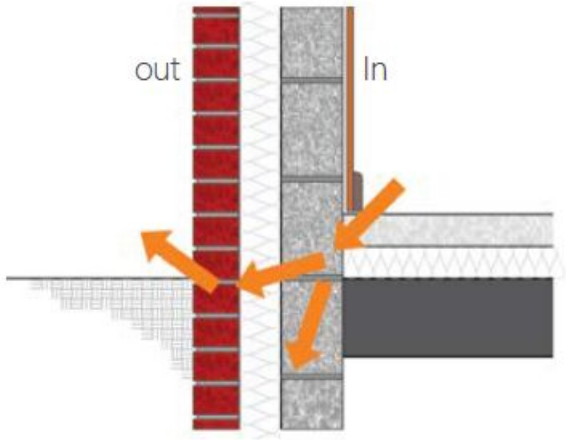
Components of a building envelope	Properties	Heat gain from roof (kWh)	Heat gain from wall (kWh)	Heat gain through windows (kWh)
 Level: Intermediate floor 6 inch RCC slab with plaster (U-value: 3.8 W/m².K)	Built-up area: 1200 m² Floor-plate dimension: 14.0 x 28.6 m Orientation: N–S No windows on east and west Overhangs: 600 mm fixed Glazing type: Single clear 6 mm (U-value: 6.1 W/m².K, VLT: 88%, SHGC: 0.81) No heat exchange through upper and lower floors No internal loads Cooling set-point: 26 °C Fresh air + Infiltration: 1 ACH	0	93	3106
 Roof: 150 mm RCC slab with plaster (U-value: 3.8 W/m².K)		7293	–791[9]	2770

Source: Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka

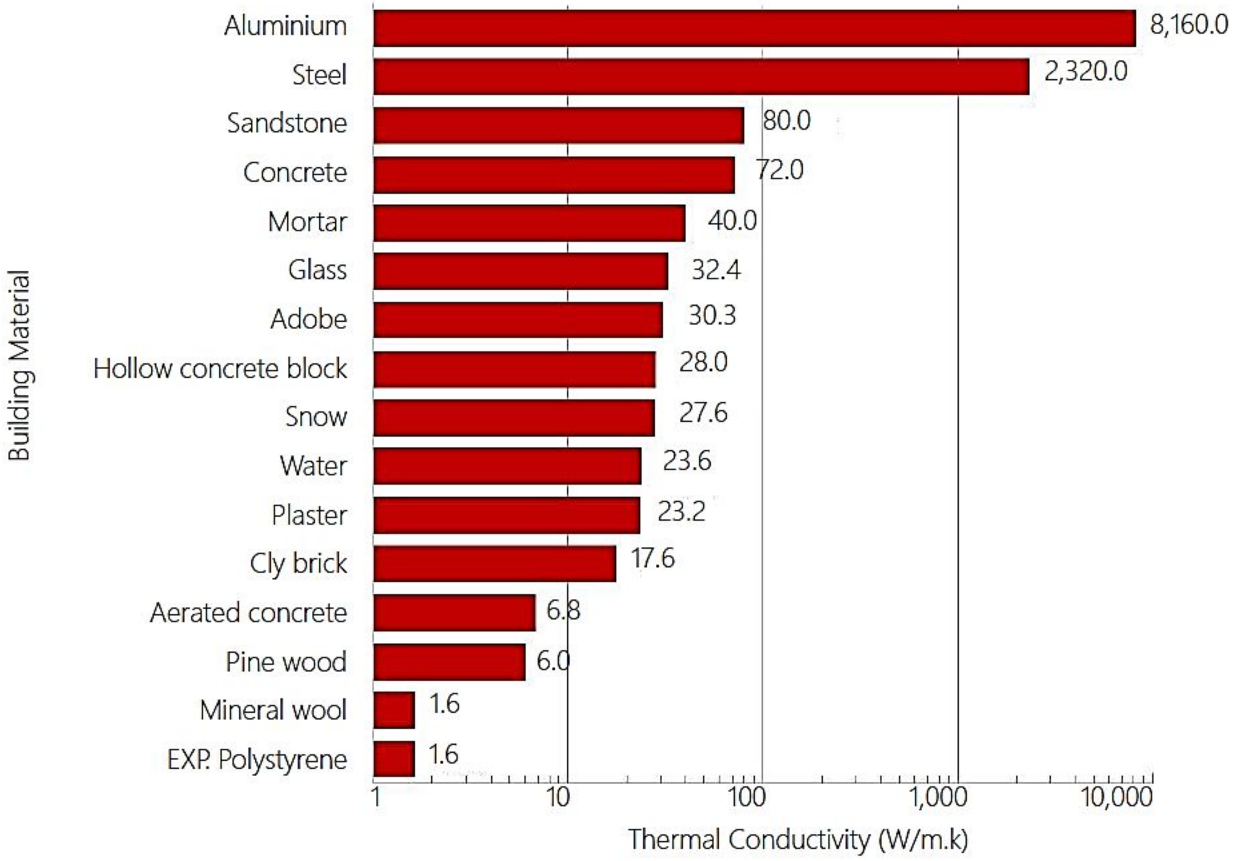
INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

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.



Walling assemblies and thermal bridging.
Information and Image Courtesy: Prof. Cloude Roulet, EMPA, Switzerland, Indo Swiss BEEP project, BEE, India



Thermal conductivities of common building materials.
Information and Image Courtesy: Prof. Cloude Roulet, EMPA, Switzerland, Indo Swiss BEEP project, BEE, India

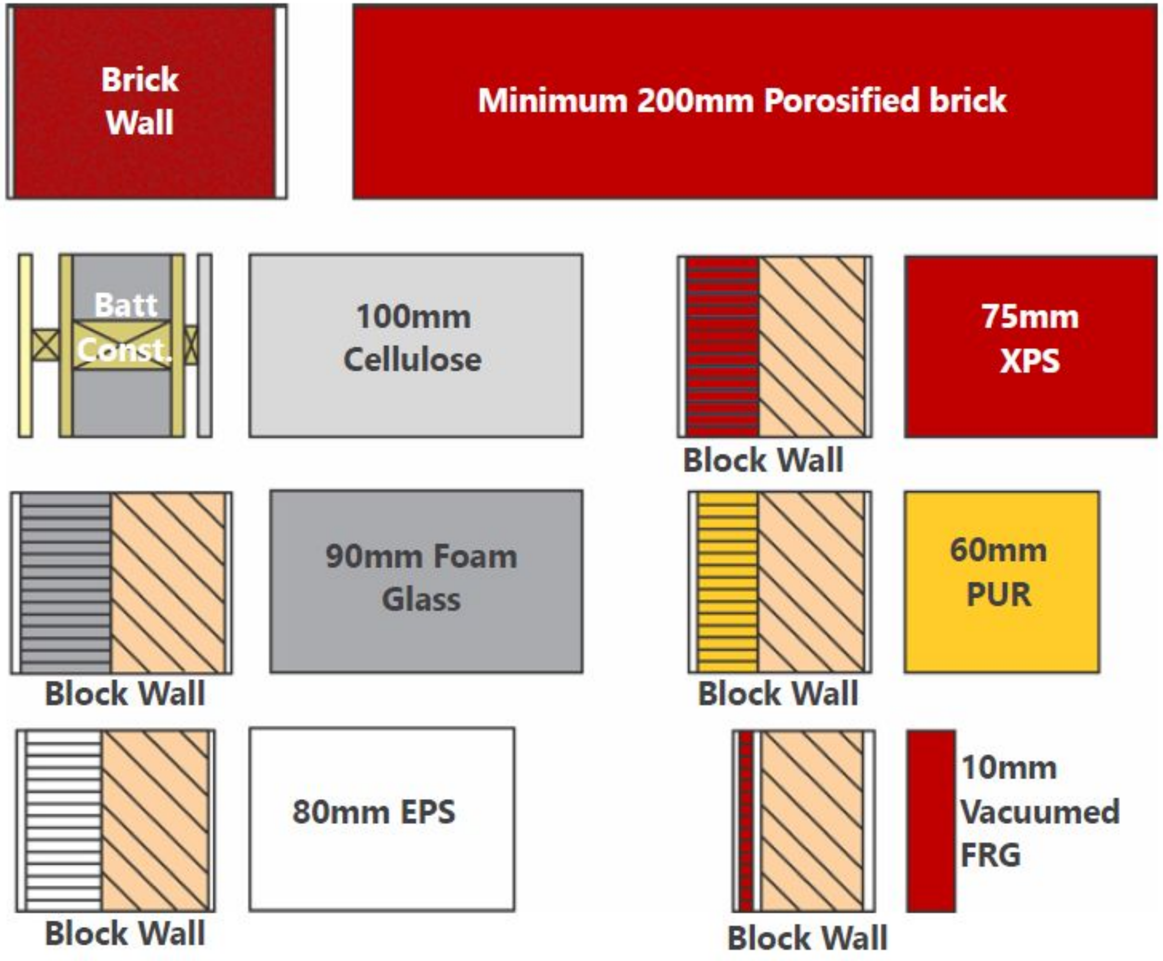
INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

Material thickness and location in walling assemblies

- Location of each material in the assembly also affects the surface temperature values and other functioning of the assembly.
- This can be understood by developing temperature profile across the wall section.

S/N	Testing parameter	Instrument	Applicable Testing Standard
1	Thermal Conductivity and Specific heat	Thermal Constants Analyser	ISO/DIS 22007-2:2015 (for both bricks and blocks) (ISO, 2008)
2	Dry density	Precision Weighing Scale, Inert Gas Oven, Water Bath	ASTM C20 (for both bricks and blocks) (ASTM, 2015)
3	Water Absorption	Precision Weighing Scale, Inert Gas Oven, Water Bath	IS 3495 (for bricks) (BIS, 1992b) IS 2185 (for blocks) (BIS, 2005)
4	Compressive Strength	Compression Testing Machine	IS 3495 (for bricks) IS 2185 (for blocks)

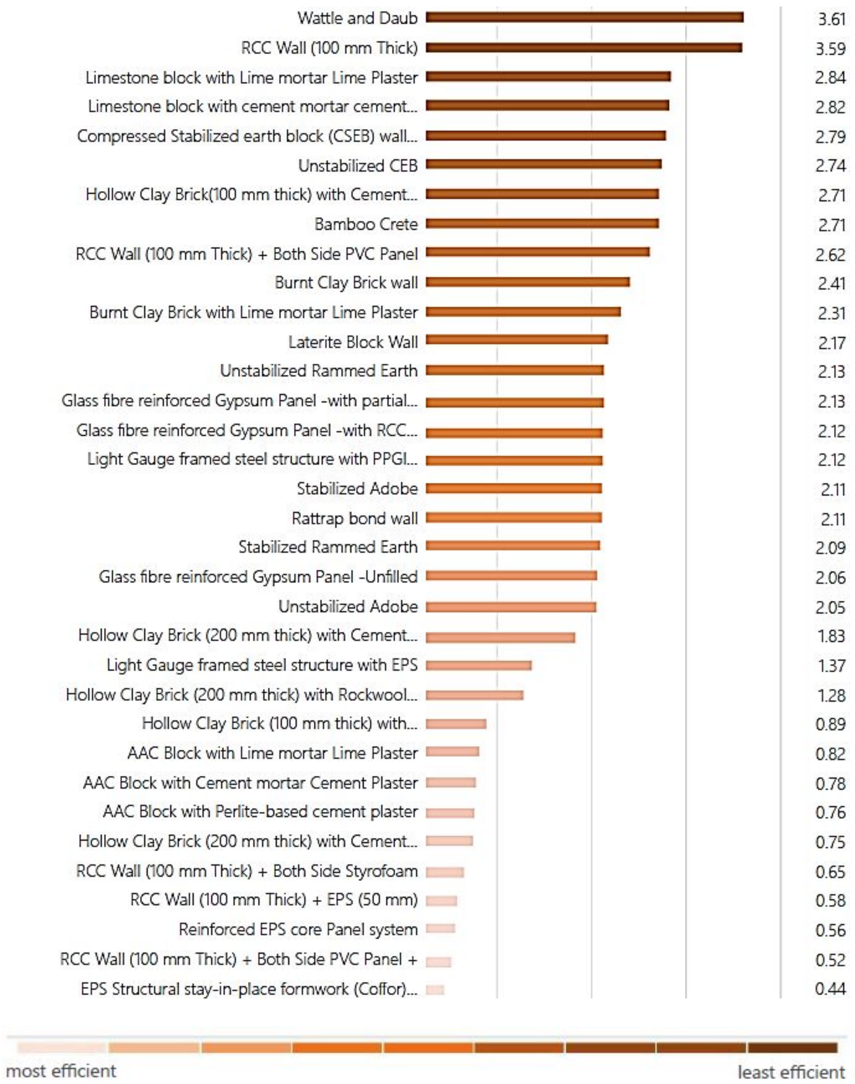
Measured properties and corresponding testing standards & instruments used



Minimum thickness needed to achieve U value < 0.4W/m2K.
Information and Image Courtesy: Prof. Cloude Roulet, EMPA, Switzerland, Indo Swiss BEEP project, BEE, India

INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

U-value database of walling assemblies



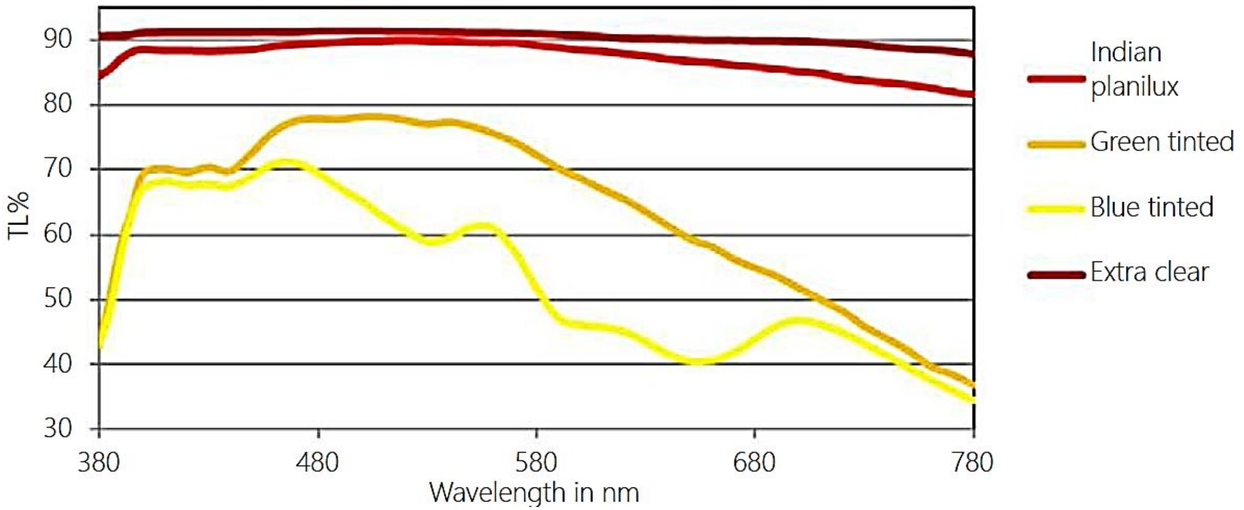
S/N	Test Phase	Wall types	Thickness (in mm)	U value (W/m².K)
1	1	Base case: Burnt Clay Brick Wall	250	2.41
2	1	Rattrap bond wall	250	2.11
3	1	Light Gauge framed steel structure with EPS	136	1.37
4	1	Light Gauge framed steel structure with PPGI Sheet	150	2.12
5	1	Reinforced EPS core Panel system	150	0.56
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
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

U-value database of all selected walling assemblies and technologies

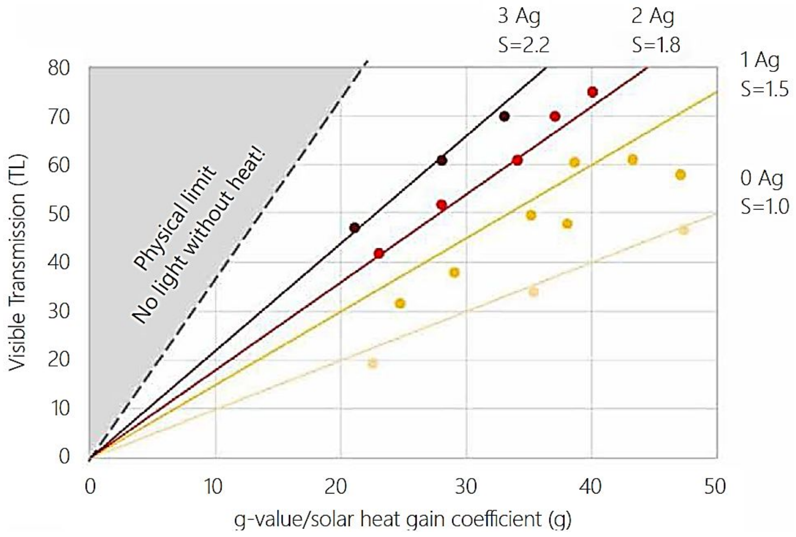
INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

Glazing assemblies

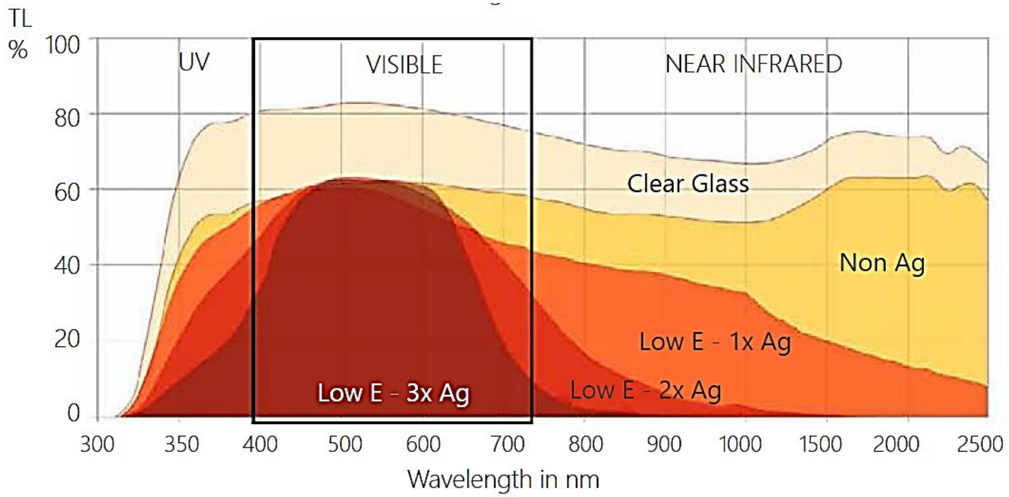
Variation in transmission levels of different types of glasses at different wavelengths within the visible light spectrum.



VLT for different types of glasses;
Information and Image Courtesy: A.R Unnikrishnan, Saint Gobain Glass



Selectivity, solar heat gain coefficient and visible light transmission of different low e-coating combinations
Information and Image Courtesy: A.R Unnikrishnan, Saint Gobain Glass



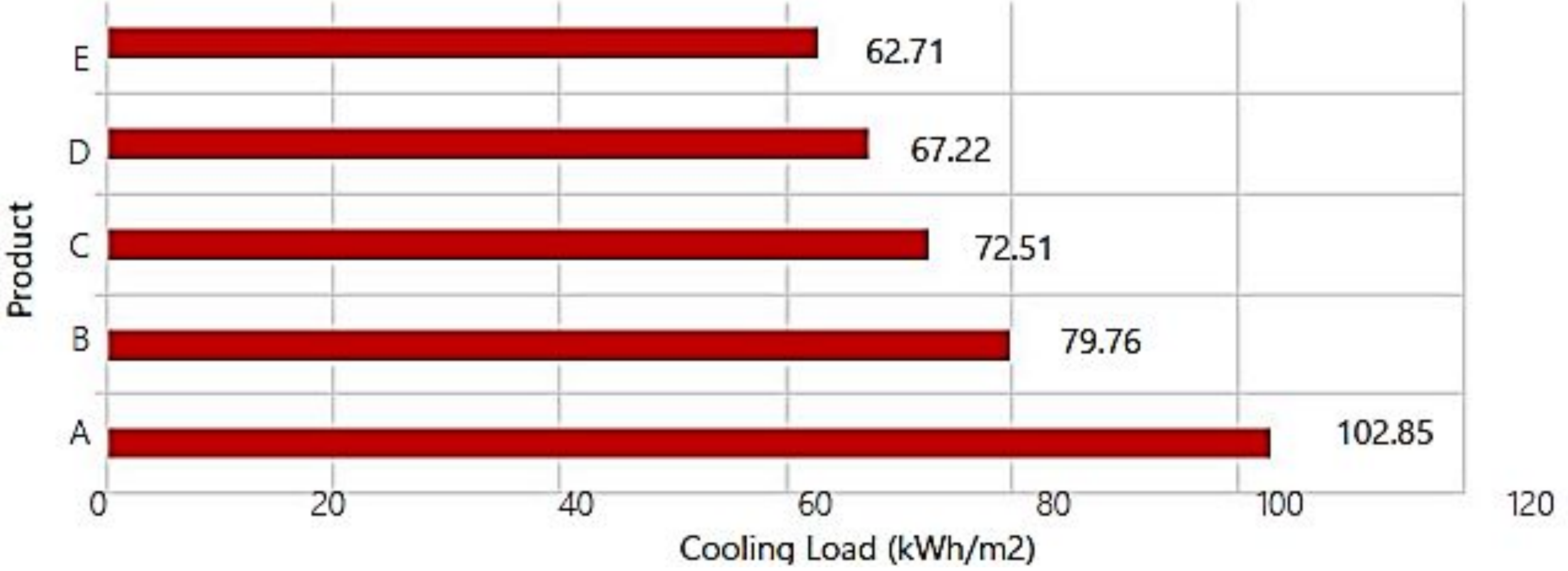
Performance of different low-e coating combinations in UV, visible light, and IR spectrums.

INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

Glazing assemblies

- Architects/ designers can utilize these graphs to determine the most suitable options in their projects.
- By knowing the maximum limit of solar heat gains permissible in the building, a cap on solar heat gain coefficient can be decided.

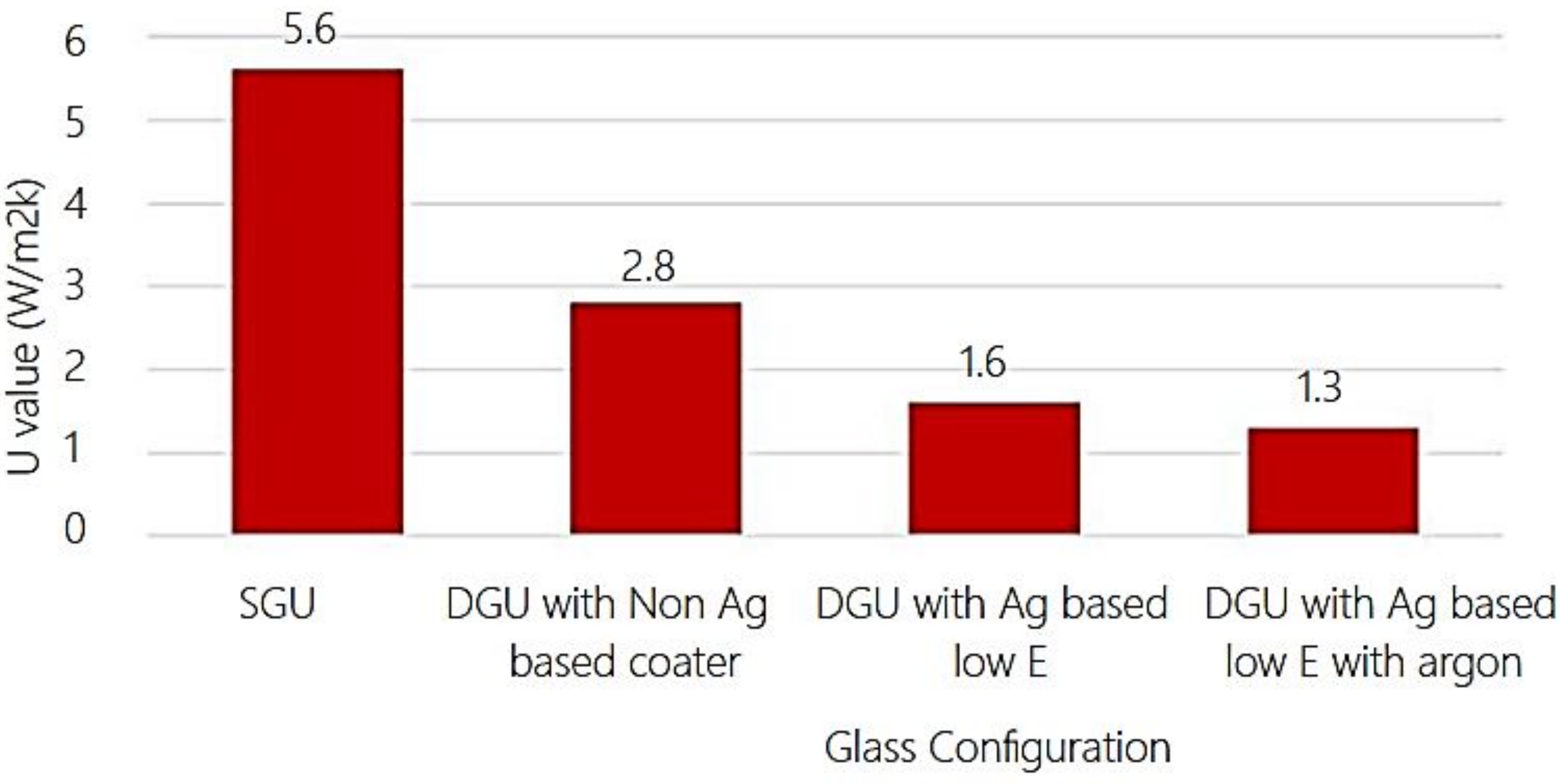
Product	VLT (%)	External Reflection (%)	Internal Reflection (%)	Solar Factor	Shading coefficient	U-value
A	80	15	15	0.76	0.87	2.6
B	46	16	18	0.22	0.25	1.5
C	46	20	22	0.47	0.54	2.8
D	51	18	22	0.28	0.33	1.5
E	47	17	11	0.38	0.43	1.9

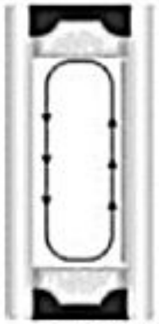


Cooling loads associated with different glazing units. Information and Image Courtesy: A.R Unnikrishnan, Saint Gobain Glass

INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

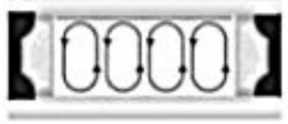
Glazing assemblies





U value: 1.1 W/m²K

U value: 1.5 W/m²K



U value: 1.7 W/m²K

U value based on glass & frame configuration; Right- Orientation of assembly with respect to horizontal affects U-value

GUIDANCE ON U- VALUE, SHGC AND VLT FOR FENESTRATIONS

Design Factors that impact on U-value, SHGC, VLT Etc..

1. Climate Analysis
2. Optimum Orientation of Building
3. Shadow Analysis
4. Daylight Analysis

Don't in Indian climatic Context

- Do not use glass with very low U value and moderate SHGC.
- Do not assume dark tinted glass brings solar control
- Do not use un-insulated frames

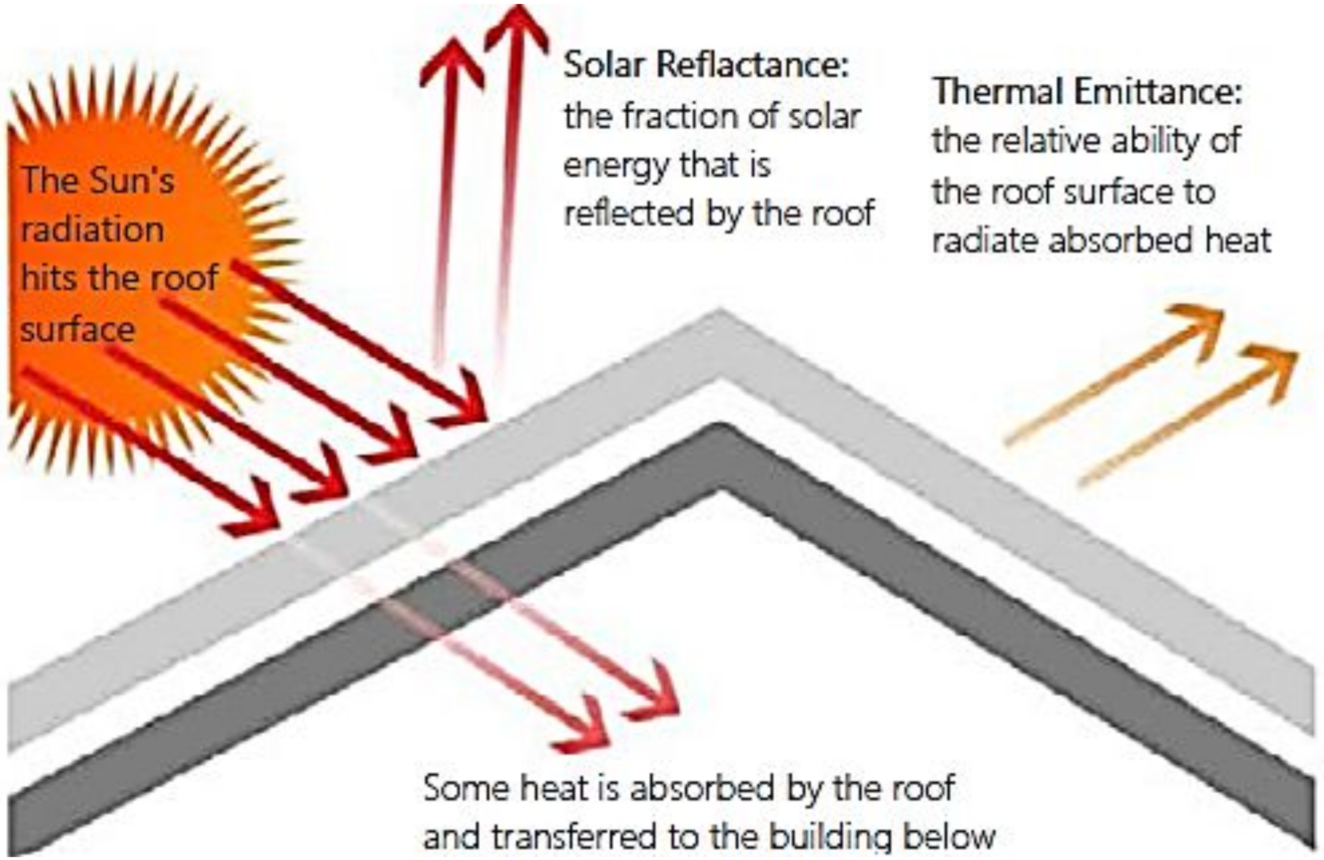
Dos in Indian climatic Context

- Products with least SHGC and U value and optimum VLT.
- Optimum set of values for U-value, solar heat gain coefficient, and visible transmittance.
- Add overhead shading, use dark tinted glass at visible height and clear at higher levels.

Note: *Remember that same fenestration product behaves differently w.r.t. the specific design. It should not be assumed that products with Low U-value and SHGC are best and universal solution.*

INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

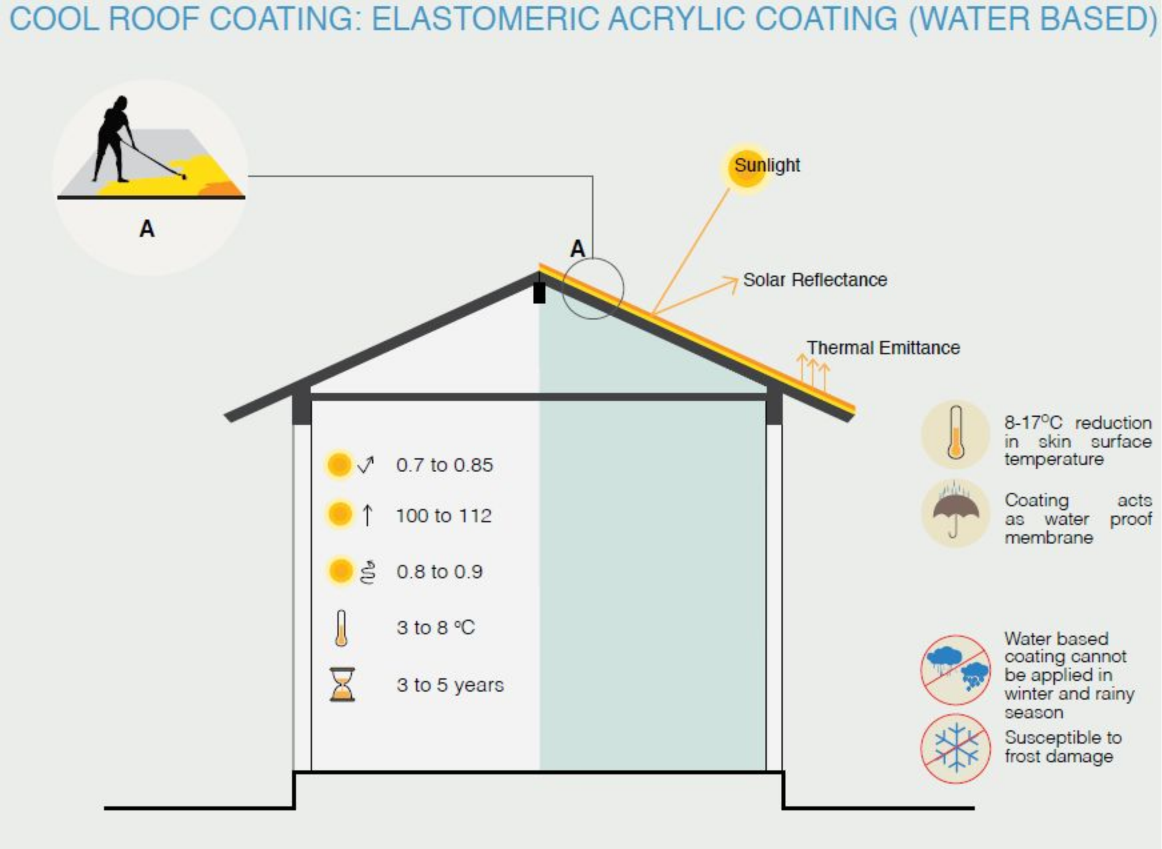
Roofing Coating Materials

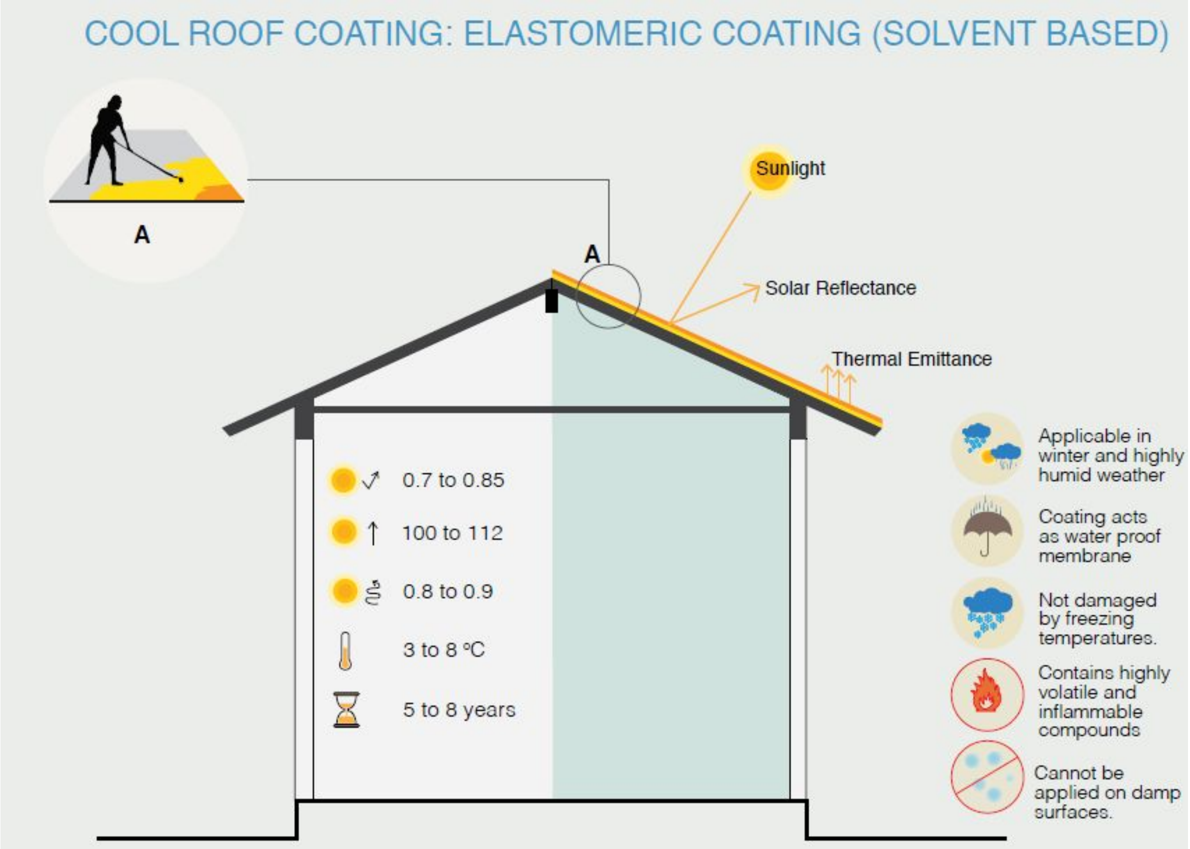


Interaction of roofing materials and surfaces with incident solar radiation.
Source (left): ASC Building Products. (2020). Energy-Efficient Cool Colours in Today's Metal Roofing. ASC Building Products. Retrieved from https://www.ascbp.com/cool-colors-and-energy-savings/.

INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

Roofing/Coating Materials





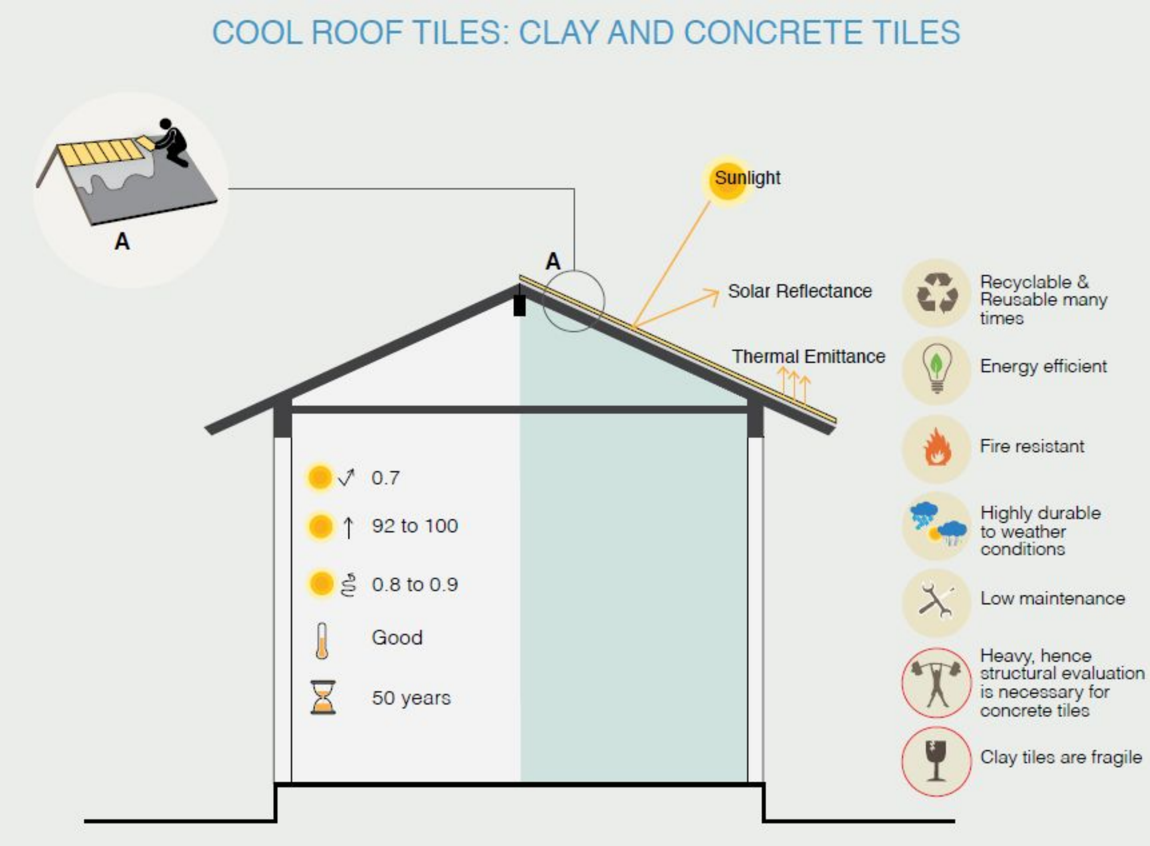
Elastomeric Coating Solvent & Water based

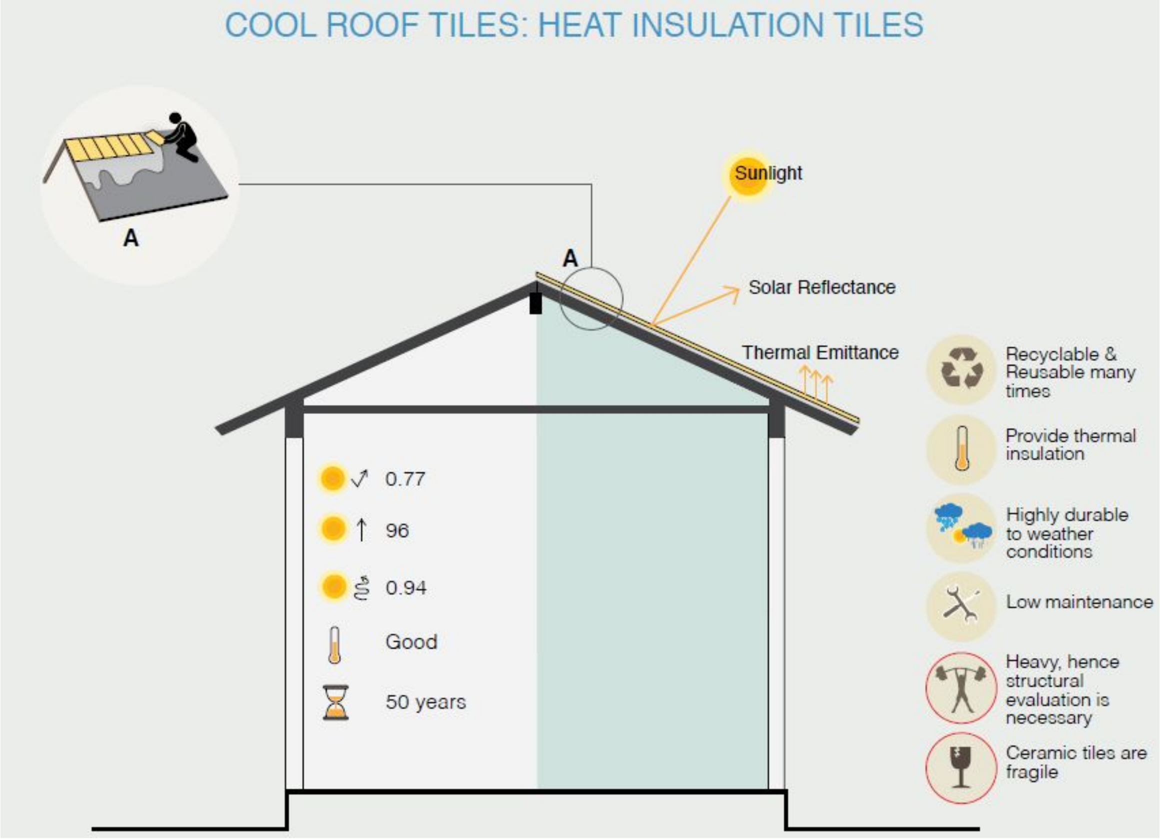
Source HANDBOOK ON ACHIEVING THERMAL COMFORT WITHIN BUILT ENVIRONMENT , VOLUME I

Ministry of Housing and Urban Affairs
Government of India

INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)

Roofing/Coating Materials





Spray Polyurethane Foam & Heat Insulation Tiles

Source HANDBOOK ON ACHIEVING THERMAL COMFORT WITHIN BUILT ENVIRONMENT , VOLUME I

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Pradhan Mantri Awas Yojana-Urban

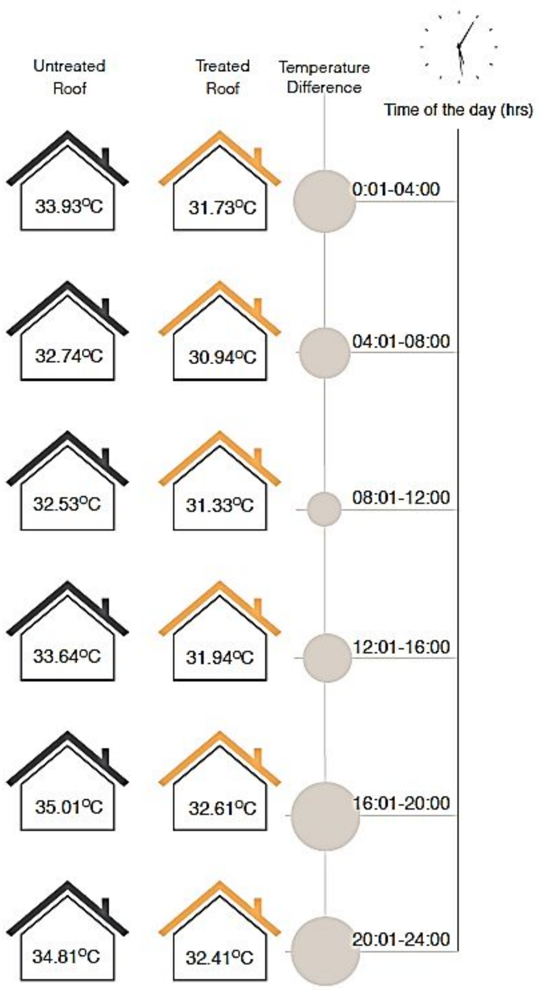
GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA

Ministry of Housing and Urban Affairs
Government of India

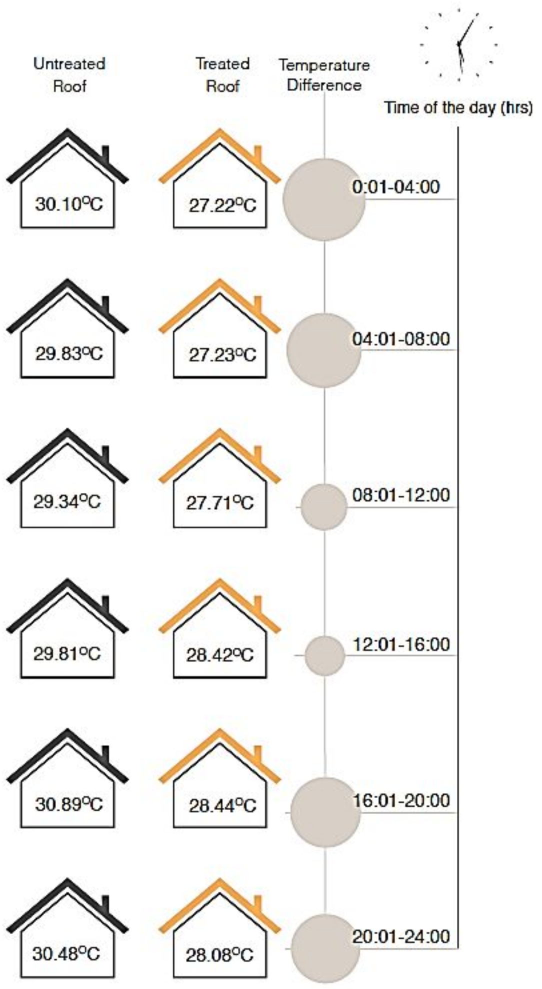
आज़ादी का अमृत महोत्सव

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

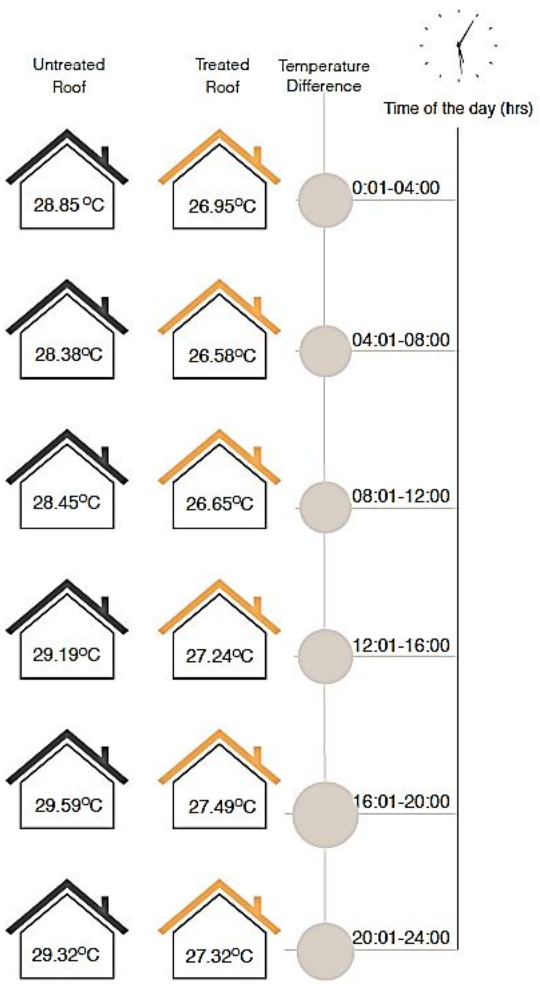
INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)



Clay Tiles



Lime Concrete



Inverted Earthen Pots

Heat Resistant Ceramic Tiles

Source HANDBOOK ON ACHIEVING THERMAL COMFORT WITHIN BUILT ENVIRONMENT , VOLUME I

प्रधान मंत्री आवास योजना-शहरी Pradhan Mantri Awas Yojana-Urban

GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA

Ministry of Housing and Urban Affairs
Government of India

आज़ादी का अमृत महोत्सव

bmtpc

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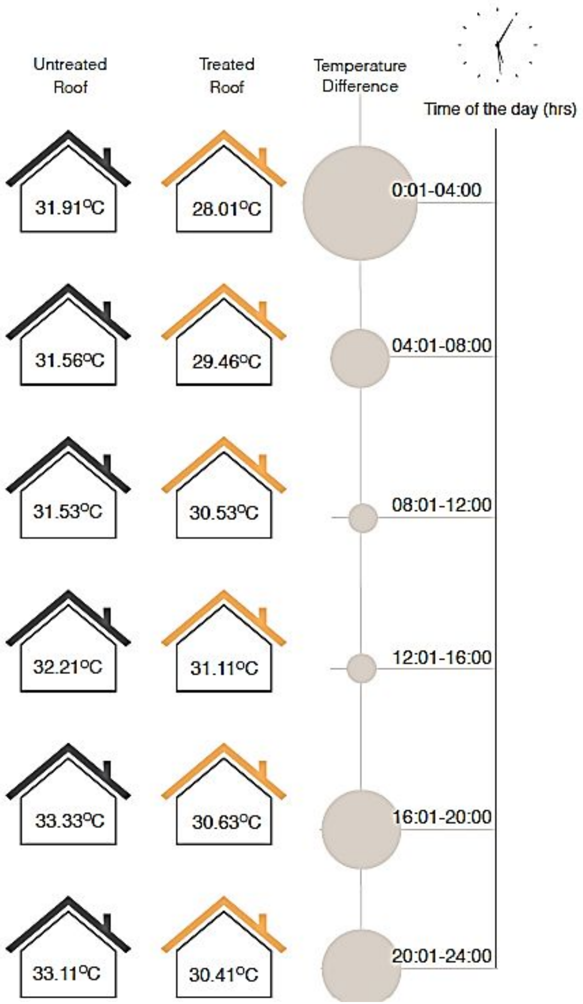
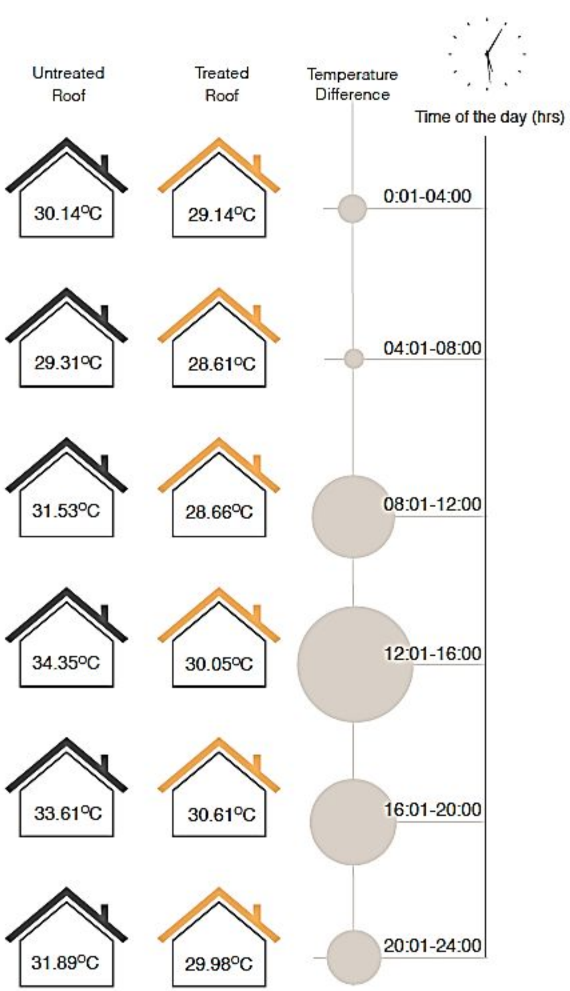
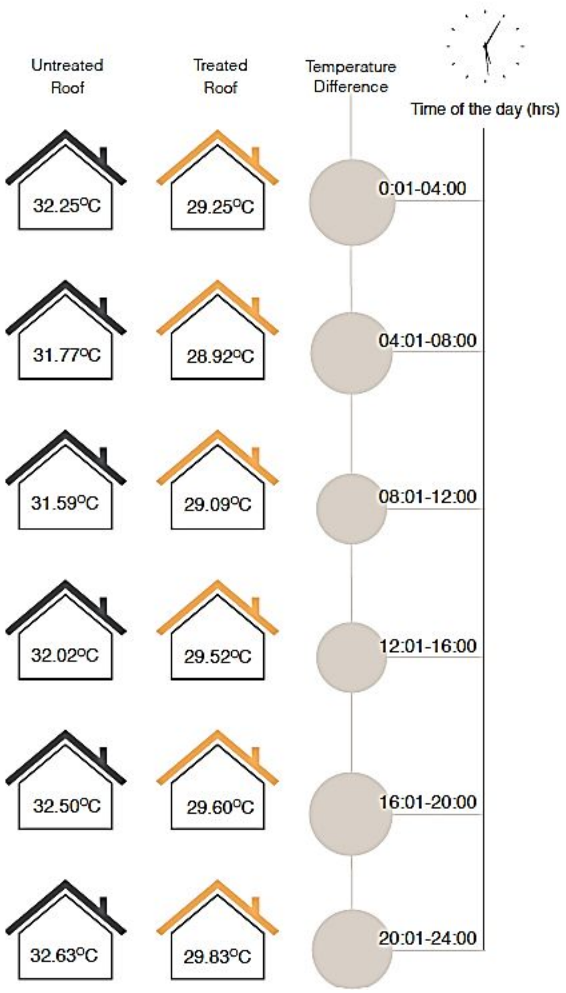
INNOVATIVE BUILDING MATERIALS (Wall, Glazing & Roof)



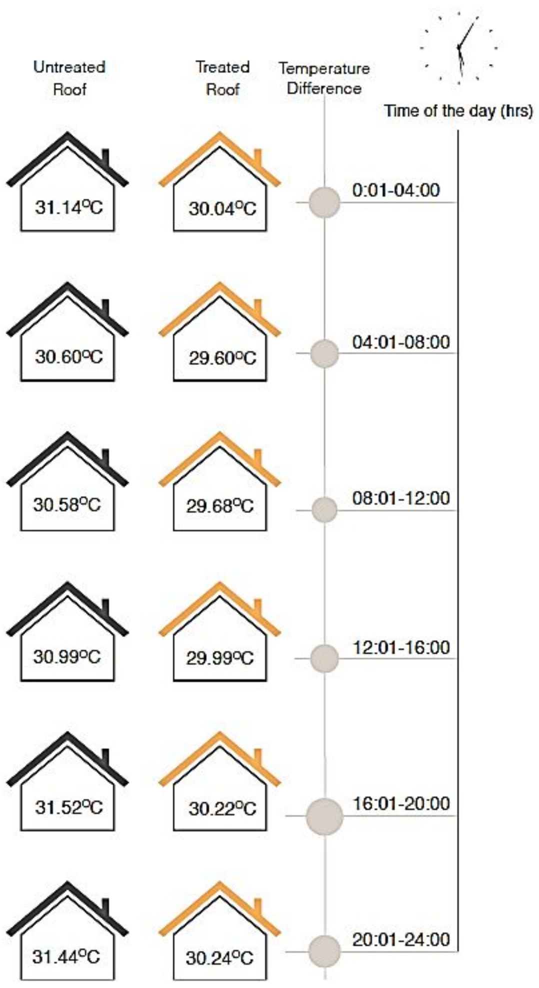
Cool Roof Paint



Bamboo Shading Screens



Green Mat Shading



China Mosaic Tiles

Source HANDBOOK ON ACHIEVING THERMAL COMFORT WITHIN BUILT ENVIRONMENT , VOLUME I

CASE STUDY- RAJKOT SMART GHAR III

RAJKOT SMART GHAR III

The climate of Rajkot is composite and the peak daytime temperatures during the summer reach 41°C-43°C.

Reducing heat gains through walls and roof:

Walling material was changed to 230mm thick AAC blocks. In doing so, the U-value of walls dropped to 0.8 W/SqmK from 2W/SqmK.

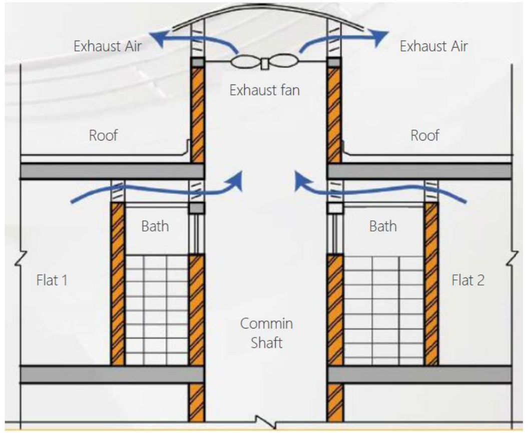
Improving Ventilation through shaft design:

A roof feature with exhaust fans on top of the shaft was added to create negative pressure in the shaft at all times

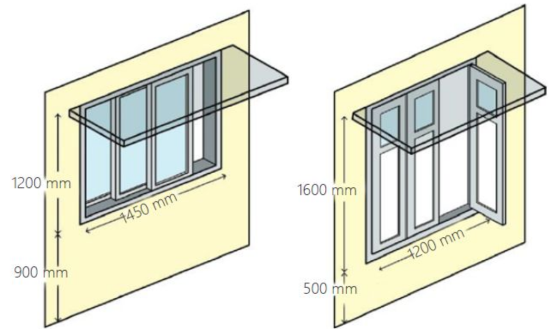
Reducing heat gains through window design and ventilation:

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.

Site layout for Rajkot Smart GHAR-III (PMAY) project.
Source: (Rawal, Shukla, Patel , Desai, & Asrani, 2021)



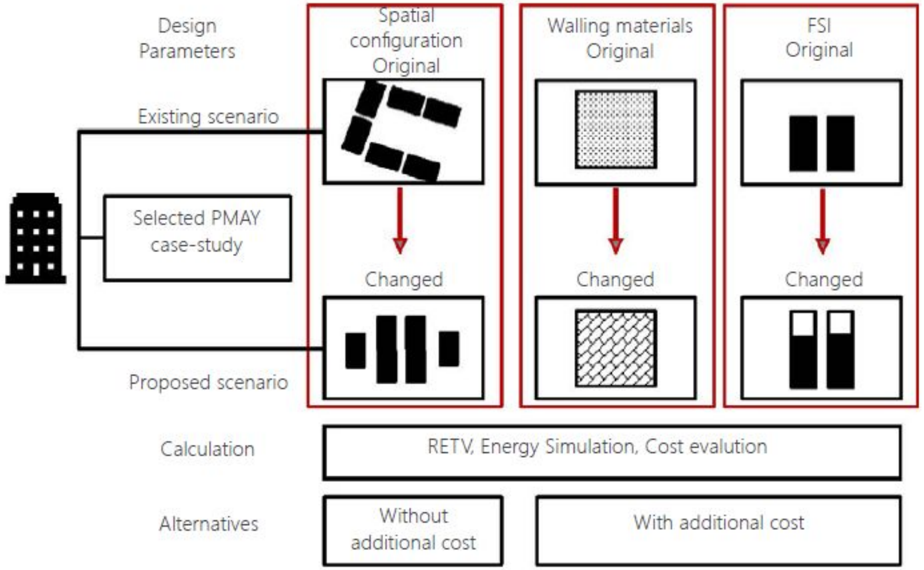
Improving ventilation through common service shaft.



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

CASE STUDY-SHREE RAM NAGAR COOPERATIVE HOUSING SOCIETY

SHREE RAM NAGAR COOPERATIVE HOUSING SOCIETY, AHMEDABAD (PMAY SITE)



No. of floors	4
Carpet Area (m²)	26.76
Building Material	Solid Concrete Block (100 mm thick)
U-value of building material (W/m² K)	4.15
RETV (W/m²)	29.46

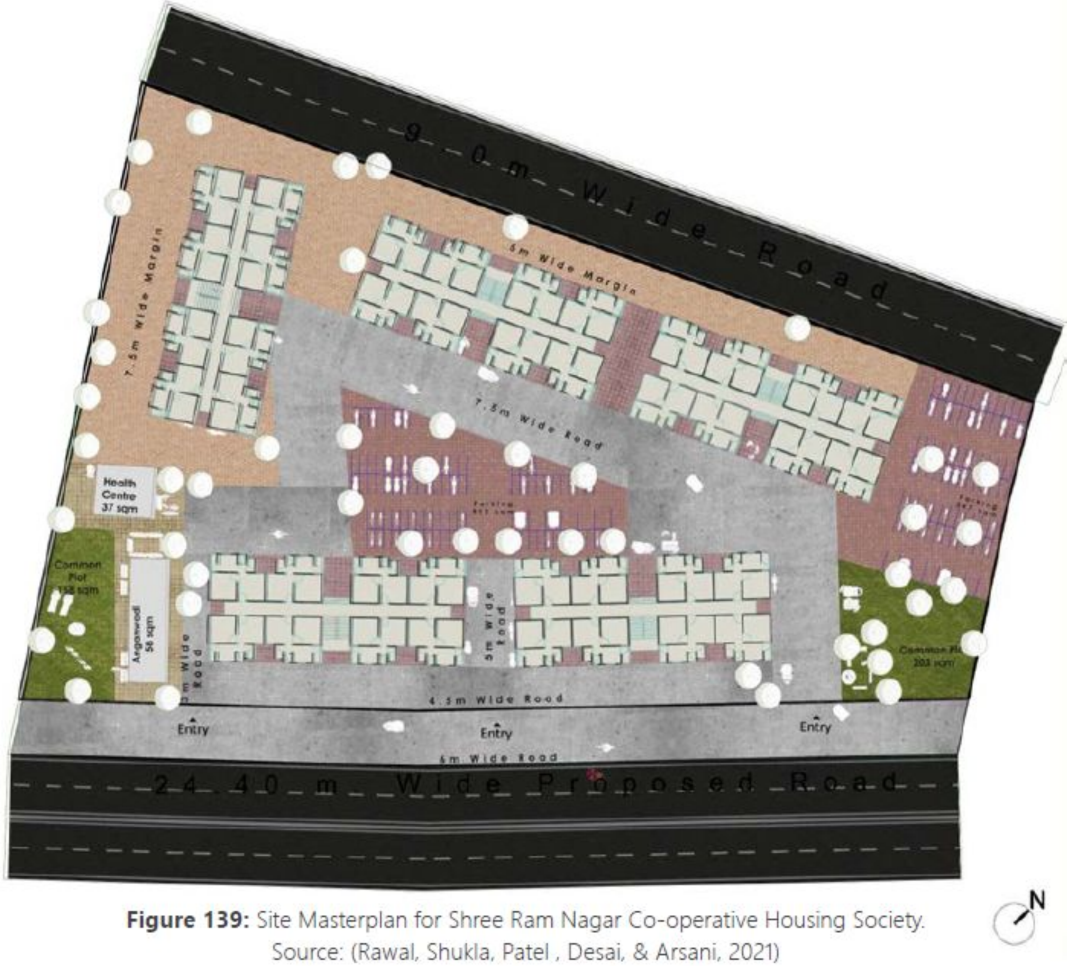


Figure 139: Site Masterplan for Shree Ram Nagar Co-operative Housing Society.
Source: (Rawal, Shukla, Patel , Desai, & Arsani, 2021)

CASE STUDY-SHREE RAM NAGAR COOPERATIVE HOUSING SOCIETY

SHREE RAM NAGAR COOPERATIVE HOUSING SOCIETY, AHMEDABAD (PMAY SITE)

Characteristics	Base Case – Existing layout	Case 1 – (Proposed) Re – oriented site	Case 3 – (Proposed) Re – oriented site + Increased FSI
No. of units	160	160	200
Utilized FSI area - % of permissible	64%	47%	58%
Common Plot Area - % of Plot Area	10%	13%	13%
Parking Area of % -utilized FSI area	21%	11%	12%
Parking Area of % -utilized FSI area	4.5 – 5.0 M	4.5 M	4.5 M

Table 32: Spatial site characteristics in cases 1, 2, and 3.

Case	Plot Area	No. of Floors	FSI			Common Plot Area		Parking Area	
			Available FSI	Permissible FSI Area (Sq.mt.)	Utilized FSI Area (Sq.mt.)	Required (Sq.mt.)	Provided (Sq.mt.)	Required (Sq.mt.)	Provided (Sq.mt.)
Case 1: Existing layout	5917 sq.mt.	G + 3	1.8	10561	6716.53	592	589.59	841.99	1235.56
Case 2 (Proposed): Re – oriented site		G + 3	1.8	10651	4900	592	750	539	547
Case 3 (Proposed): Re – oriented site + Increased FSI		G + 4	1.8	10651	6100	592	750	539	679

Case development.

CASE STUDY-SHREE RAM NAGAR COOPERATIVE HOUSING SOCIETY

SHREE RAM NAGAR COOPERATIVE HOUSING SOCIETY, AHMEDABAD (PMAY SITE)

Table 33: Comparison of RETV, EPI, discomfort hours, and cost differences for various walling material options in case 1

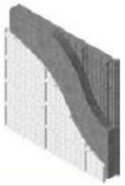
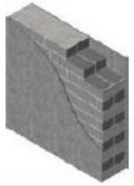
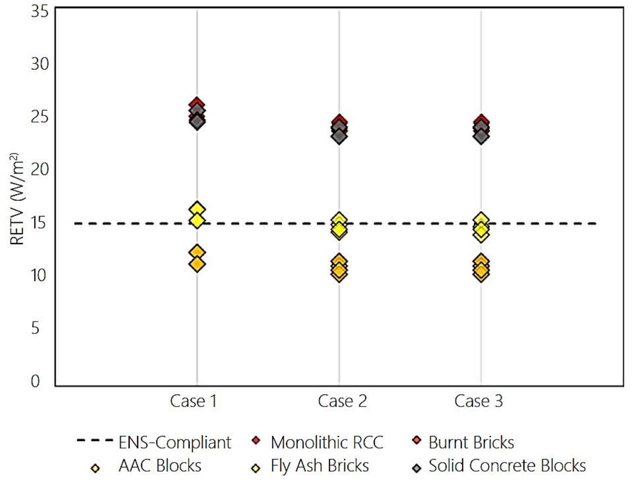
	Existing RCC (Mascon)	Burnt Clay Brick	Fly Ash Brick	AAC Block	Solid Concrete Block
					
Case	**Case 1**	**Case 1B 1**	**Case 1C 1**	**Case 1D 1**	**Case 1E 1**
Shading			Without		
RETV	26.00	16.62	16.34	12.35	25.48
EPI	75.92	48.53	47.71	36.06	74.40
Comfort hours	4760 - 7627	4887-8599	4716-8608	1874-8760	4618-8009
Difference in cost	₹ -	₹ -79,50,926	₹ -66,03,988	₹ -76,08,377	₹ +61,12,630
Case	**Case 1A2**	**Case 1B 2**	**Case 1C 2**	**Case 1D 2**	**Case 1E 2**
Shading			With 600mm overhangs		
RETV	24.95	15.56	15.28	11.29	25.47
EPI	72.85	45.44	44.62	32.97	71.74
Comfort hours	4815-7683	5230-8657	5147-8670	2943-8760	4671-8042
Difference in cost	₹ +46,072	₹-79,04,854	₹ -65,57,916	₹-75,62,305	₹ +61,58,702

Figure 142: (a)- Site plan for case 1; (b) Site plan for case 2 and 3

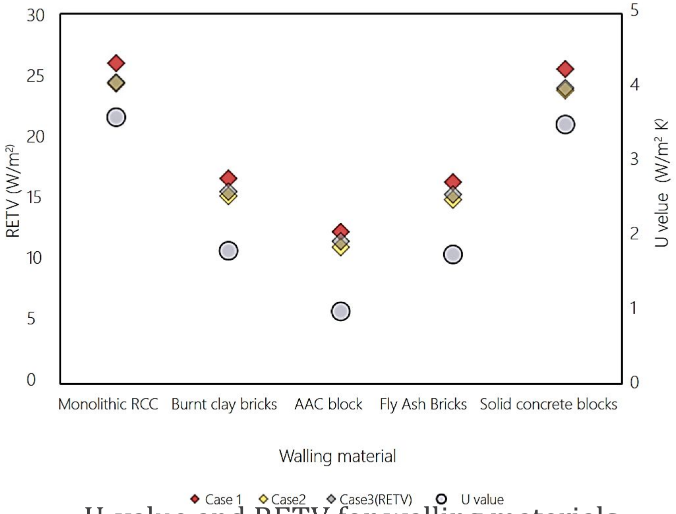
Reorientation and rearrangements of blocks.

CASE STUDY-SHREE RAM NAGAR COOPERATIVE HOUSING SOCIETY

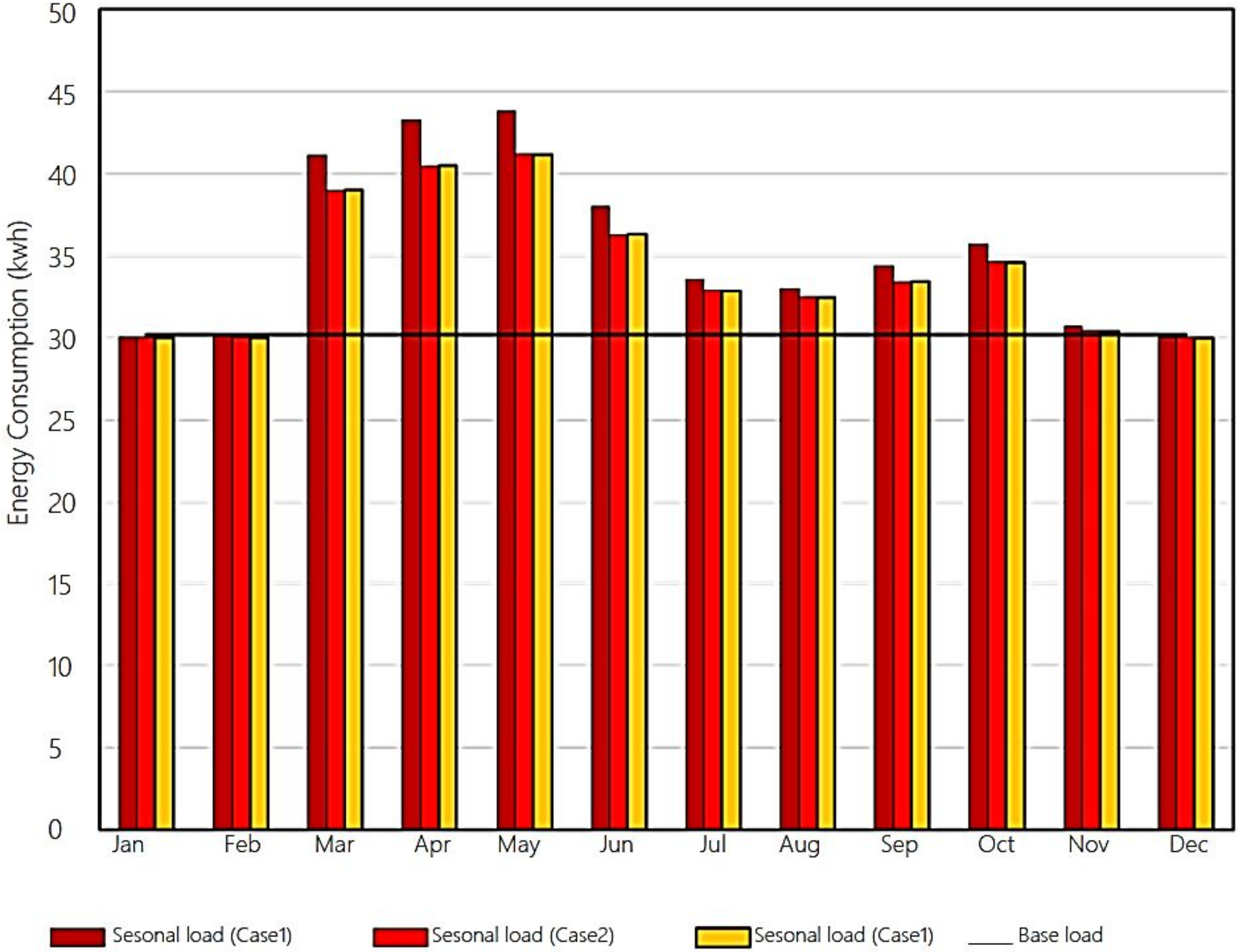
SHREE RAM NAGAR COOPERATIVE HOUSING SOCIETY, AHMEDABAD (PMAY SITE)



RETV as per walling materials



U-value and RETV for walling materials



THANK YOU!