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

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Innovative Construction Technologies & Thermal Comfort for Affordable Housing

RACHNA 2.0

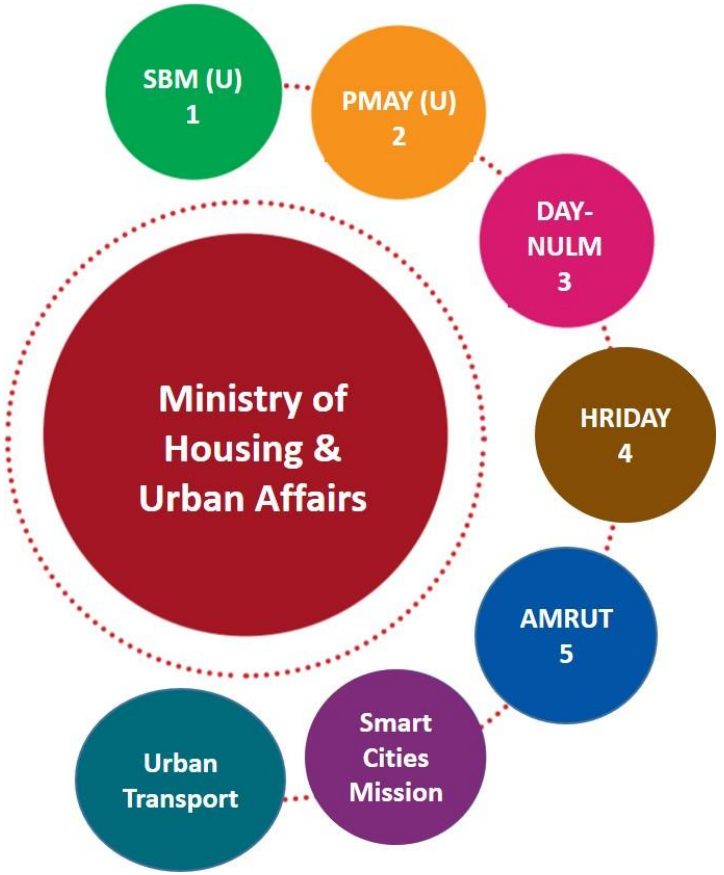
RESILIENT, AFFORDABLE AND COMFORTABLE HOUSING THROUGH NATIONAL ACTION

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 Yojana-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 Transformation

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 November 2022

Overall Sanctions for 1.23^ crore Houses

Construction of Houses (Nos in lakh)

Demand	Sanctioned	Grounded*	Completed/ Delivered*
112.24	122.69	106.01	64.60

Financial Progress (₹ in Cr)

Committed	Released	Expenditure	UC Received
2,03,427	1,27,584	1,17,408	1,17,260

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 Centers 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, at Rajkot.

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 the 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

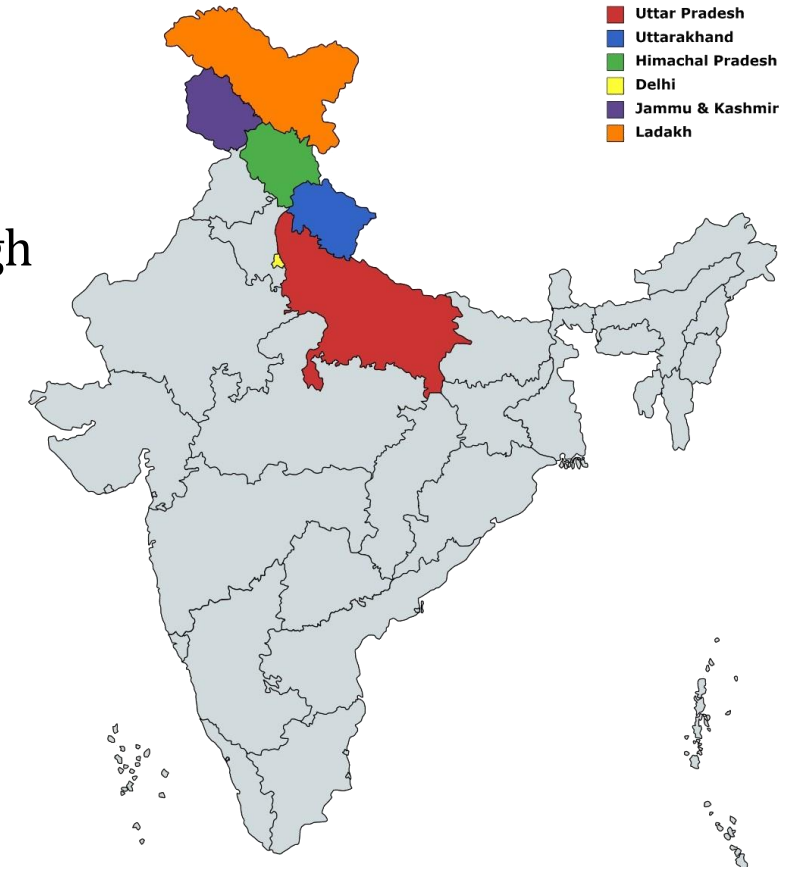
Ministry of Housing and Urban Affairs (MoHUA) aims to enhance climate resilience and thermal comfort in the affordable housing segment through GIZ under Indo German Energy programme (IGEN)'s programme, **Climate Smart Buildings (CSB)**.

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.



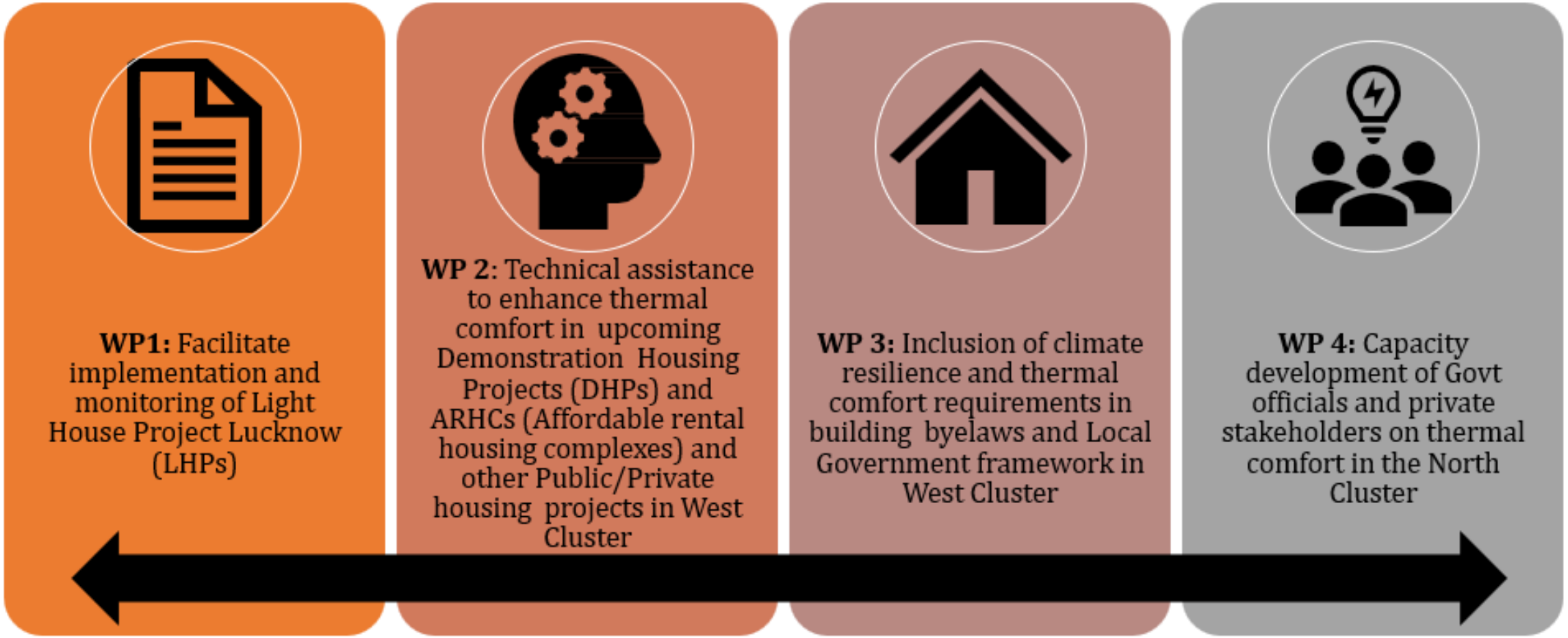
Goal:

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

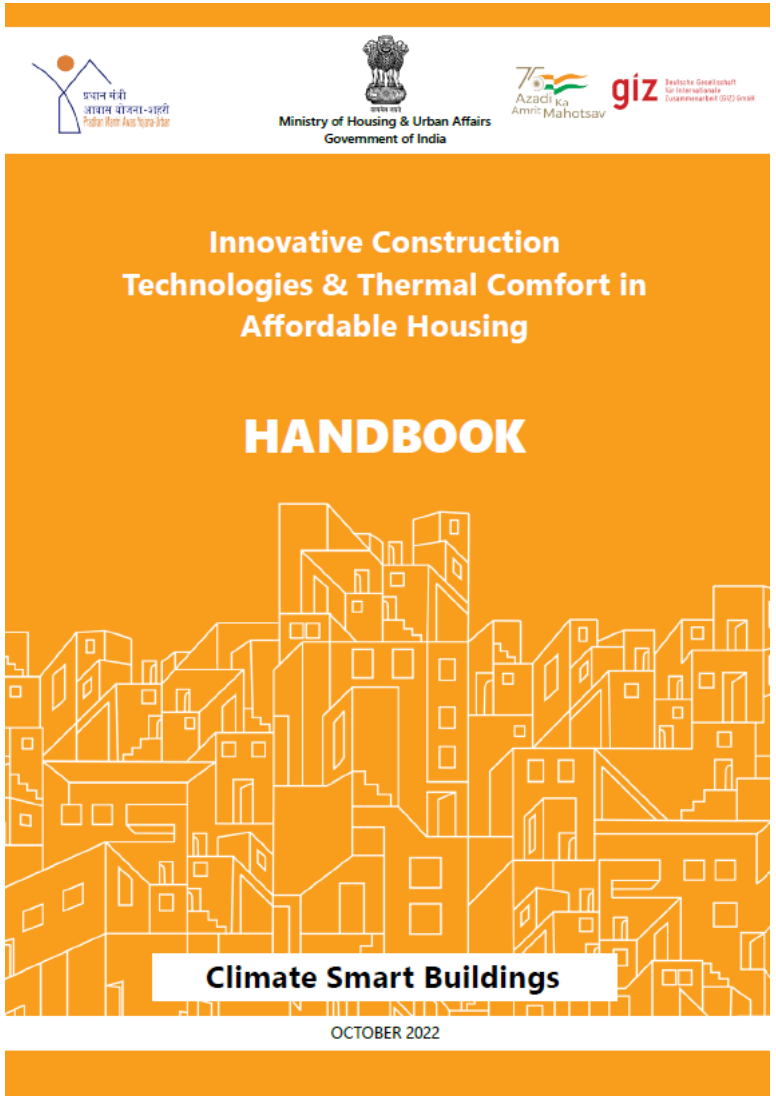
In the direction to achieve the goal of sustainability and thermal comfort in affordable housing, CSB Cell is working with following objectives:



Handbook: Innovative Construction Technologies & Thermal Comfort in Affordable Housing

A Handbook for training programmes on innovative construction technologies & Thermal comfort in Affordable housing was curated and launched by **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

1. Inception of Light House Project
2. Innovative construction technologies

AIM FOR THE INCEPTION OF LIGHT HOUSE PROJECTS

- **Light House Projects** have been conceptualized as part of **Global Housing Technology Challenge – India (GHTC-India)**
- 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.
- Construction of six **LHPs** with allied infrastructure and six categories of globally proven innovative technologies were envisaged in six different states.

CONCEPT OF LHP PROJECTS

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

- Serve as **live laboratories** for the transfer of technology to the field by, planning, design, production of components, construction practices, and testing.

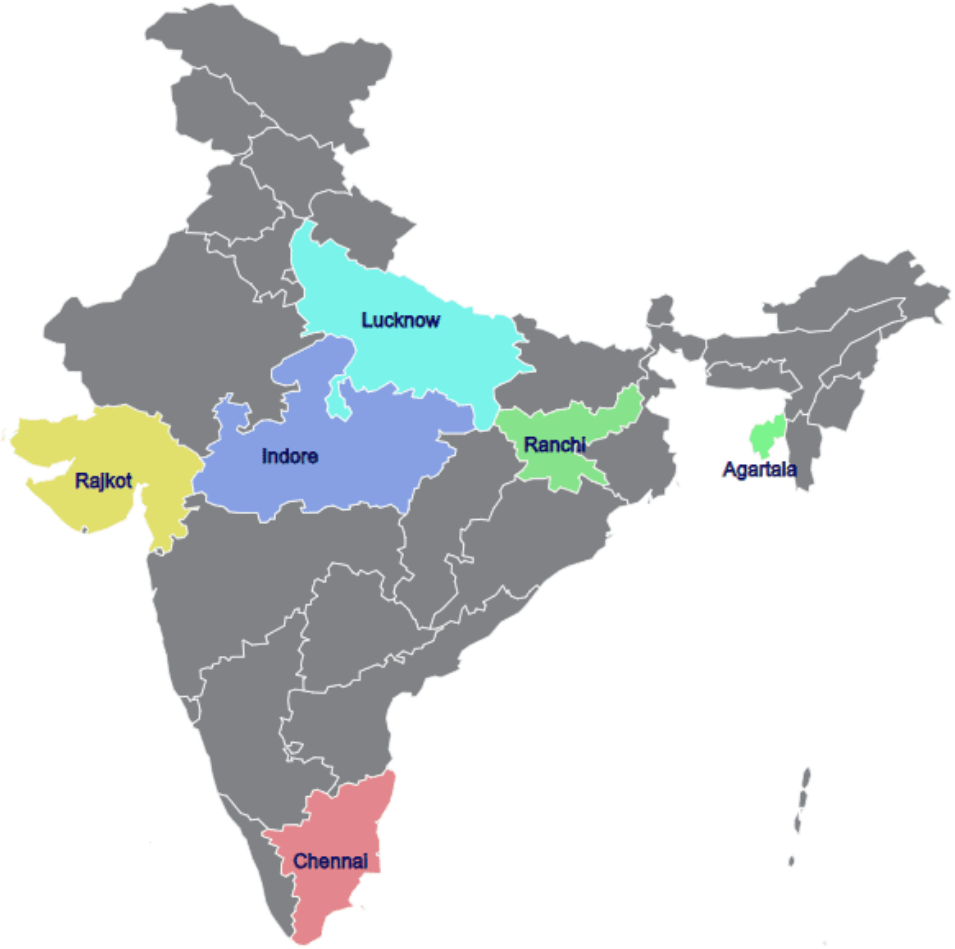
Live Lab for :

- ✓ ***Students,***
- ✓ ***Faculties,***
- ✓ ***Builder,***
- ✓ ***Professionals of Public and Private sectors, and other stakeholders, to create technical awareness for on-site learning.***

THE LIGHT-HOUSE PROJECTS- INDIA

Hon'ble Prime Minister Shri Narendra Modi laid the foundation stone of six Light House Projects (LHPs) each consisting of approx. 1000 houses on January 1, 2021, in six cities :

- **Indore** (Prefab Sandwich panel),
- **Rajkot** (Monolithic concrete construction using tunnel formwork)
- **Chennai** (Precast concrete construction system assembled at the site)
- **Ranchi** (Precast concrete construction system- 3d volumetric)
- **Agartala** (Light gauge steel and PEB)
- **Lucknow** (Stay in place formwork and PEB)

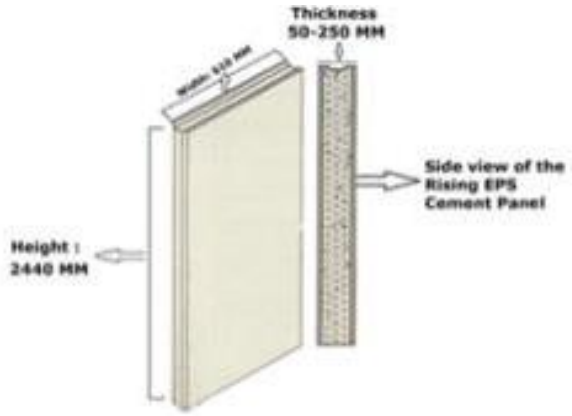


THE LIGHT-HOUSE PROJECTS: SUMMARY

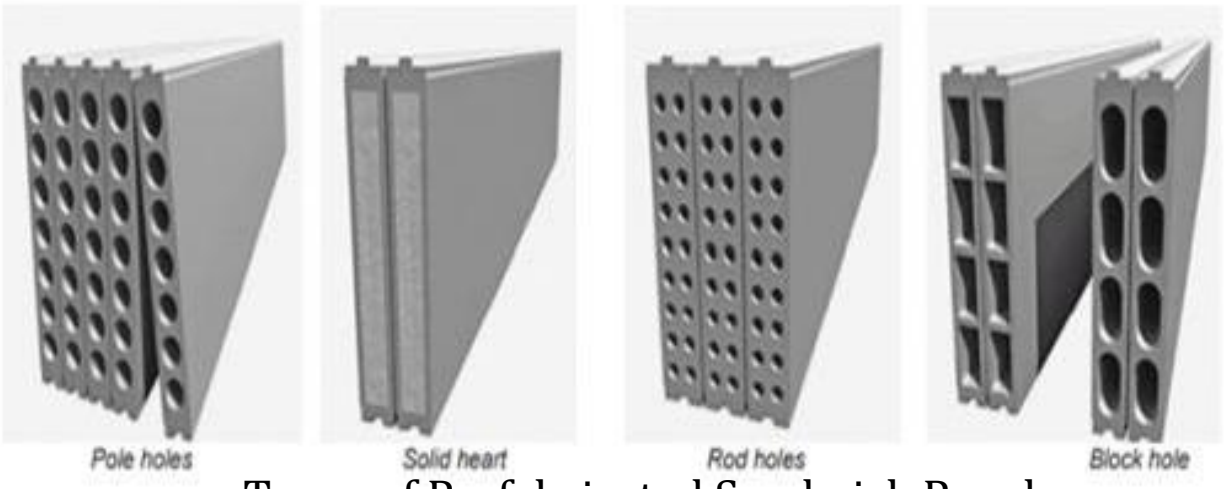
LHP Location			Chennai (Tamil Nadu)	Rajkot (Gujarat)	Indore (Madhya Pradesh)	Ranchi (Jharkhand)	Agartala (Tripura)	Lucknow (Uttar Pradesh)
Sl. No	Particulars	Units						
1	Name of Technology	Name	Precast Concrete Construction System- Precast Components	Monolithic Concrete Construction using Tunnel Formwork	Prefabricated Sandwich Panel System	Precast Concrete Construction System – 3D Volumetric	Light Gauge Steel Frame System (LGSF) with Pre-Engineered Steel Structural System	Stay in Place Formwork System
2	No. of Houses	No.	1,152	1,144	1,024	1,008	1,000	1,040
3	No. of Floors	No.	G+5	S+13	S+8	G+8	G+6	G+13
4	Plot Area	Sqm	33,596	39,599	41,920	31,160	24,000	20,000
5	Per House Carpet Area	Sqm	26.58	39.77	29.04	29.85	30.00	34.50
6	Project Cost	INR (in Cr)	116.27	118.90	128.00	134.00	162.50	130.90
7	Per House cost (with infrastructure)	INR (in Lakh)	10.09	10.39	12.50	13.29	16.25	12.58

LHP Indore-Prefabricated Sandwich Panel System

- Lightweight composite wall, floor and roof sandwich panels made of thin fibre cement or calcium silicate board as face covered boards.
- Core material is EPS granule balls, adhesive, cement, sand, fly ash and other 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 beams and columns.



Prefabricated EPS Sandwich Panel



Types of Prefabricated Sandwich Panels

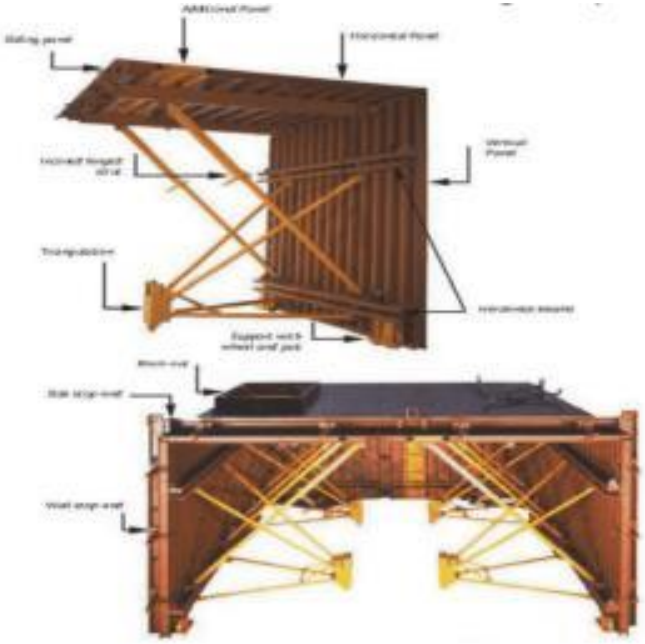
Steel Structure Prefabricated EPS Panel

LHP Indore-Prefabricated Sandwich Panel System

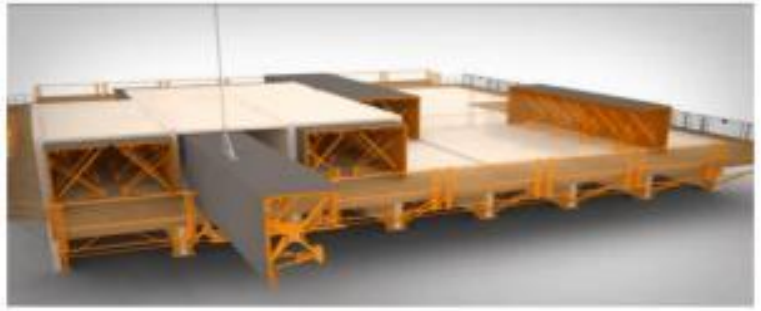
LHP Indore Explain by Video

LHP Rajkot- Monolithic Concrete Construction using Tunnel Formwork

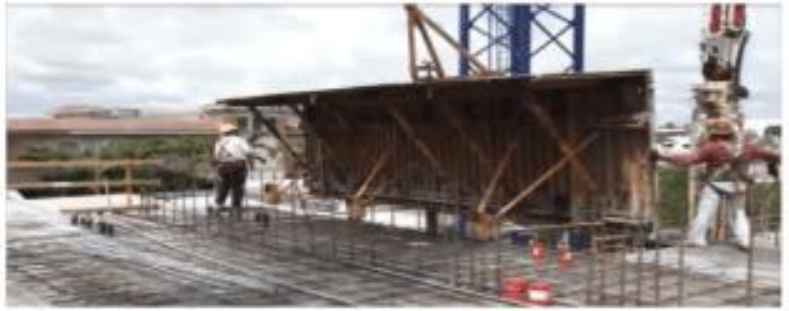
- Customized engineering formwork replacing conventional steel or plywood shuttering systems.
- Mechanized system for cellular structures.
- Two half shells which are placed together to form a room or cell.
- Walls and slab are cast in a single day.
- The formwork is stripped the next day for subsequent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



Tunnel Formwork



Box out of door and windows



Kicker form of tunnel formwork panel

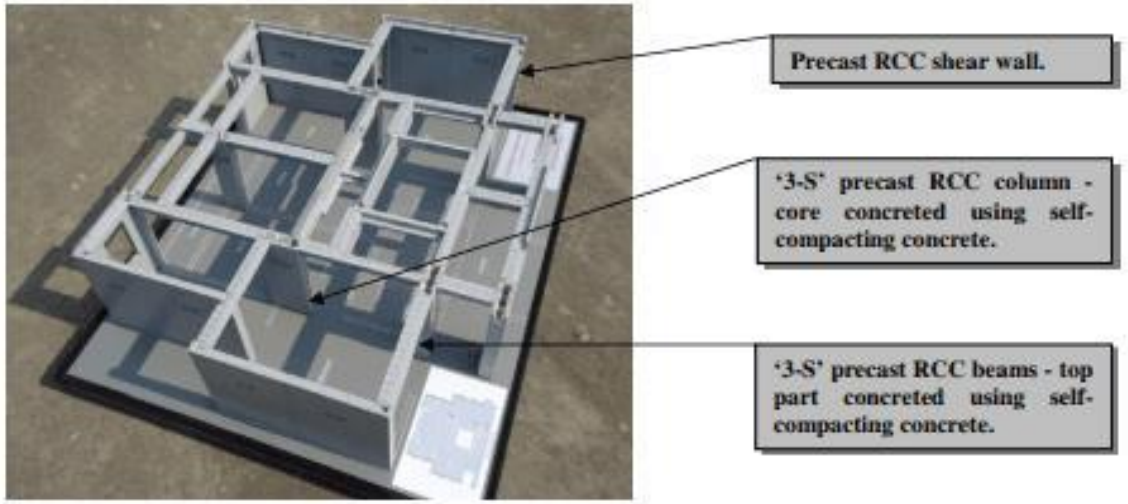
Monolithic Tunnel Formwork Panel

LHP Rajkot- Monolithic Concrete Construction using Tunnel Formwork

LHP Rajkot Explain by Video

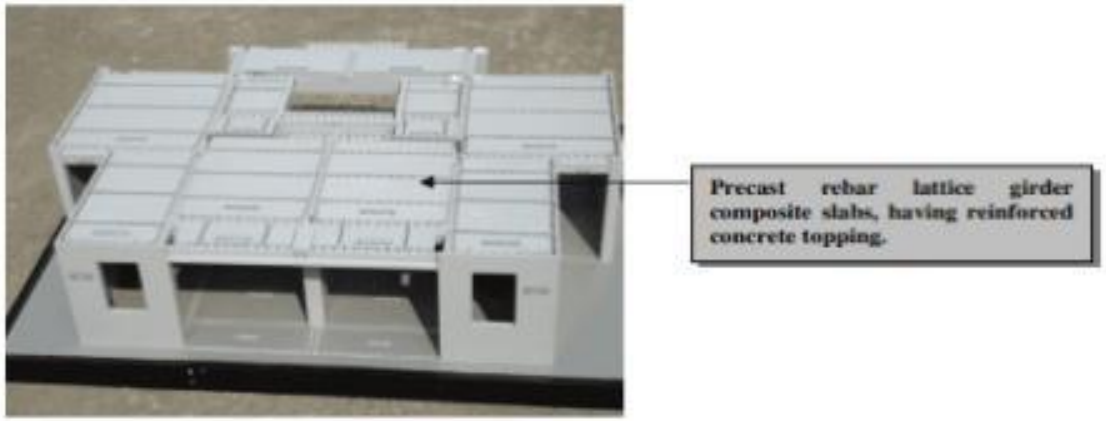
LHP Chennai-Precast Concrete Construction System Assembled at Site

- 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.



Installation of panels

Precast concrete wall (Panels)



LHP Chennai-Precast Concrete Construction System Assembled at Site

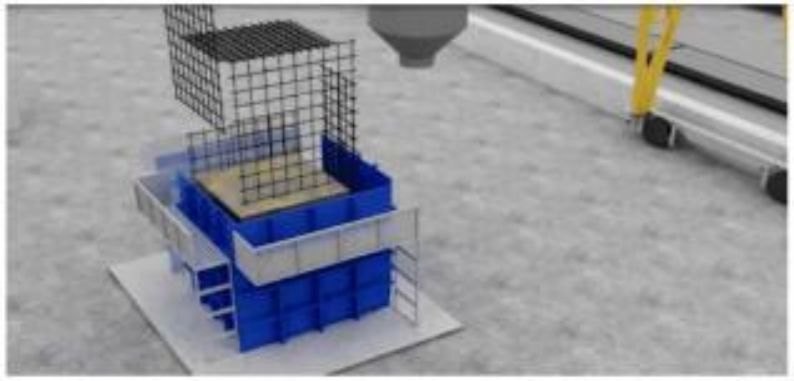
LHP Chennai Explain by Video

LHP Ranchi- Precast Concrete Construction System – 3D Volumetric

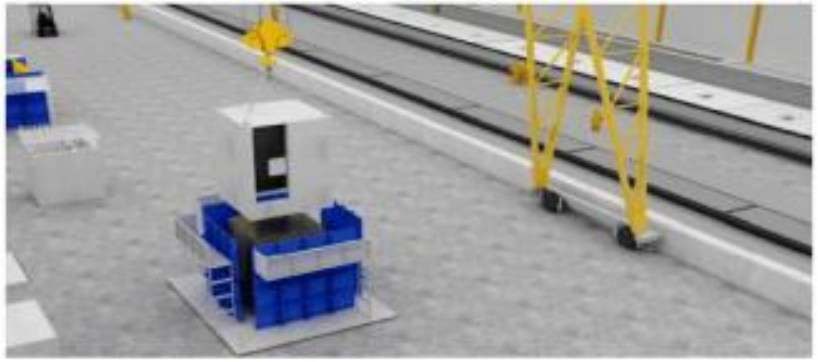
- Components like room, Bathroom, Kitchen etc are cast monolithically in Plant or Casting yard in a controlled condition.
- Magic Pods (Precast Components) are transported, erected & installed using cranes .
- Prestressed slabs are installed as flooring elements.
- Consecutive floors are built in similar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

Transportation of Magic Pods

Construction and installation



Pre Casting of building modules



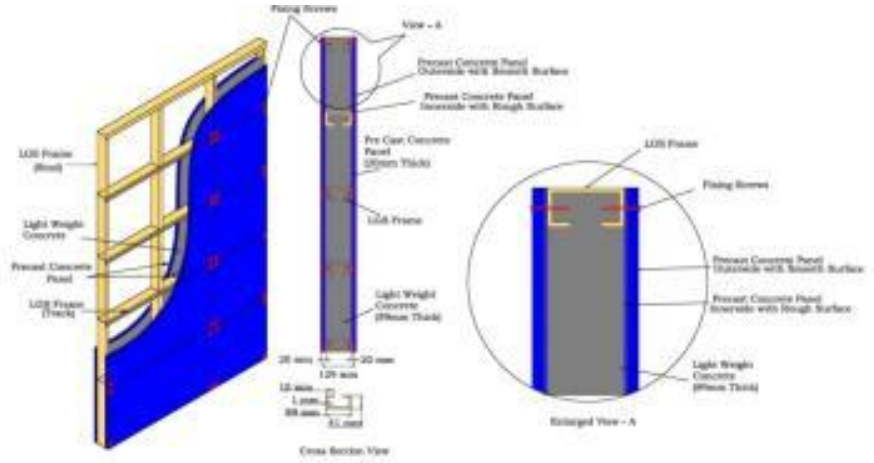
Pre Casting of building modules

LHP Ranchi- Precast Concrete Construction System – 3D Volumetric

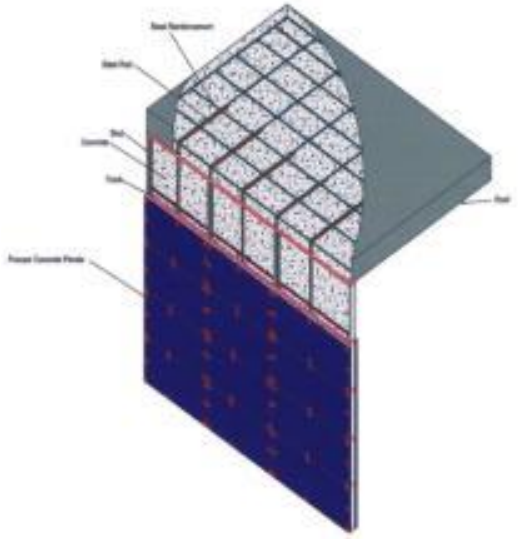
LHP Ranchi Explain by Video

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 Agartala- Light Gauge Steel Framed Structure with Infill Concrete Panels (LGSFS-ICP)

LHP Agartala- Light Gauge Steel Framed Structure with Infill Concrete Panels (LGSFS-ICP)

LHP Agartala Explain by Video

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 Details:

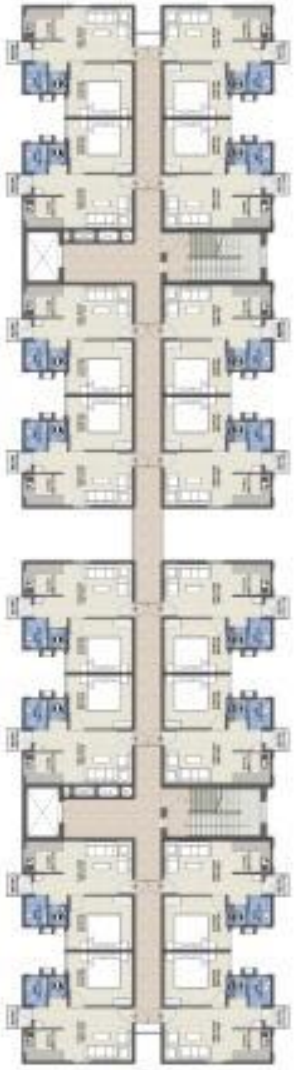
Technology Used: Stay In Place PVC Formwork with PEB Steel Structure
Plot area : 20,036 sq.mt.
Carpet area of each DU : 34.51 sq.mt.
No. of Floors: S+13
No. of DUs: 1024
No. of Blocks: 4
Community Hall
Commercial Block

Amenities:

Rooftop Solar PV/Solar Street lights
Sewage Treatment Plant
Under Ground water reservoir
Rainwater Harvesting
Solid Waste Management
Elevator
Emergency Power Backup
Fire Fighting System

LHP LUCKNOW- PROJECT PLAN

SITE PLAN



TYPICAL FLOOR PLAN

Unit Plan

LHP LUCKNOW- PROJECT PLAN

LHP Lucknow Aerial View

LHP Lucknow- Technology

- SIP formwork is an advanced hybrid construction technology consisting of rigid polyvinyl chloride-based polymer panel infilled with self-compacting concrete in a building envelope.
- In this wall system PVC panel is used as a permanent stay-in-place finished formwork instead of concrete walls.
- Hot rolled Pre-Engineered building steel sections act as a structural framework of the building.
- SIP formwork works as a partition of building walls.



LHP Agartala- Light Gauge Steel Framed Structure with Infill Concrete Panels (LGSFS-ICP)

LHP Lucknow Explain by Video

LHP Lucknow- Construction Methodology

Foundation

RCC Raft Foundation by conventional method

PEB Structure

Hot rolled Steel Section

Deck Slab

0.9 mm thick GI sheet. Reinforcement and deck slab casting

Panel Placement

Individually placed by sliding and interlock

Panel Reinforcement

8 mm steel bar used in 250x250 mm mesh

Electric & Plumbing Ducts

Ducts must be places before the concreting

Concrete Pouring

Self-compacting concrete is used as infilled material in PVC SIP panel

Finishing

Door
Window
False Ceiling
Electrical & Plumbing Services

LHP Lucknow- Foundation

- Conventional as per geo-technical investigations, bearing capacity, soil strata, water table, etc.
- Raft foundation with RCC column up to plinth height.
- RCC plinth beam and grade slab at plinth level.

LHP Lucknow- Foundation

- Reinforcement and shuttering for raft foundation

LHP Lucknow- Foundation

- All building blocks have Raft foundation with 500 mm thick M-25 Concrete.
- **An additional thickness of 400 mm has been constructed around staircase and lift well.**

LHP Lucknow- Foundation

- Columns of M25 Grade Concrete are being cast upto plinth height over already laid cured raft.

LHP Lucknow- Foundation

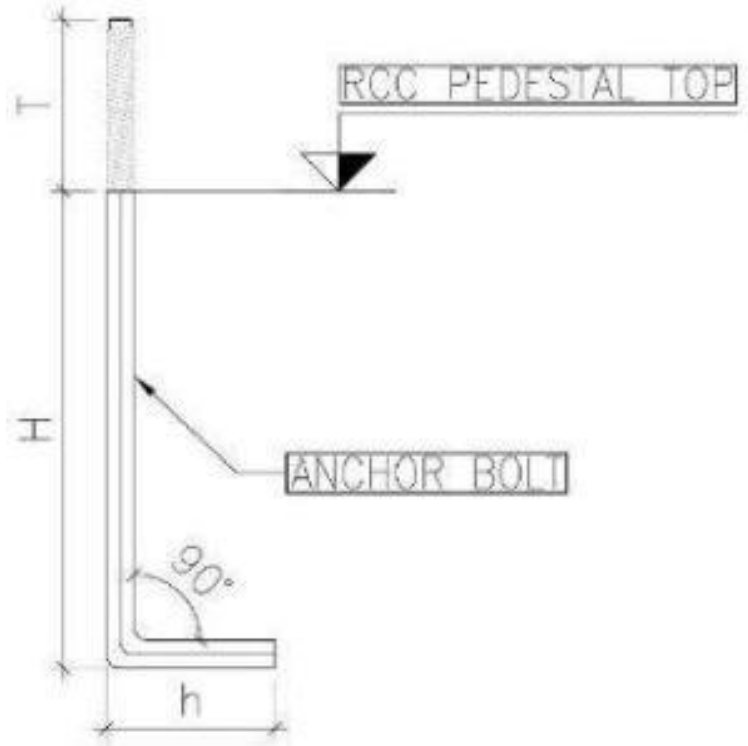
- Back filling with soil and water in layers of 200 mm with proper compaction.

LHP Lucknow- Foundation

- Anchor bolts have been cast with concrete at plinth level over which factory made built up columns with base plate will be erected.
- The reinforcement laying & shuttering work is in progress for shear wall construction of lift & staircase portion.

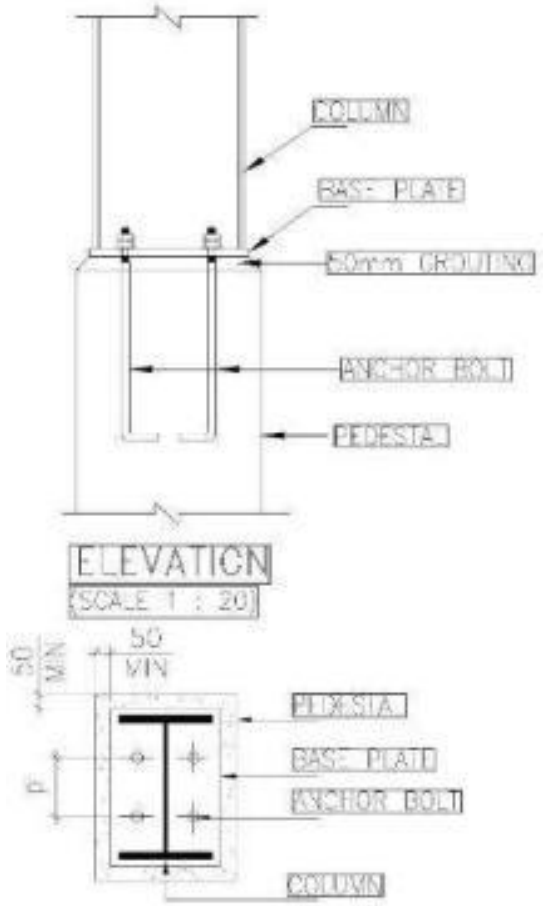
LHP Lucknow- Structure

- Connection details of built up steel column at plinth level (Stilt) with foundation (plinth beam)



Typical anchor bolt detail

Anchor bolt is inserted below plinth level upto height H and projected above plinth up to height "T".



Typical base plate detail

The built up steel I column is being fixed with anchor bolts and base plate

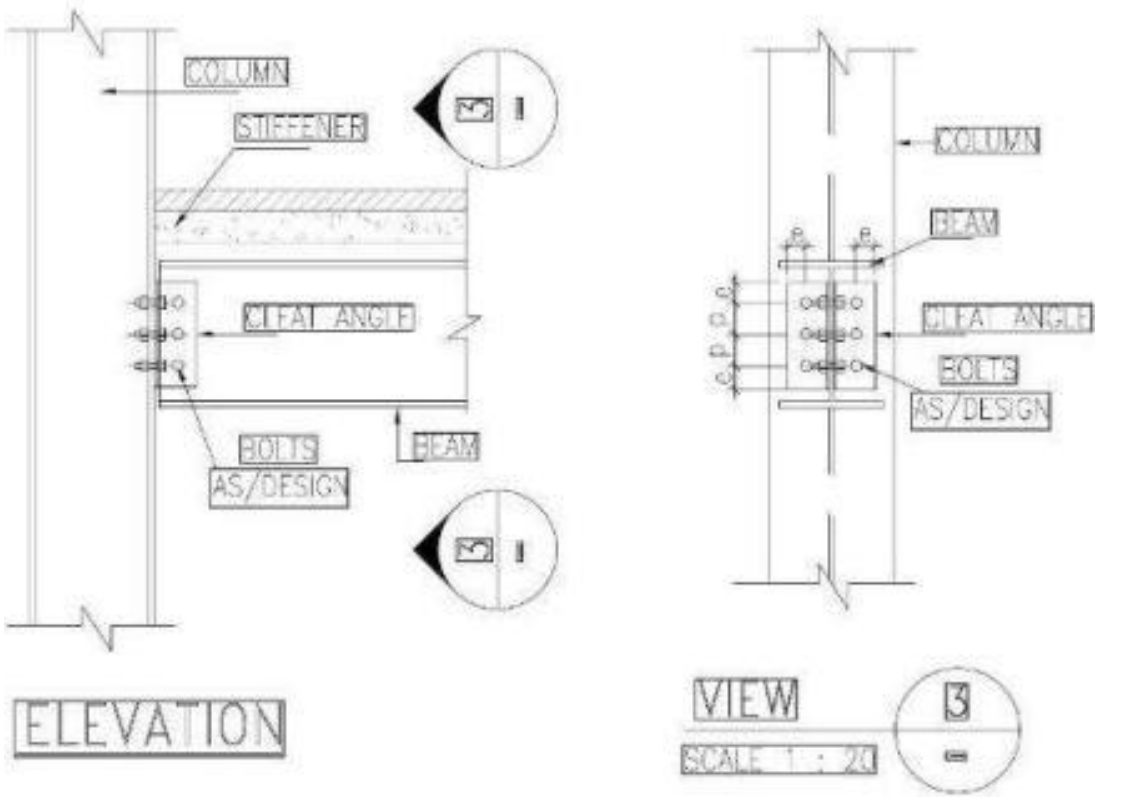
Dia (mm)	H (mm)	h (mm)	T (mm)
16	400	100	100
20	500	100	100
24	600	100	150
27	700	100	150
30	800	100	150

Anchor bolts schedule

LHP Lucknow- Structural System

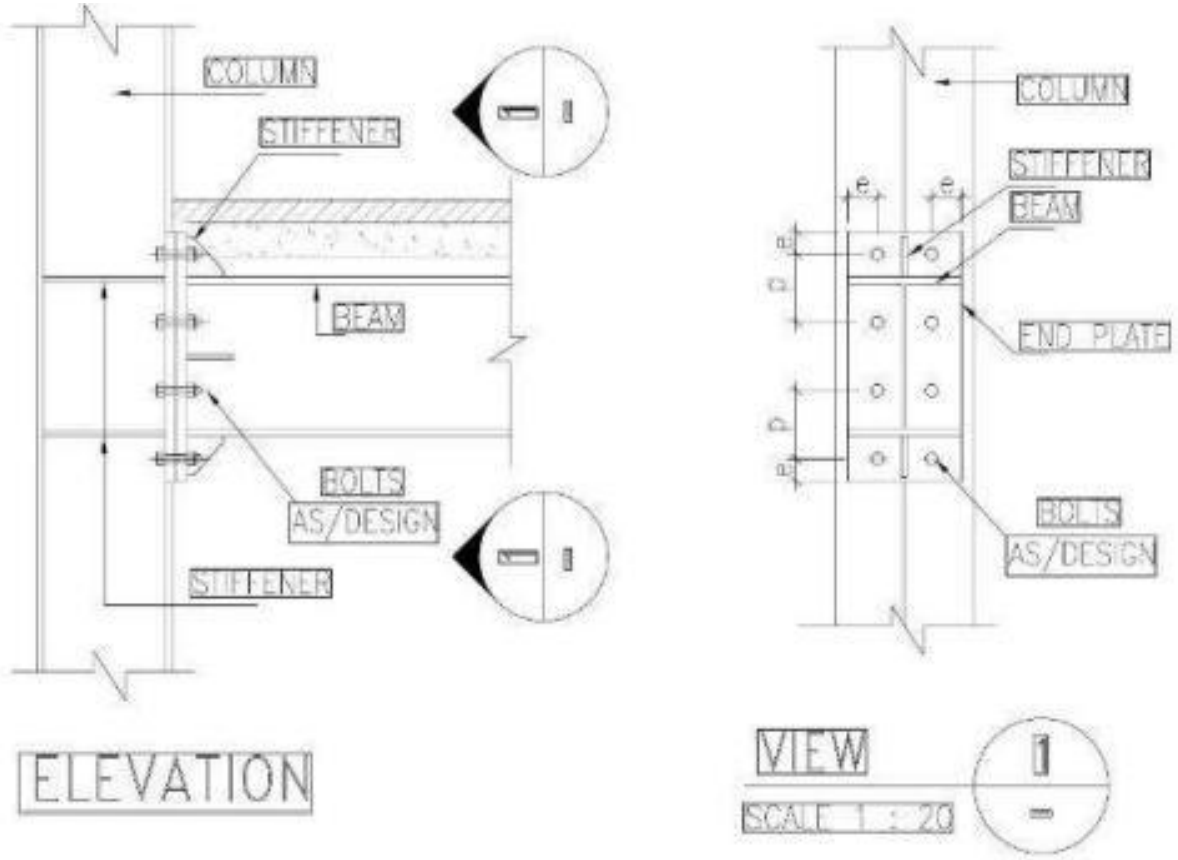
- Pre-Engineered Building system comprising of built-up fabricated I sections for beams and columns

LHP Lucknow- Structure



Typical beam to column flange shear connection

Steel beam is being connected to the column through cleat angle connected to the web portion of beam



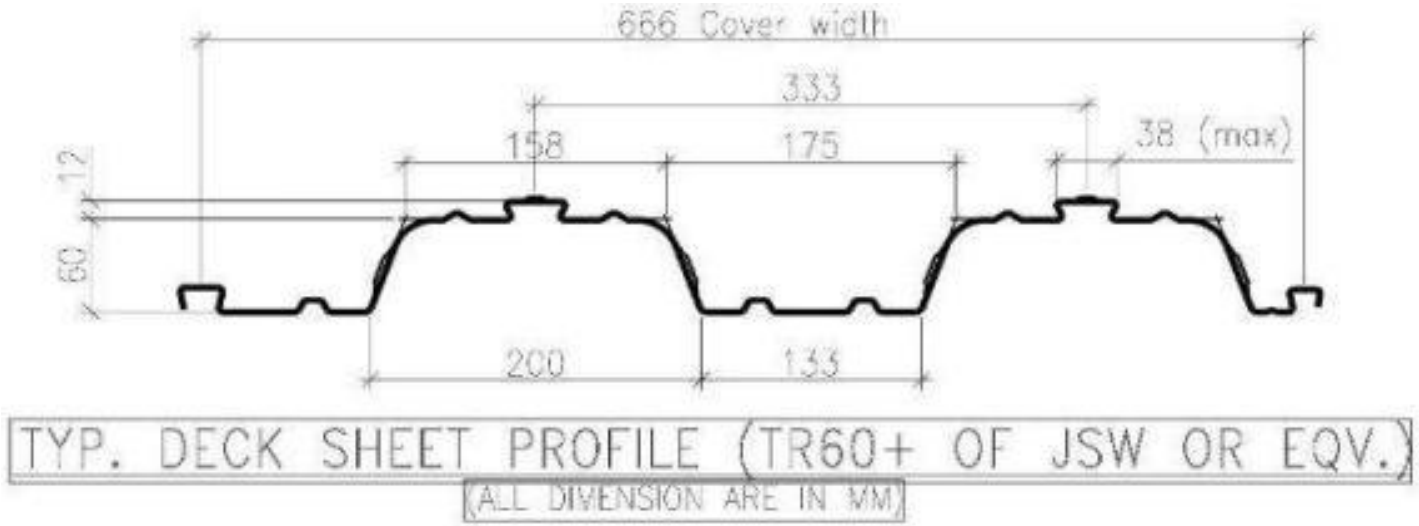
Typical beam to column flange moment connection

The steel beam is being connected to column through plates on flange & web portion

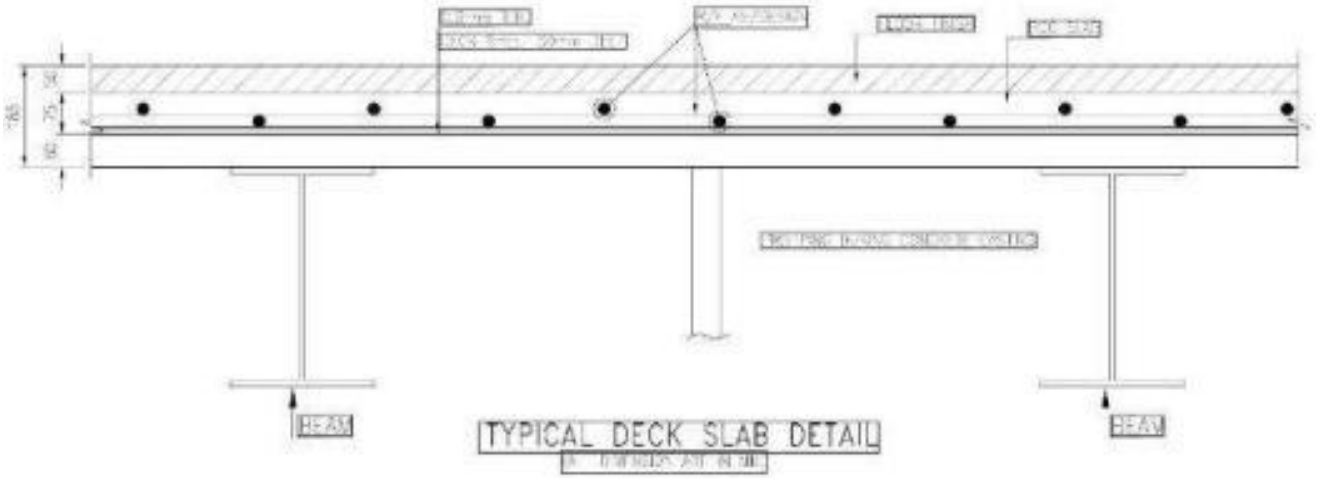
LHP Lucknow- Erection of Steel Structure

LHP Lucknow- Deck Slab

- After erection of steel beams and column (PEB Structure), steel deck sheet of thickness 0.9 mm are placed with required bearing on the beams.
- Concrete screed of 75 mm is poured on the deck sheet in M25 with reinforcement as per structural design.
- Structural design for reinforcement is as per IS 456-2000.
- Generally, nominal reinforcement is provided in concrete screed of deck slab to take care of shrinkage & cracking.



Typical deck sheet profile



Typical deck slab detail

LHP Lucknow- Deck Slab

LHP Lucknow- Deck Slab

LHP Lucknow- Wall Erection

LHP Lucknow- Wall Erection Process

LHP Lucknow- Wall Erection Process

LHP Lucknow- Reinforcement in Walls

LHP Lucknow- Electrical & Plumbing Conduiting

LHP Lucknow- Wall Concreting

LHP Lucknow- Other Services

Electrical Switch Board

False Ceiling

Structure Cover with Cement Fiber Board

False Ceiling with Gypsum Board

False Ceiling with Gypsum Board

LHP Lucknow- Complete Structure of Block-A

LHP Lucknow- Complete Structure of Block-A

LHP Lucknow- Complete Structure of Block-A

Commercial Block

Community Block

LHP Lucknow- Sample Finished House

LHP Lucknow- Quick Reference Table

1	**Timing**	SIP should be installed within 24 hours of pouring the slab or footing.
2	**Speed of installation**	150 sqm installed by four people per day on average.
3	**Storage and handling**	• Stack up to two packs high with spacers on a level surface. Spacers should be at four points for even distribution of dead weight, particularly to prevent distortion in extreme heat. • Panels are lightweight (maximum 23 kgs per sqm) and can be handled by two people.
4	**Placing and pouring height**	• Place panels carefully to accommodate starter bars and other details. Panels clip and slide into place and lock together with ease. Use a rubber mallet or similar for adjustment and persuasion to height and line. • Panels will withstand the dynamic bursting pressure of fresh concrete in single pours up to three meters high. Use horizontal bracing for pours greater than three meters.

LHP Lucknow- Quick Reference Table

5	Reinforcement	• Place from the top, aligning as close as possible to starter bars if applicable. The internal ribs will assist in achieving desired centres. Can be designed and placed at a vertical spacing of 150mm or 200mm increments. • If necessary, thread from the open end of the wall as the wall progresses. When a run ends at an existing wall and horizontal bars are required, place a length of a horizontal bar with an attached draw wire in the voids, then ease the bar forward. Spacing is to relate to voids in vertical diaphragms at 150mm increments.
6	Propping and aligning	• Use raking props at 1500mm centers to maintain plumb. For walls up to three meters in height, affix prop to a panel at the top third of the height. • The base should be plumb from the previous set. Use a laser to check horizontal and vertical alignment/plumb of panels.
7	Concrete mix and pouring	• Advisable mix should be minimum 25MPa for load bearing and 7.5mpa for non-load bearing, 10mm aggregate at 180mm slump. • Fill SIP panels carefully in layers of concrete not exceeding three meters high at a time. To reduce pressure and segregation at the base of the panels, discharge the concrete so that it impacts on as many internal ribs as possible.

LHP Lucknow- Quick Reference Table

8	Vibrating and contraction control	• Only certain cases vibrate poured concrete at a low frequency. The slick fine PVC surface will allow the concrete to slide easily into any air pockets or voids of SIP. • No contraction control is required
9	Services and door window openings	• Services and all other in situ requirements are the same as conventional formwork systems. • Windows, doors, and other openings are easily placed and cut in with standard pre-pour procedures.
10	Finishing	• SIP panels have a clean, straight, semi-gloss substrate perfect for a range of internal and external render and paint systems. • For concealing PEB we can use gypsum board and cement fibreboard and other wooden compatible materials also.

LHP Lucknow- Limitations

- Stay in Place PVC Form walls need pre-planned installation of MEP services for concealed networks.
- Doors and windows position shall not be changed after pouring of concrete.
- Erection of panels shall be under the supervision of trained staff.
- High-intensity UV rays harm the outer envelope, so it is not advisable in the tropical region.
- Skilled worker needed for PEB Erection and SIP Installation.

LHP Lucknow- Advantages

- Gives very aesthetic finished surface in different colour options without plastering.
- No curing is required. About 50% less use of water.
- Faster as compared to conventional buildings.
- About 40% Less usage of manpower as compared to conventional construction. As all panels are prefabricated in the factory.
- Light in weight as compared to other conventional materials.
- SIP does not corrode, chip, or stain & is resistant to UV, bacteria, fungi, etc.,
- The polymer content used in the manufacturing of formwork is up to 55% recycled content and is further recyclable, making it an eco-friendly material.
- The PVC system provides insulation from the surroundings and gives better thermal comfort to occupants. Overall, this system is energy efficient as less water and operation energy requirements are less as compared to conventional buildings.

SESSION -2

1. Construction Process & Efficiency
2. Basics of Thermal Comfort
3. Passive Design Strategies

Stabilization of soil

The three basic types of soil stabilization techniques are

Compaction

The simplest stabilization processes are compaction and drainage (if water drains out of wet soil it becomes stronger)

Mechanical

Stabilization can be achieved through physical process by altering the physical nature of native soil particles by either induced vibration or compaction or by incorporating other physical properties such as barriers and nailing.

Chemical

Soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect.

Column Laying & Structure

RCC columns mainly constructed in 4 stages:

- Column Layout Work
- Column Reinforcement Work
- Column Formwork
- Pouring of Concrete

Defects of columns

- Cracking
- Honeycombing
- Poor Formwork Installation

Improving Efficiency in Construction

How to Improve?

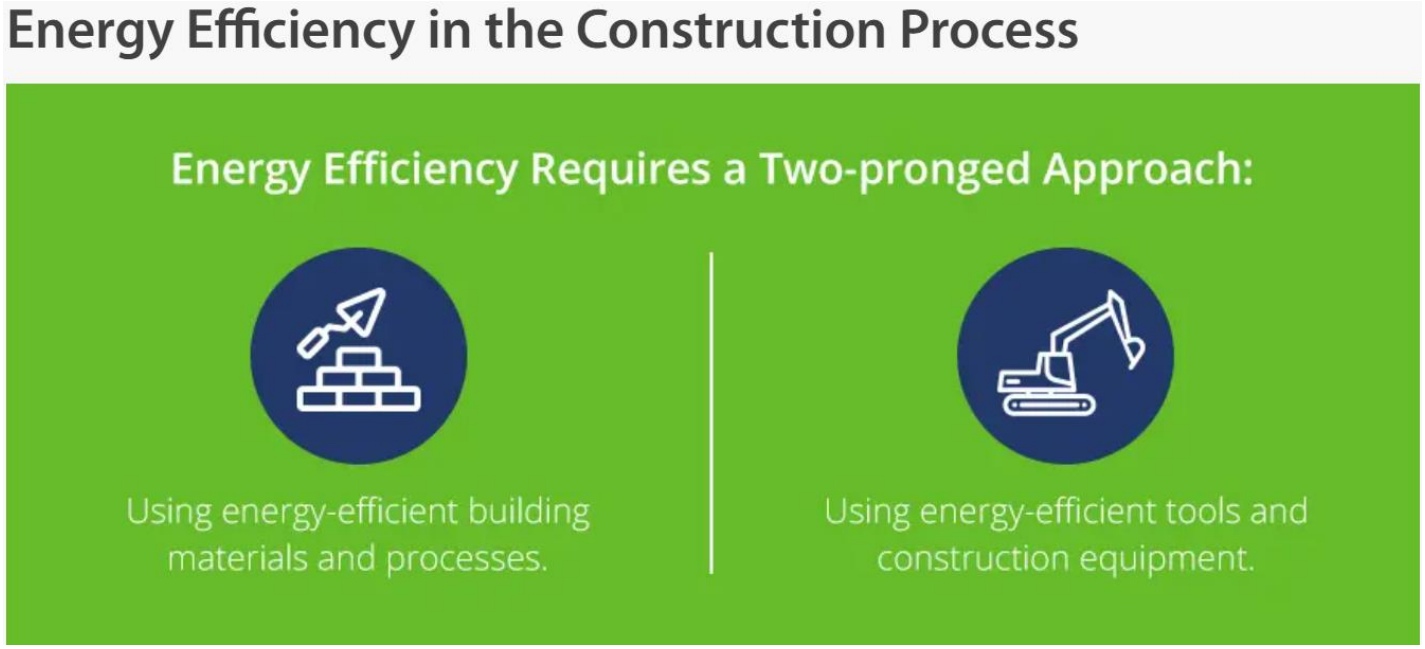
Construction deficiency include improperly designed materials, poor workmanship, and failure to follow construction codes. Any deficiency in a building project can be considered a construction defect, including:

- Defective architectural designs
- Lack of planning or supervision
- Lack of a proper inspection
- Improper construction

Results following common visible defect which need to be addressed:

- **Erosion of Mortar**
- **Peeling Paint**
- **Cracking of Walls / Leaning Walls**
- **Unstable Foundations**
- **Roof Defects**
- **Honeycombing**
- **Dampness**

Improving Efficiency in Construction



Energy efficiency for construction applies to every part of the process, from the construction process ,tools, equipment used to the appliances installed in a new building.

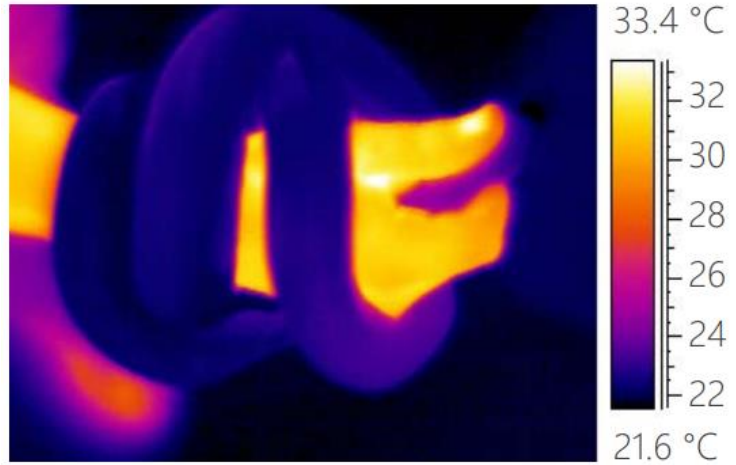
Energy-efficiency can apply to:

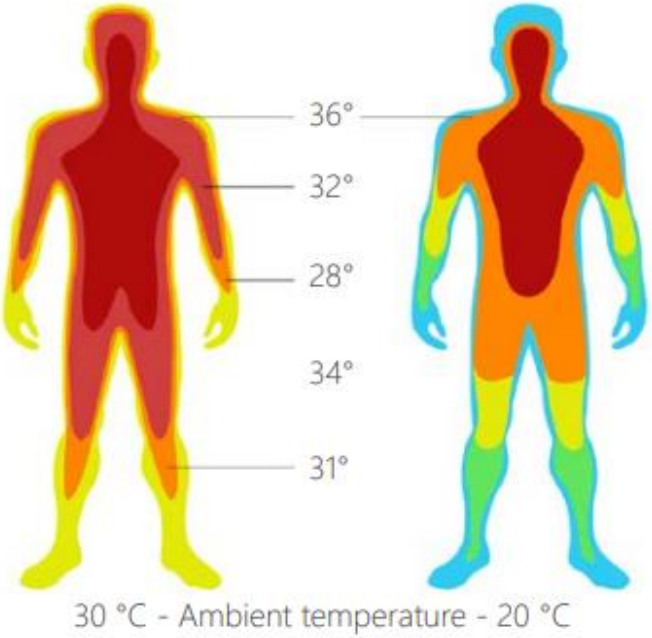
- **Building materials**
- **Transporting materials**
- **Site preparation**
- **Tools**
- **Heavy equipment**
- **Fuel requirements**
- **Landscaping**
- **Insulation**
- **Windows**
- **Appliances**
- **Lighting**
- **Heating, ventilation and air conditioning (HVAC) systems**

WHAT IS THERMAL COMFORT & IMPORTANCE?

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

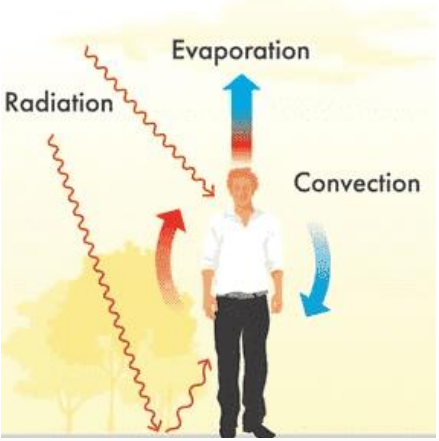
- In case of humans, the core body temperature lies in a narrow range around 37° C (ASHRAE, 2021).
- To maintain the body core temperature during varying external temperatures, the human body is constantly acclimatizing itself to its external environmental conditions through exchange of heat between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





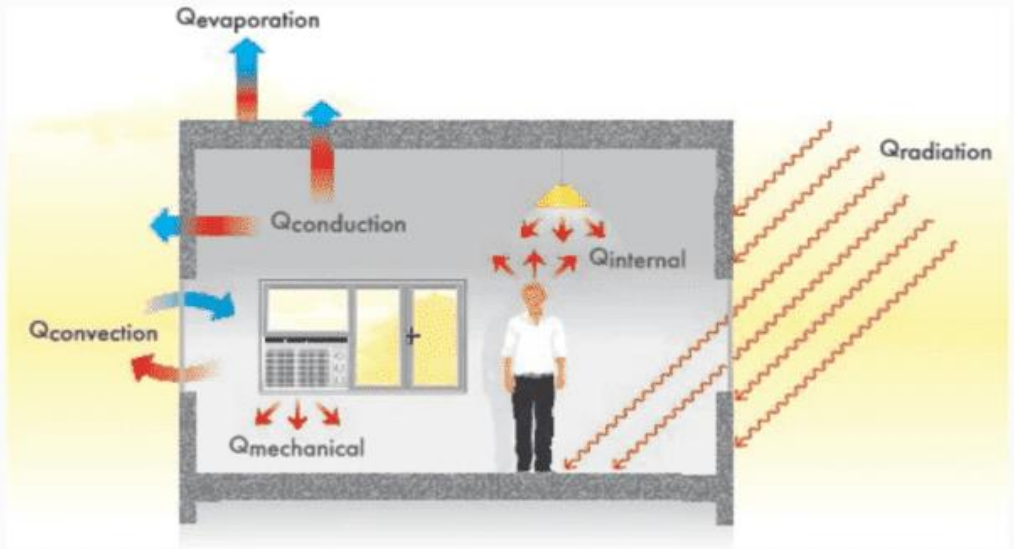
TRANSFER OF HEAT FROM HUMAN BODY

Mode of Transfer of Heat



What affects the **Thermal indoor environment?**

- 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 & COOLING DEMAND

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.

AFFORDABLE HOUSING & PASSIVE STRATEGIES

Strategies for various modes of heat transfer

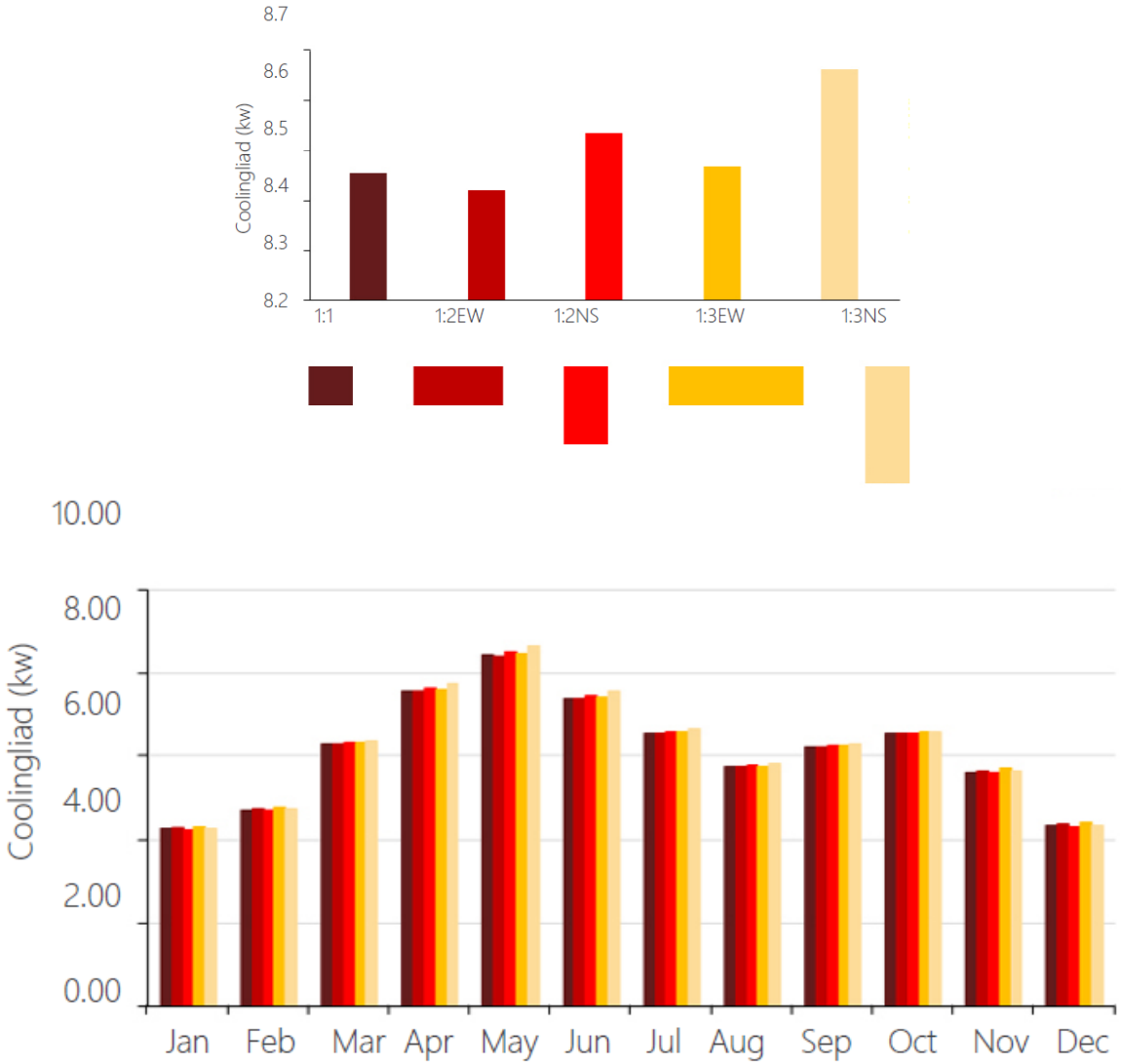
Passive design strategies may tackle either one or a combination of these modes of heat transfer.

- 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

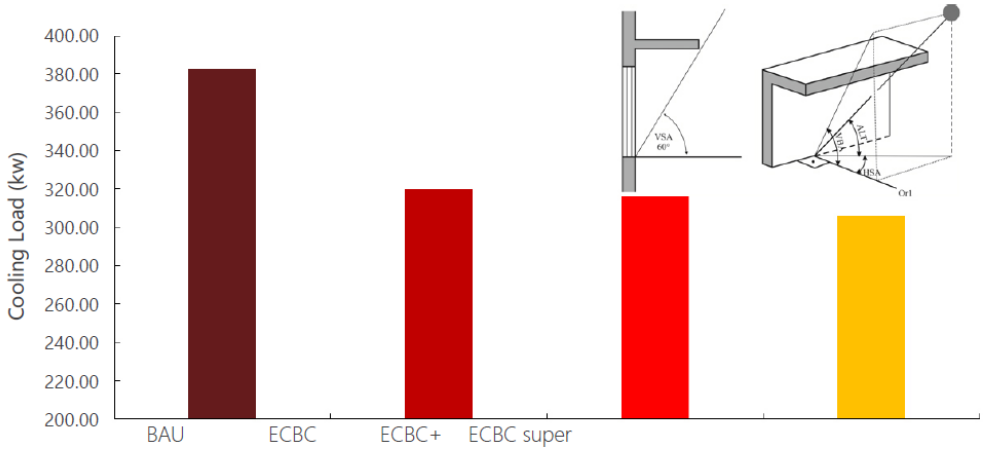


Form & orientation of the building

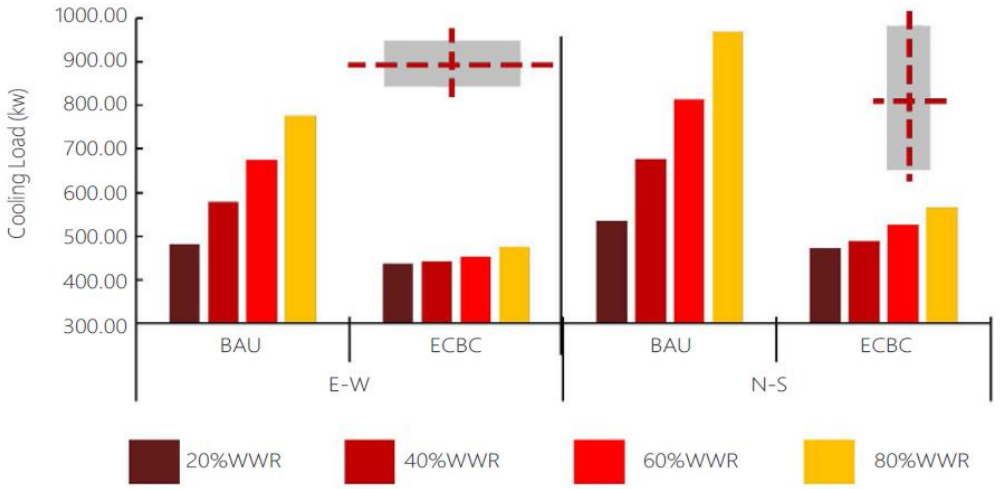
- Daylight penetration and fenestration design have implications on heat gain/loss through the building envelope.
- Careful orientation of fenestration can help achieve thermal and visual comfort
- Daylight harvesting from the north and south facade should be maximized with proper orientation of the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

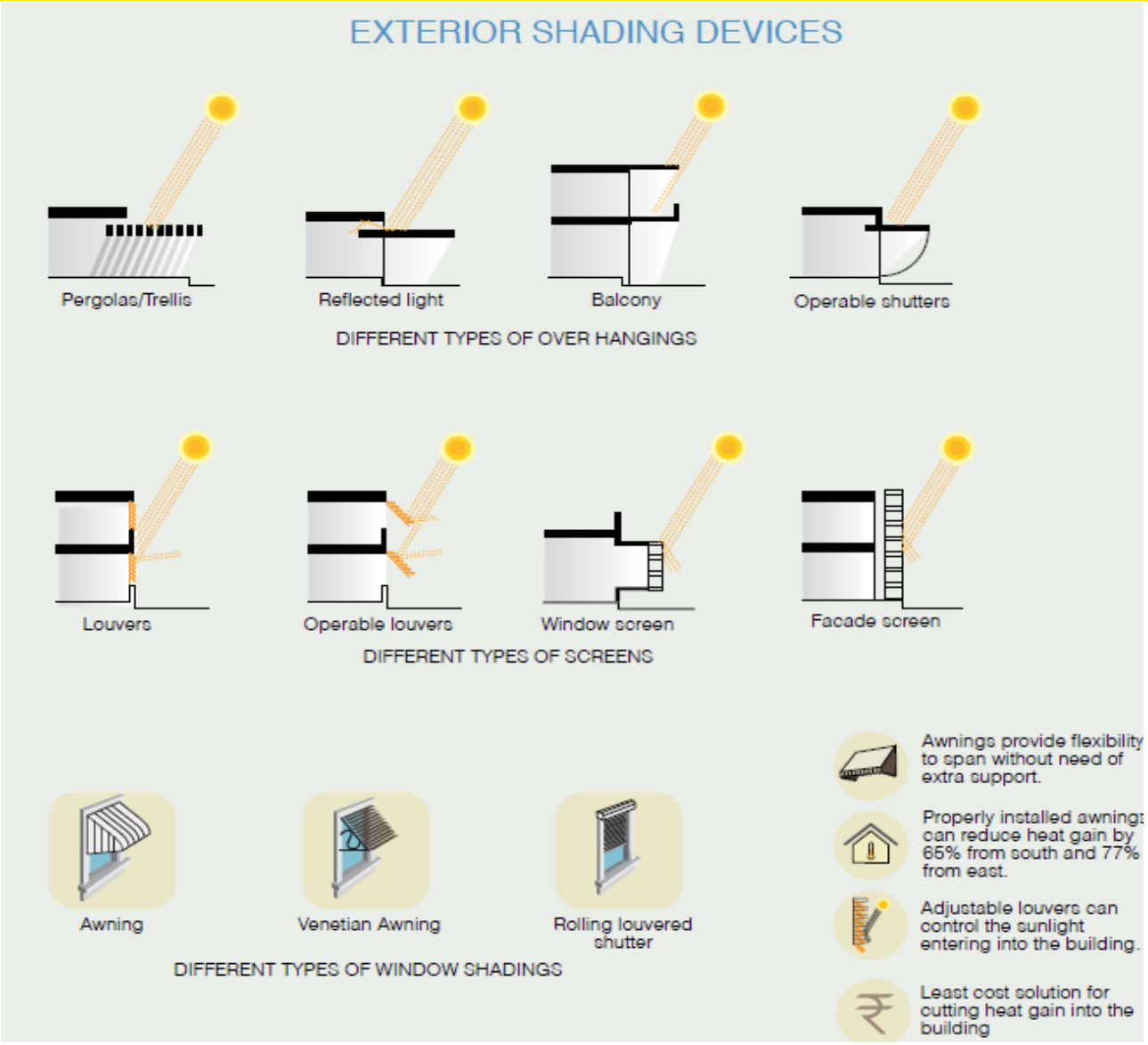


Comparative analysis of various WWR levels in East-West and North-South orientations for business-as-usual and ECBC compliant buildings

Shading & WWR

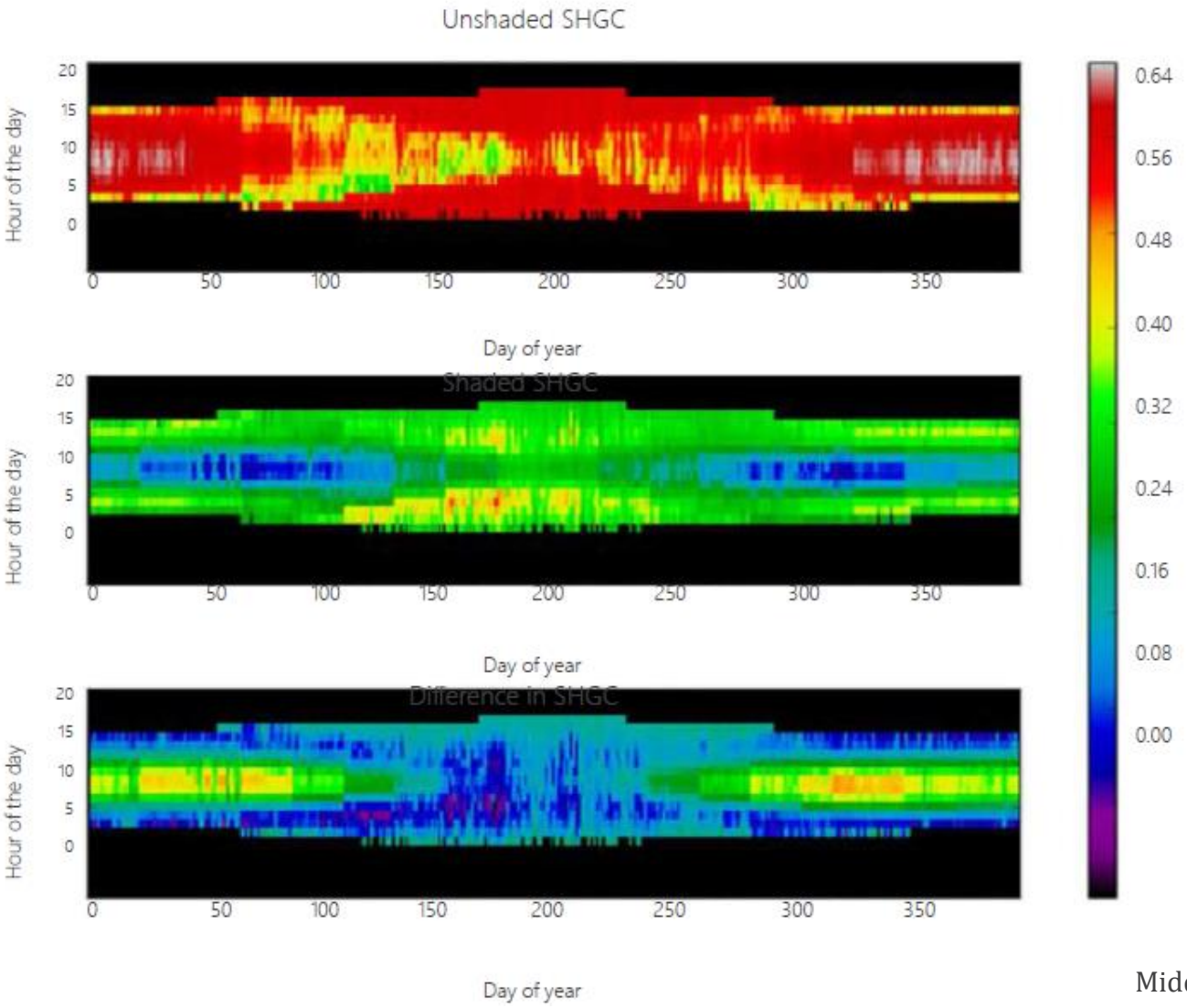
- Reduce heat gain and cooling energy use of the building.
- Dynamic movable external shading systems, vertical shading elements like fins are more useful in cutting radiations when the sun is at a lower altitude i.e., in East and West facades
- Greater WWR escalates the cooling load significantly in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

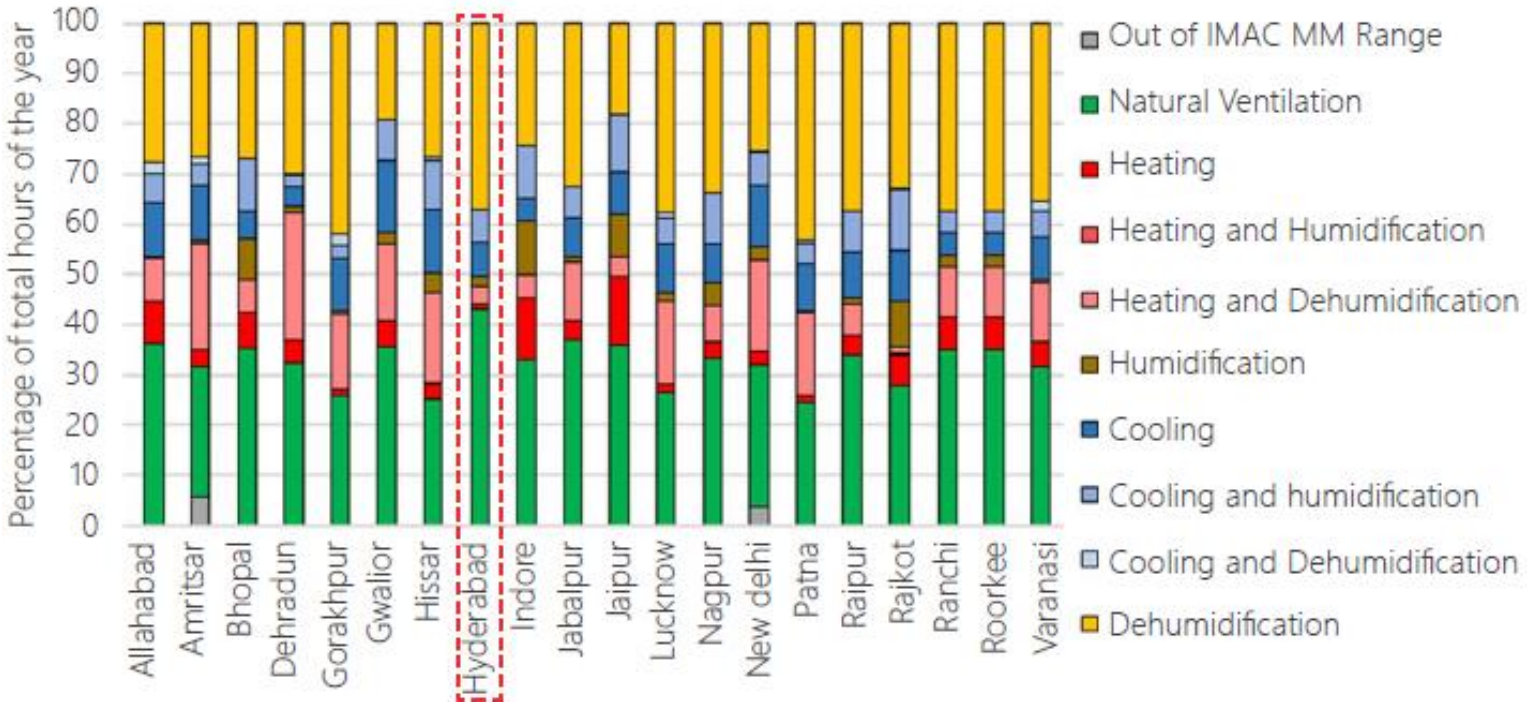
Top- SHGC values of an unshaded window throughout the year;
Middle- SHGC values of the same windows in case of shading present throughout the year;
Bottom- Difference in SHGC values of the first two graphs.

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.

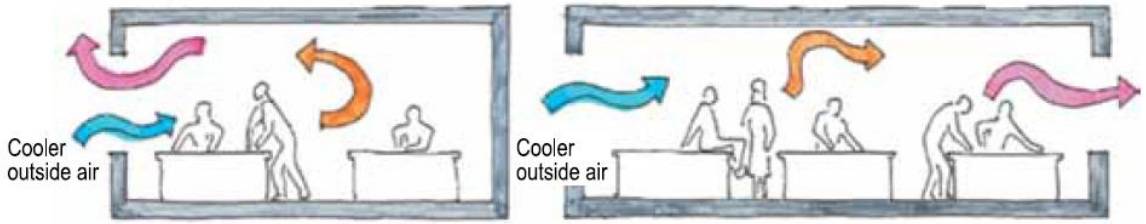


Percentage of comfort hours in a year for different building operation modes listed in IMAC-MM. Source: M., Shulka, Y., Rawal, R., Loveday, D., de Faria, L., Angelopoulos, C. (2020). Low Energy Cooling and Ventilation in Indian Residences Design Guide. CEPT Research & Development Foundation & Loughborough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

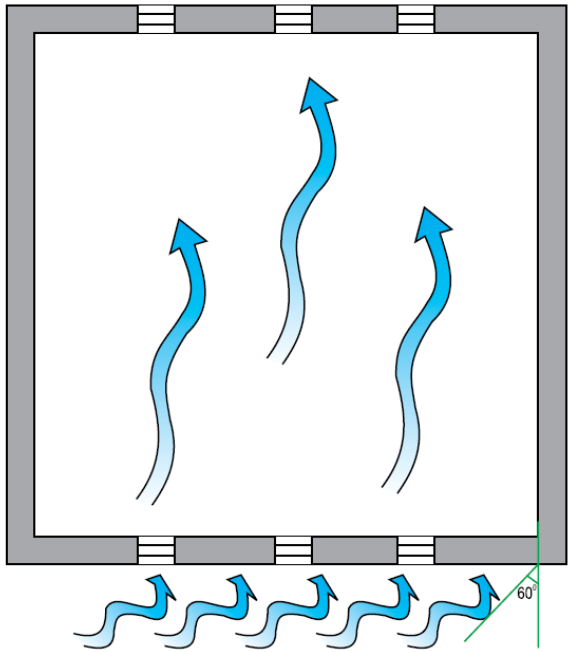
AFFORDABLE HOUSING & PASSIVE STRATEGIES

Natural ventilation

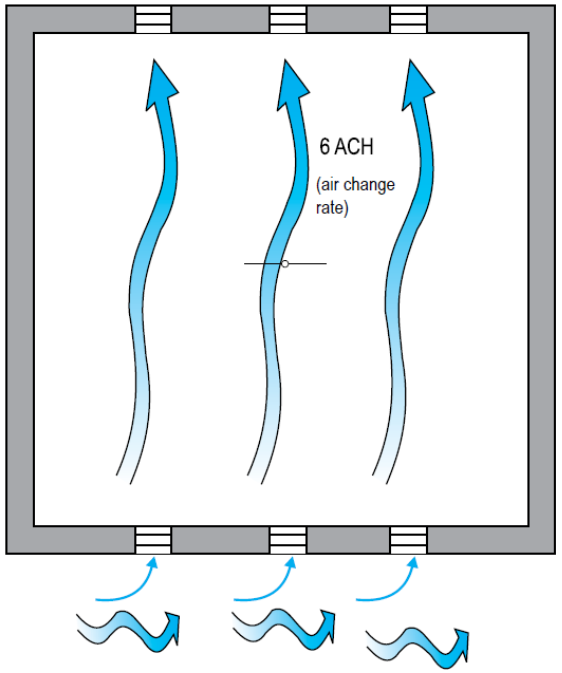
It is shown that the ACH improved from 6 ACH per hour to 14 ACH per hour with the use of the deflectors.



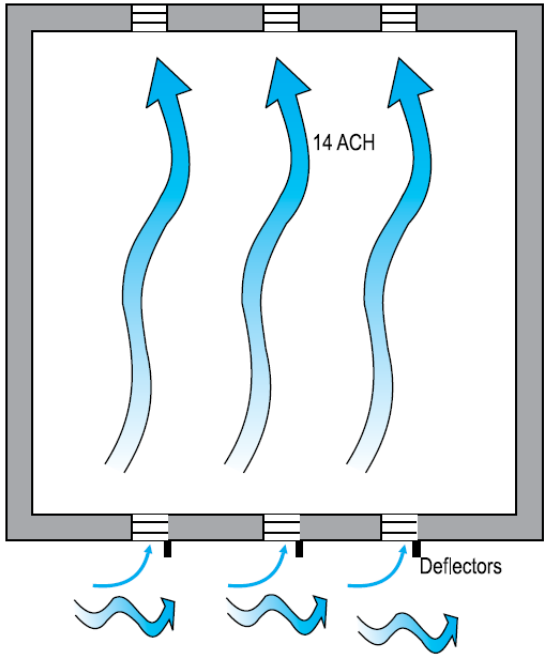
Principles of single-sided ventilation and cross-ventilation



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



Wind blowing parallel to the façade

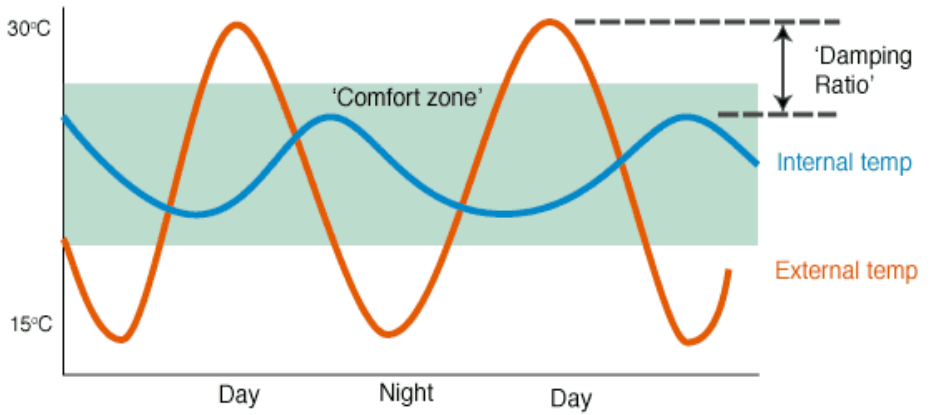


Deflectors that help in harnessing wind for natural ventilation

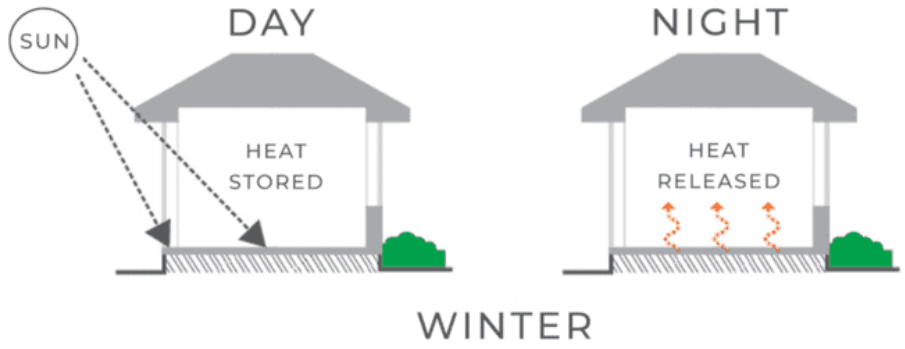
Source: Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka

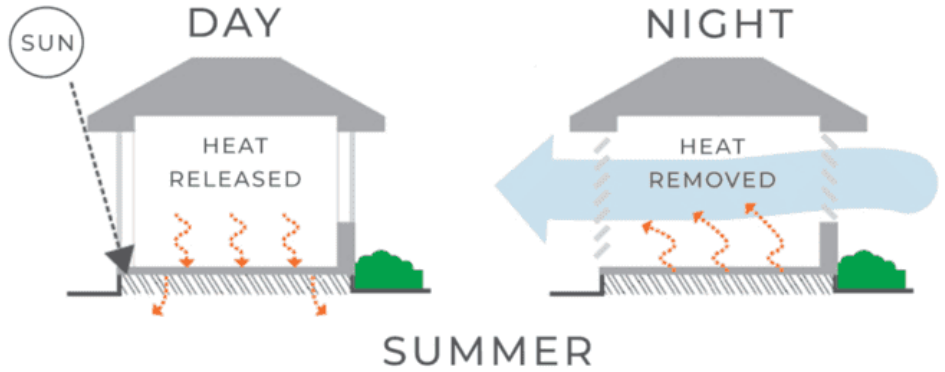
AFFORDABLE HOUSING & PASSIVE STRATEGIES

'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.**

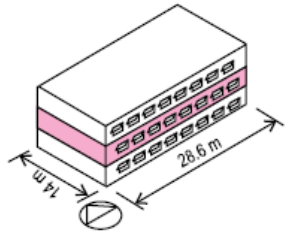
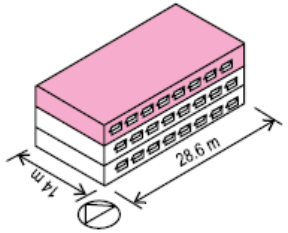




AFFORDABLE HOUSING & PASSIVE STRATEGIES

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

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