GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA

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

Ministry of Housing and Urban Affairs
Government of India

Azadi Ka Amrit Mahotsav

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

RACHNA 2.0

RESILIENT, AFFORDABLE AND COMFORTABLE HOUSING THROUGH NATIONAL ACTION

Innovative Construction Technologies & Thermal Comfort for Affordable Housing

Presented by South Cluster CSB Cell

Introduction - GIZ

GIZ

GIZ is an international cooperation enterprise for sustainable development which operates worldwide, on a public benefit basis. GIZ is fully owned by the **German Federal Government**, GIZ implement development programs in partner country on behalf of the German Government in achieving its development policy objectives.

german
cooperation
DEUTSCHE ZUSAMMENARBEIT

The focal areas of Indo-German cooperation currently are:

- ❑ Energy
- ❑ Environment, Preservation, and Sustainable Use of Natural Resources
- ❑ Sustainable Urban & Industrial Development
- ❑ Sustainable Economic Development

GIZ

Energy

We support our partners in developing framework conditions for the promotion of renewable energy, improved energy efficiency and rural energy access.

- Indo-German Energy Forum – Support Office
- Indo-German Energy Programme – Access to Energy in Rural Areas
- Integration of Renewable Energies into the Indian Electricity System
- Indo-German Solar Partnership – PVRT
- Promotion of Solar Water Pumps
- Indo-German Energy Programme – Green Energy Corridors
- Energy Efficiency in Buildings Programme
- Indo-German Energy Programme – Energy Efficiency

Sustainable Urban and Industrial Development

We support the development of urban and industrial areas to become cleaner, more liveable, inclusive, climate-friendly and resilient.

- Land Use Planning and Management
- Sustainable and Environment-friendly Industrial Production
- Support to Ganga Rejuvenation
- Integrated and Sustainable Urban Transport Systems for Smart Cities in India
- Sustainable Urban Development – Smart Cities
- Climate Smart Cities

MoHUA + GIZ

MoHUA
(Ministry of Housing & Urban Affairs)

Government of India

+

GIZ
(Deutsche Gesellschaft für Internationale Zusammenarbeit)

Government of Germany

Indo-German Energy Program (IGEN)

IGEN Program: Climate Smart Buildings

- **Thermal Comfort Action Plan**
- **Standard / Guidelines**

- **Implementation of GHTC India**
- **Establishment of Cluster Cells**

Introduction – Climate Smart Buildings Cell

Ministry of Housing and Urban Affairs
Government of India

GIZ Climate Smart Buildings Cell (CSB cell)

Light House Project – Implementation Monitoring & Evaluation

Technical Assistance to DHPs & AHRCs

GIZ Climate Smart Building Cell (CSB)

Inclusion of Thermal Comfort requirements in Bye-laws

Capacity Building of Stakeholders

South Cluster Cell covers

- ***Tamilnadu***
- ***Karnataka***
- ***Kerala***
- ***Andhra Pradesh***
- ***Telangana***
- ***Puducherry***
- ***Andaman & Nicobar***
- ***Lakshadweep***

Demonstration Housing Project (DHPs)

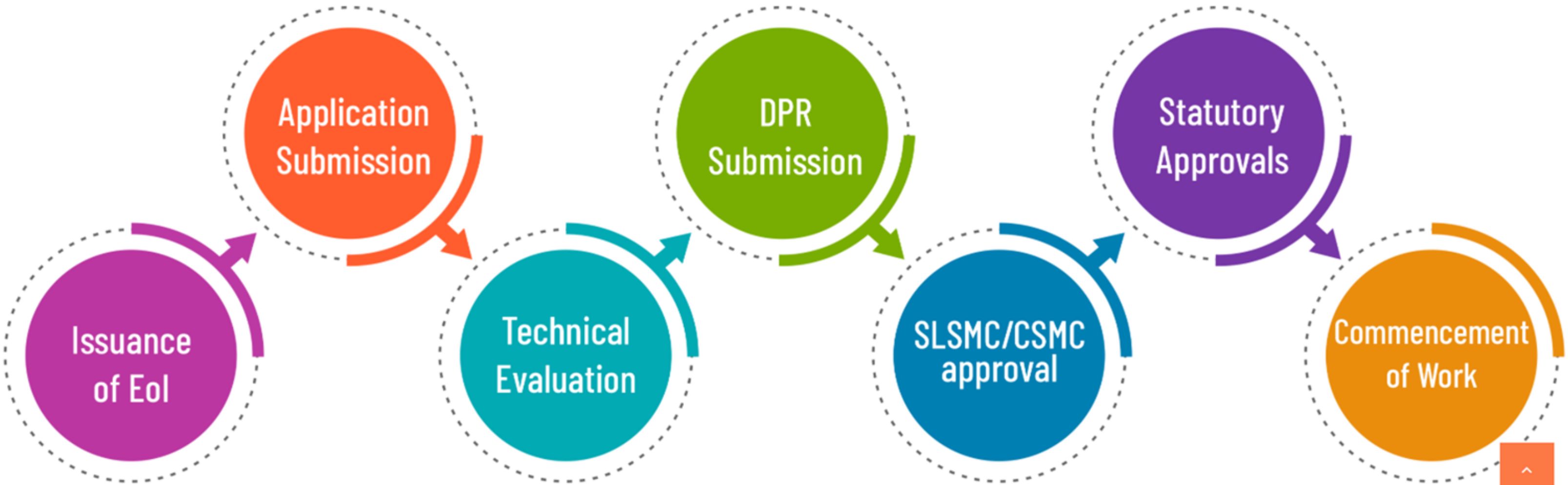
To showcase the field level application of new / alternate technologies, **MoHUA** has taken an initiative to construct Demonstration Housing Project (DHP) through **Building Materials & Technology Promotion Council (BMTPC)** as a part of Technology Sub-Mission under **PMAY(U)**.

Collection of drawings and other inputs at the Design Stage → **Technical Commercial feasibility analysis** → **Outputs & Recommendations through ENS and Simulations (softwares)** → **Specifications of Proposed strategies** → **Techno-Economic Feasibility Report** → **Acceptance & Implementation of recommendations** → **Monitoring & Verification of Thermal Comfort during & post construction**

ARHCs

- COVID-19 pandemic has resulted in **reverse migration** of urban migrants/ poor in the country. They need **decent rental housing** at affordable rate at their work sites.
- In order to address this need, **Ministry of Housing & Urban Affairs** has initiated **Affordable Rental Housing Complexes (ARHCs),** a sub-scheme under Pradhan Mantri AWAS Yojana- Urban (**PMAY-U**).
- Scheme will be implemented in 2 models: **Model 1** (Utilizing vacant Gov. houses)

MODEL-2



Ministry of Housing and Urban Affairs
Government of India

RACHNA 1.0 & 2.0

Session 1: Innovative Construction Technologies of LHPs, Study & Observations

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Global Housing Technology Challenge - India

MoHUA has initiated the **Global Housing Technology Challenge-India (GHTC-India)** which aims to identify and mainstream a basket of innovative construction technologies from across the globe for housing construction sector that are sustainable, eco-friendly and disaster-resilient.

They are to be cost effective and speedier while enabling the quality construction of houses, meeting diverse geo-climatic conditions and desired functional needs.

MoHUA, through a **Technical Evaluation Committee (TEC)**, shortlisted **54 innovative** proven technologies suiting different geo-climatic conditions that could be considered for demonstration through actual ground implementation of six Light House Projects (LHP) in six different States/UTs of PMAY(U) regions across the country.

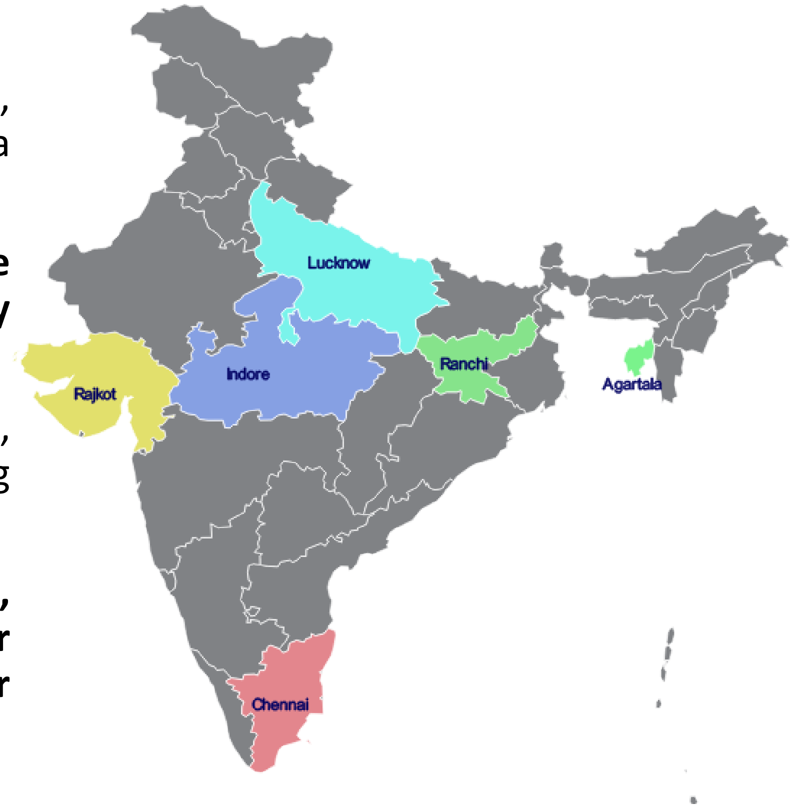
Hon'ble Prime Minister Shri Narendra Modi laid the foundation stone of these LHPs on January 1, 2021

GHTC-India Components

- **Construction Technology India: Expo-cum-Conference**
- Identifying and Mainstreaming Proven Demonstrable Technologies for the construction of **Light House Projects**
- Identifying Potential Future technologies for Incubation and Acceleration Support through **ASHA-India (Affordable Sustainable Housing Accelerators)**

Light House Project

- **Model housing projects with approximately 1,000 houses built with shortlisted alternate technology suitable to the geo-climatic and hazard conditions of the region.**
- Demonstrate and deliver ready to live houses with speed, economy and with better quality of construction in a sustainable manner.
- **Period of construction is maximum 12 months from the date of handing over of sites to the construction agency after all statutory approvals.**
- LHPs shall serve as LIVE Laboratories for planning, design, production of components, construction practices, testing etc.
- **Site infrastructure development such as internal roads, pathways, common green area, boundary wall, water supply, sewerage, drainage, rain water harvesting, solar lighting, external electrification, etc.**
- **Incentives for early completion.**

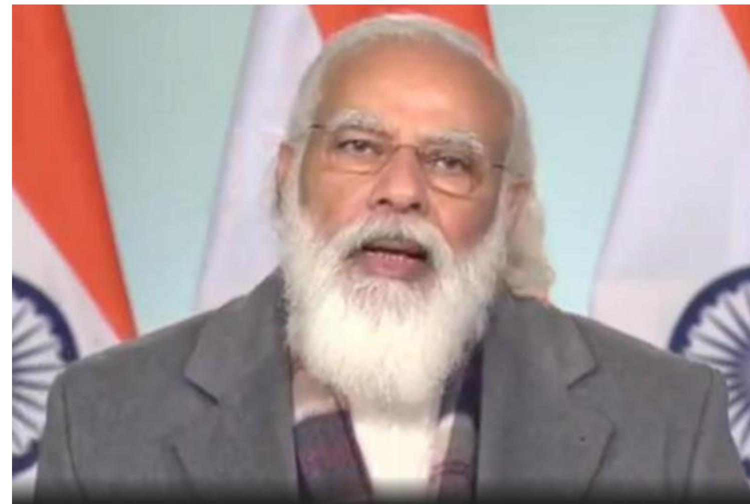


Light House Projects

As a part of **GHTC- India**, six Light House Projects (LHP) consisting of about 1,000 houses each with physical & social infrastructure facilities is being constructed at six places across the country namely

1. Indore
2. Rajkot
3. Chennai
4. Ranchi
5. Agartala
6. Lucknow

These projects will showcase the use of the six distinct shortlisted innovative technologies for field level application, learning and replication. LHPs will demonstrate and deliver ready to live mass housing at an expedited pace as compared to conventional brick and mortar construction and will be more economical, sustainable, of high quality and durability. These projects shall serve as Live laboratories for all stakeholders including R & D leading to the successful transfer of technologies from the lab to the field



Prime Minister Narendra Modi during the foundation laying ceremony of Light House Projects in six States, via videoconference, in New Delhi on January 1, 2021. Twitter/@narendramodi

Light House Project

Six Technology providers have been selected through a rigorous online bidding process for construction of Light House Projects (LHPs) at six different locations in six states.

1. Precast Concrete Construction System - 3D Precast volumetric

2. Precast Concrete Construction System - Precast components assembled at site

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

4. Prefabricated Sandwich Panel System

5. Monolithic Concrete Construction

6. Stay In Place Formwork System

LHP Indore

Prefabricated Sandwich Panel System

Number of Houses : 1024

- Factory made Prefabricated Sandwich Panel System is made out of cement or calcium silicate boards and cement mortar with EPS granules balls, and act as wall panels.
- These replace conventional brick & mortar walling construction practices and can be used as load-bearing and non-load bearing walling for residential and commercial buildings.
- Under this LHP, houses are being constructed using Prefabricated Sandwich Panel System with Pre-Engineered Steel Structural System.
- In this system the EPS Cement Panels are manufactured at the factory in controlled condition, which are then dispatched to the site. The panels having tongue and groove are joint together for construction of the building.

LHP Rajkot

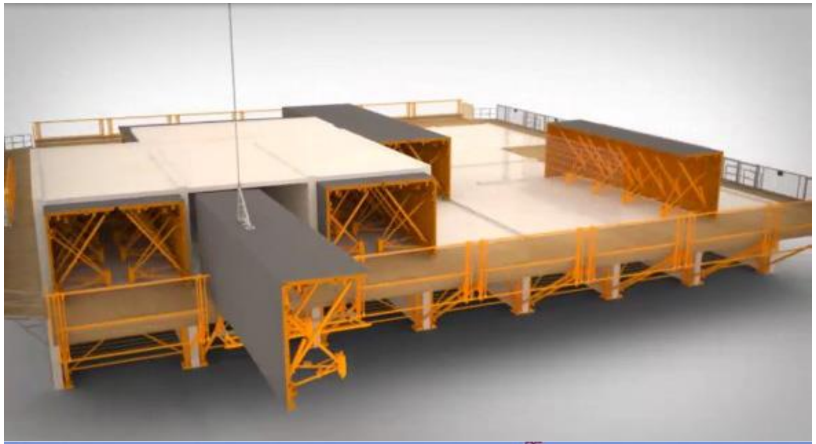
Monolithic Concrete Construction using Tunnel Formwork

- In ‘TunnelForm’ technology, concrete walls and slabs are cast in one go at site giving monolithic structure using high-precision, re-usable, room-sized, Steel forms or moulds.
- The system intends to replace the conventional RCC Beam-Column structure which uses steel/plywood shuttering.
- ‘TunnelForm’ system uses customized engineered steel formwork consisting of two half shells which are placed together and then concreting is done to form a room size module. Several such modules make an apartment.

Construction Process:

- Stripping of the formwork from the previous day.
- Positioning of the formwork for the current day’s phase, with the installation of mechanical, electrical and plumbing services.
- Installation of reinforcement in the walls and slabs.
- Concreting

Number of Houses : 1144



LHP Chennai

Precast Concrete Construction System – Precast Components Assembled at Site

- Precast concrete construction is a system where the individual precast components such as walls, slabs, stairs, column, beam etc, of building are manufactured in plant or casting yard in controlled conditions. The finished components are then transported to site, erected & installed.
- The construction process comprises of manufacturing of precast concrete Columns, Beams and Slabs in steel moulds.
- The reinforcement cages are placed at the required position in the moulds. Concrete is poured and compaction of concrete is done by shutter/ needle vibrator.
- Casted components are then moved to stacking yard where curing is done for requited time. These precast components are installed at site by crane and assembled together through in-situ jointing and/or grouting etc.

Number of Houses : 1152

Ground Floor Column Work in Progress - March 2021

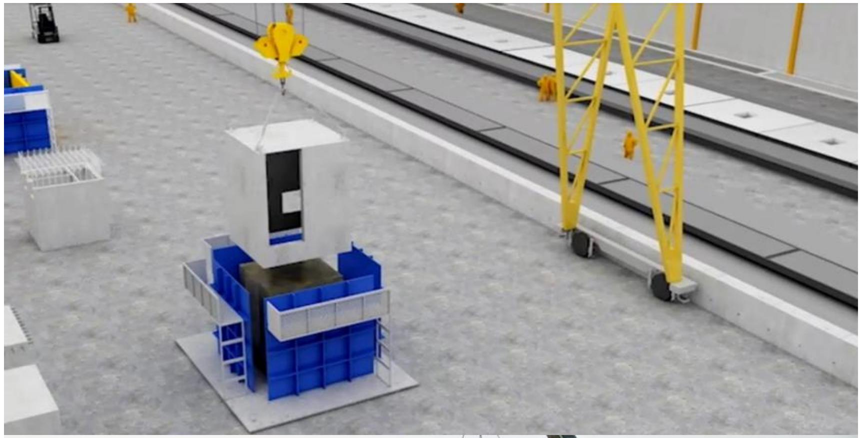
First Floor Column & Beam Erection - May 2021

LHP Ranchi

Precast Concrete Construction System – 3D Volumetric

- 3D Volumetric concrete construction is the modern method of building by which solid precast concrete structural modules like room, toilet, kitchen, bathroom, stairs etc. & any combination of these are cast monolithically in Plant or Casting yard in a controlled condition.
- These Modules are transported, erected & installed using cranes and push-pull jacks and are integrated together in the form of complete building unit.
- Factory finished building units/modules are installed at the site with the help of tower cranes. Gable end walls are positioned to terminate the sides of building.
- Pre stressed slabs are then installed as flooring elements. Rebar mesh is finally placed for structural screed thereby connecting all the elements together. Consecutive floors are built in similar manner to complete the structure.

Number of Houses : 1008



LHP Agartala

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

- Light Gauge Steel Frame (LGSF) System uses factory made galvanized light gauge steel components. LGSF is used in combination with pre-engineered steel structural system for buildings above G+3 for longevity, speedier construction, strength and resource efficiency.
- The sequence of construction comprises of foundation laying, fixing of Pre-Engineered Steel Structural System, fixing of tracks, fixing of wall panels with bracings as required, fixing of floor panels, decking sheet, fixing of electrical & plumbing services and finally fixing of concrete walling panels with light weight concrete as infill.
- The other options of dry walling components such as sandwich panels with insulation material in between can also be used. Similarly, the floors can either by composite slab/deck slabs/precast hollow core slabs as per the need & requirements.

Number of Houses : 1000

LHP Agartala

PVC Stay In Place Formwork System

- Plant manufactured rigid poly-vinyl chloride (PVC) based polymer components serve as a permanent stay-in-place finished form-work for concrete walls. The formwork System being used acts as pre-finished walls requiring no plaster and can be constructed instantly.
- Construction is done in a sequential manner where at first, the Prefabricated PVC Wall panels and Pre-Engineered Steel Structural Sections as per the design are transported to the Site.
- Then, these Sections are erected on the prepared foundation using cranes and required connections. Floor is installed using decking sheet. Once the structural frame and floor is installed and aligned, wall panels are fixed on decking floor.
- The pre-fabricated walling panels having provisions of holes for services conduits, are fixed along with the reinforcement & cavities inside the wall panels are filled with concrete. Upon installment of wall panels, flooring and ceiling, the finishing work is executed.

Number of Houses : 1040

Light House Project : CHENNAI

TECHNOLOGY SELECTED:

Precast Concrete Construction System – Precast Components Assembled at Site

AGENCY: **M/s B.G. Shirke Construction Technology Pvt. Ltd.**

No. of Towers: 12 **No. of Houses: 1128** **No. of Floors: 6**

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Light House Project : CHENNAI

Project Brief

Location of Project : Nukkampalayam Road, Chennai, Tamil Nadu

No. of DUs : 1,152 (G+5)

Plot area : 29,222 sq.mt.

Carpet area of each DU : 26.78 sq.mt.

Total built up area : 43439.76 sq.m

Technology being used : Precast Concrete Construction System - 3S System

Other provisions : Anganwadi, shops, milk booth, library and ration shop.

Broad Specifications:

- Foundation RCC isolated footing
- Structural Frame RCC precast beam/columns
- Walling AAC Blocks Floor Slabs/Roofing RCC precast

Door Frame/ Shutters:

- Pressed steel door frame with flush shutters
- PVC door frame with PVC Shutters in toilets.
- Window Frame/ Shutter:
- uPVC frame with glazed panel and wire mesh shutters.

Flooring:

- Vitrified tile flooring in Rooms & Kitchen
- Anti-skid ceramic tiles in bath & WC
- Kota stone Flooring in the Common area.
- Kota stone on Staircase steps.

Light House Project : CHENNAI

Description	Unit	Length	Width	Area
Hall	Sqmt	3.175	3.025	9.60
Kitchen	Sqmt	1.8	2.8	5.04
Bed Room	Sqmt	2.725	2.528	7.70
Bed Room Offset	Sqmt	0.9	0.2	0.18
Bath Room	Sqmt	1	1.4	1.4
W.C	Sqmt	0.9	1.55	1.395
Passage	Sqmt	1	1.2	1.2
Kitchen Opening	Sqmt	0.9	0.1	0.09
Door 1	Sqmt	1	0.15	0.15
Door 2	Sqmt	0.9	0.1	0.09
Door 3	Sqmt	0.75	0.1	0.075
Column Deduction	Sqmt			0.22
Total Carpet Area				**26.78**

Light House Project : CHENNAI

Precast concrete construction

- The construction process comprises manufacturing precast concrete Columns, Beams and Slabs in steel moulds. The reinforcement cages are placed at the required position in the moulds.
- Concrete is poured and compaction of concrete is done by shutter/ needle vibrator.
- Casted components are then moved to the stacking yard where curing is done for requited time and then these components are ready for transportation and erection at site.
- These precast components are installed at site by crane and assembled together through in-situ jointing and/or grouting etc.

Light House Project : CHENNAI

Special Features

- Nearly all components of building work are manufactured in plant/casting yard & the jointing of components is done In-situ leading to reduction in construction time.
- The controlled factory environment brings resource optimization, improved quality, precision & finish.
- The concrete can be designed as industrial by-products such as Fly Ash, Ground granulated blast furnace slag (GGBFS), Micro silica etc. resulting in improved workability & durability, while also conserving natural resources.
- Helps in keeping a neat & clean construction site and dust free environment.
- Optimum use of water through recycling.
- Use of shuttering & scaffolding materials is minimal.
- All weather construction & better site organization.

Efficiency in Construction

LHP Chennai – 3S Precast system

- **Timeline** - Completed 1152 dwelling units & external infrastructure within 12 months amidst covid & heavy rains in Chennai
- **Reduced use of Natural Resources** - Concrete mixed with industrial by-product Ground granulated blast furnace slag (GGBFS) while also conserving natural resources. Optimum use of water through recycling & use of sprinkler for curing precast components.
- **Use of Recycled materials** - Concrete mixed with industrial by-product Ground granulated blast furnace slag (GGBFS). Usage of AAC blocks. Window glazing from Saint gobain with 18% recycled contents.
- **Use of Low Carbon technology** – Reduced timeline & labor aids to less carbon footprint during construction
- **Manpower management** – With less dependency on labors, construction works carried out during covid times with help of machineries.

Mainstreaming & replication of Technology

LHP Chennai – 3S Precast system

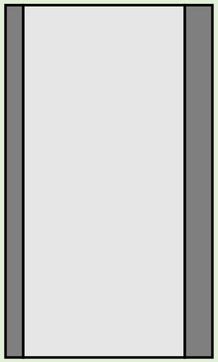
- **Cost of technology** - LHP technology of Chennai is 20% costlier than conventional technology. The cost of setting up a factory for casting elements will be null by the factor of scalability of the project or repetitive use of the precast moulds used.
- **Quality of construction** - LHP Chennai has 25% better quality than conventional construction due to factory made components reducing man made errors & unskilled labors.
- **Speed of construction** – 3 units per day was constructed at LHP.
- **Design flexibility** – Typical design can be completed at ease but flexibility of design is difficult as all components are precast.
- **Skilled labor requirement** – Almost 75% additionally skilled labors are required than the conventional construction technology.

ENS Part 1 & Thermal Comfort analysis for the LHP Chennai

LHP Site - Thermal Features

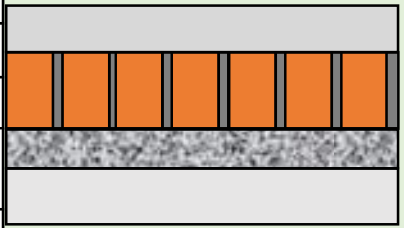
- 150mm AAC block is used for Masonry work & 100mm AAC block is used for internal partitions

20mm Plaster + 150mm AAC block + 12mm Plaster

External Wall Assembly								
Layer no.	***Material***	***Density (kg/m3)***	***Specific Heat (kJ/kg.K)***	***Thickness (m)***	***Conductivity (W/m-K)***	***R value m^2K/W***	***Source***	***Wall section***
1	Interior surface film resisitance	-	-	-	7.700	0.130	ENS 2018	
2	Internal cement Plaster	1762	0.840	0.012	0.721	0.017	ENS 2018	
3	AAC Block	642	1.240	0.150	0.184	0.815	ENS 2018	
4	External cement Plaster	1762	0.840	0.020	0.721	0.028	ENS 2018	
5	Exterior surface film resisitance	-	-	-	25.000	0.040	ENS 2018	
U value of assembly (W/m2K)						**0.97**		

LHP Site Thermal Features

- 305mm RCC wall is used for Roof. Brick bat koba is used as weathering course.

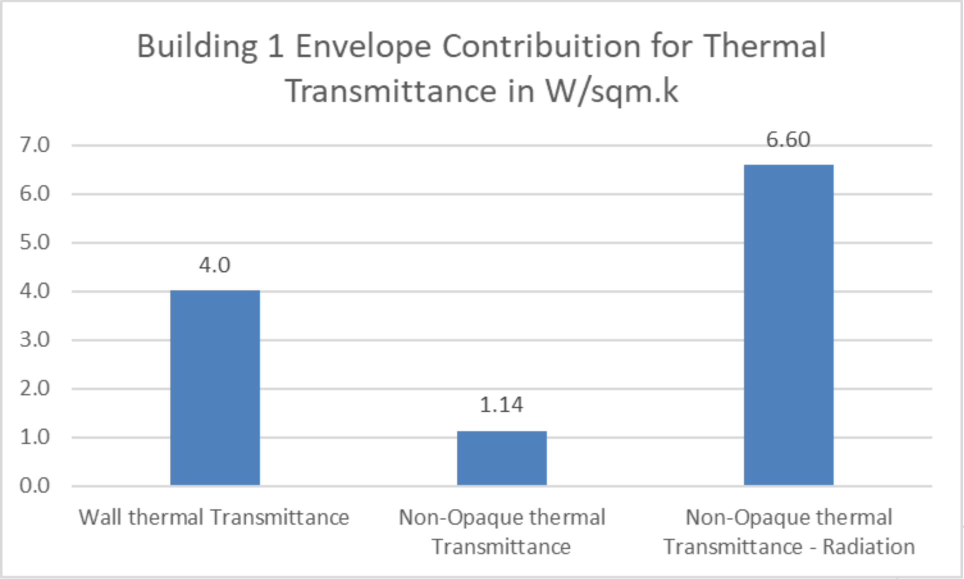
Roof Assembly								
Layer no.	*Material*	*Density (kg/m3)*	*Specific Heat (kJ/kg.K)*	*Thickness (m)*	*Conductivity (W/m-K)*	*R value m^2K/W*	*Source*	*Roof section*
1	Interior Surface film resisitance	-	-	-	5.900	0.169	ENS 2018	
2	Precast slab (RCC)	2288	NA	0.075	1.580	0.047	ENS 2018	
3	Screeding (RCC)	2288	0.920	0.055	1.580	0.035	ENS 2018	
4	BrickBat	1440	NA	0.100	0.620	0.161	ENS 2018	
5	External cement mortar	1648	0.840	0.075	0.719	0.104	ENS 2018	
6	Exterior Surface film resisitance	-	-	-	25.000	0.040	ENS 2018	
U value of assembly (W/m2K)						**1.79**		

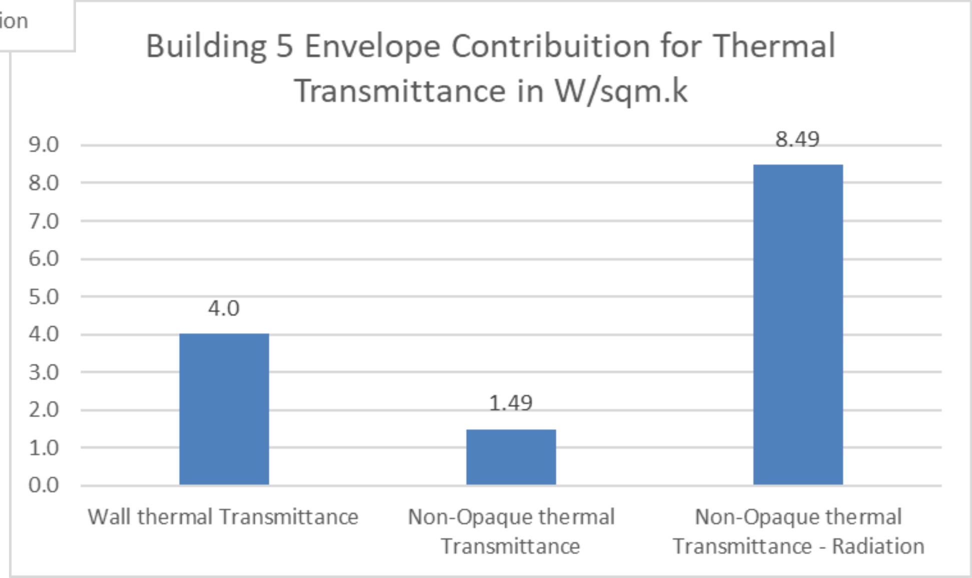
- According to ENS code, U value of roof should be within **1.2 W/sqmK**
- Inclusion of 25 mm EPS overdeck insulation would make the roof comply with ENS codes

LHP Site Analysis

ENS Compliance Parameters	Achieved		ENS Requirement	Compliance Status
	Building 1	Building 5		
Openable Window to Floor Area Ratio (WFR_{op})	**26.59**	**26.59**	≥ 16.66 %	Complied
Visible Light Transmittance (VLT)	**0.89**	**0.89**	≥ 0.27	Complied
Thermal Transmittance of Roof (U_{roof})	**1.8**	**1.8**	≤ 1.2 $W/m^2.K$	Not Complied
Residential Envelope Transmittance Value (RETV)	**11.8**	**14.1**	≤ 15 $W/m^2.K$	Complied

LHP Site Analysis





Light House Project (LHP), Chennai

Discomfort Hour Percentage

LHP Project Building 1 (North - South)

Building 1									
	Ground floor			Middle floor			Top floor		
	Bedroom	Living	Kitchen	Bedroom	Living	Kitchen	Bedroom	Living	Kitchen
Jan	87%	87%	52%	100%	92%	69%	100%	98%	69%
Feb	57%	84%	51%	94%	91%	68%	96%	96%	69%
Mar	51%	68%	51%	80%	89%	63%	85%	90%	67%
Apr	97%	90%	77%	100%	100%	89%	100%	100%	91%
May	94%	91%	92%	99%	96%	94%	100%	98%	95%
Jun	85%	67%	70%	94%	88%	78%	96%	91%	80%
Jul	80%	60%	67%	93%	82%	71%	94%	88%	71%
Aug	98%	78%	72%	100%	97%	74%	100%	98%	75%
Sep	92%	80%	66%	99%	94%	80%	99%	95%	81%
Oct	55%	60%	40%	74%	69%	46%	81%	71%	52%
Nov	54%	63%	44%	84%	75%	49%	89%	78%	58%
Dec	63%	67%	33%	95%	82%	48%	97%	90%	53%

Light House Project (LHP), Chennai

Discomfort Hour Percentage

LHP Project Building 5 (East - West)

Building 5	Ground floor			Middle floor			Top floor		
	Bedroom	Living	Kitchen	Bedroom	Living	Kitchen	Bedroom	Living	Kitchen
Jan	99%	98%	66%	100%	100%	72%	100%	100%	72%
Feb	87%	92%	62%	100%	100%	77%	100%	100%	79%
Mar	60%	95%	61%	99%	99%	72%	100%	100%	76%
Apr	100%	100%	84%	100%	100%	96%	100%	100%	96%
May	100%	100%	92%	100%	100%	94%	100%	100%	96%
Jun	98%	92%	74%	100%	99%	82%	100%	100%	86%
Jul	99%	92%	69%	100%	96%	73%	100%	97%	76%
Aug	100%	100%	74%	100%	100%	81%	100%	100%	82%
Sep	99%	99%	72%	100%	100%	87%	100%	100%	88%
Oct	76%	75%	42%	88%	88%	53%	92%	89%	57%
Nov	86%	82%	47%	92%	91%	58%	97%	94%	60%
Dec	94%	86%	46%	100%	96%	55%	100%	99%	62%

Light House Project (LHP), Chennai

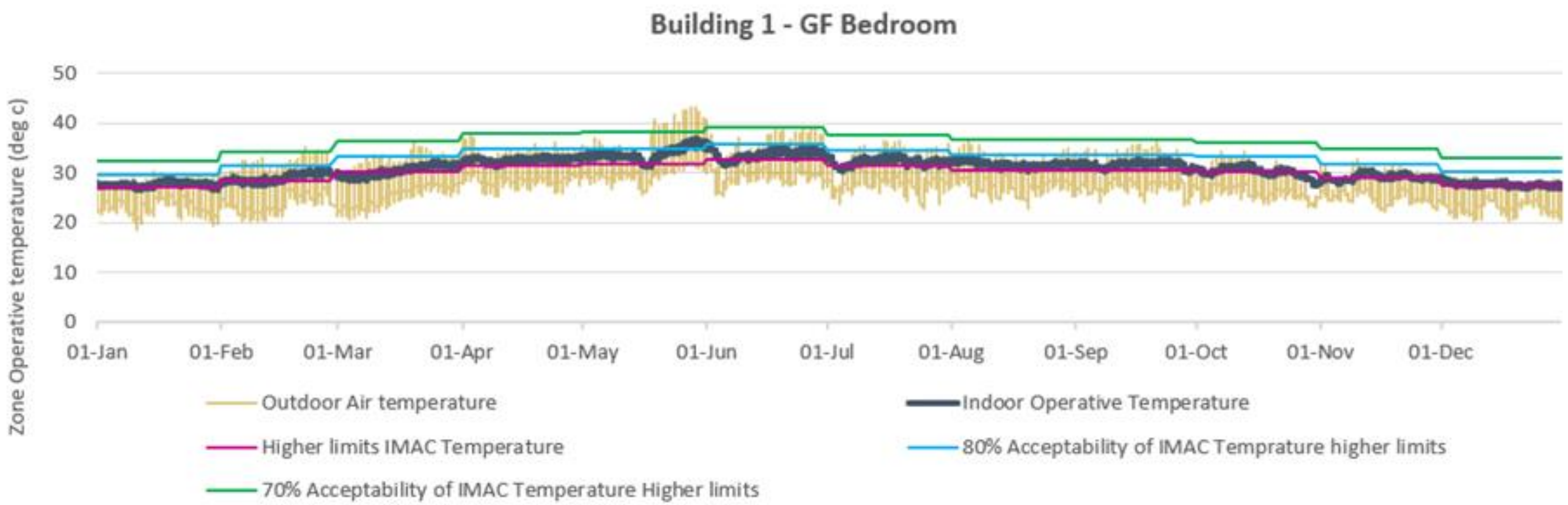
Percentage of occupied hours that meets IMAC Adaptive thermal comfort Range

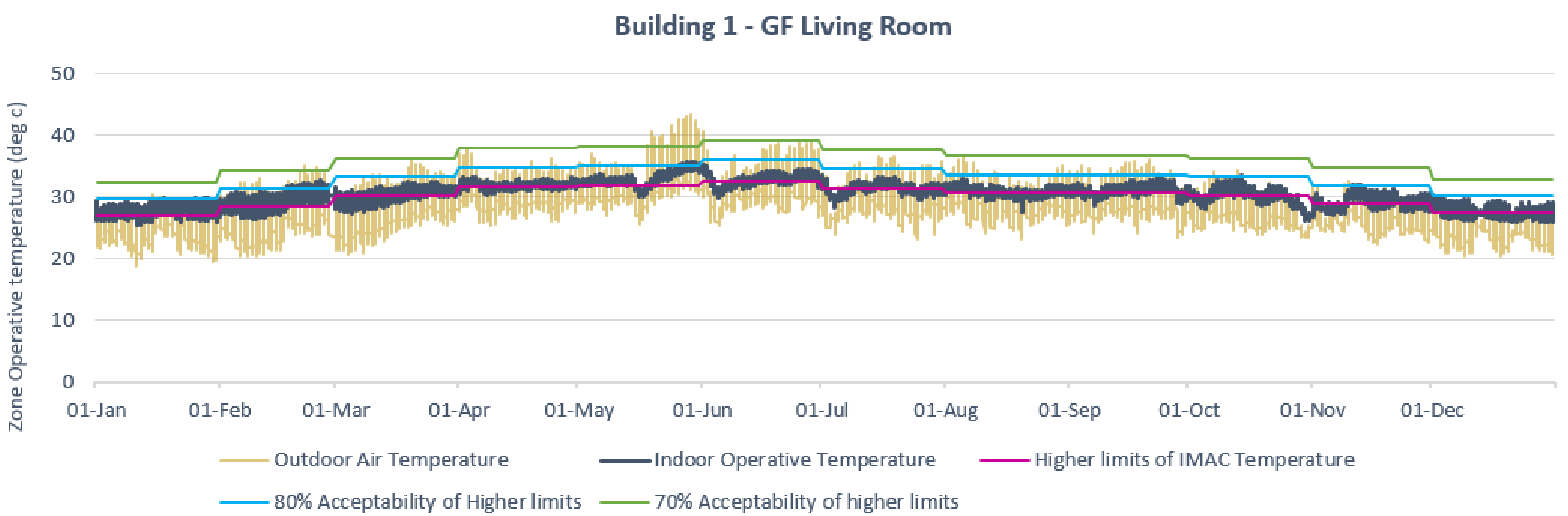
IMAC Temperature		
Month	Min	Max
January	22.31	27.07
February	23.75	28.51
March	25.52	30.28
April	26.8	31.56
May	27.06	31.82
June	27.89	32.65
July	26.67	31.43
August	25.86	30.62
September	25.82	30.58
October	25.44	30.2
November	24.17	28.93
December	22.7	27.46

Zone name	Building 5			Building 1		
	Ground floor	Middle floor	Top Floor	Ground floor	Middle floor	Top Floor
Percentage of Occupied hours within 90% acceptability limits						
Bedroom	8%	2%	1%	24%	7%	5%
Living	7%	2%	2%	25%	12%	9%
Kitchen	34%	25%	23%	40%	31%	28%
Percentage of Occupied hours within 80% acceptability limits						
Bedroom	97%	57%	34%	99%	84%	72%
Living	92%	41%	26%	98%	84%	66%
Kitchen	88%	77%	62%	88%	82%	71%
Percentage of Occupied hours within 70% acceptability limits						
Bedroom	100%	97%	92%	100%	99%	97%
Living	100%	95%	82%	100%	99%	98%
Kitchen	99%	98%	96%	99%	98%	97%

Case Study : Light House Project (LHP), Chennai

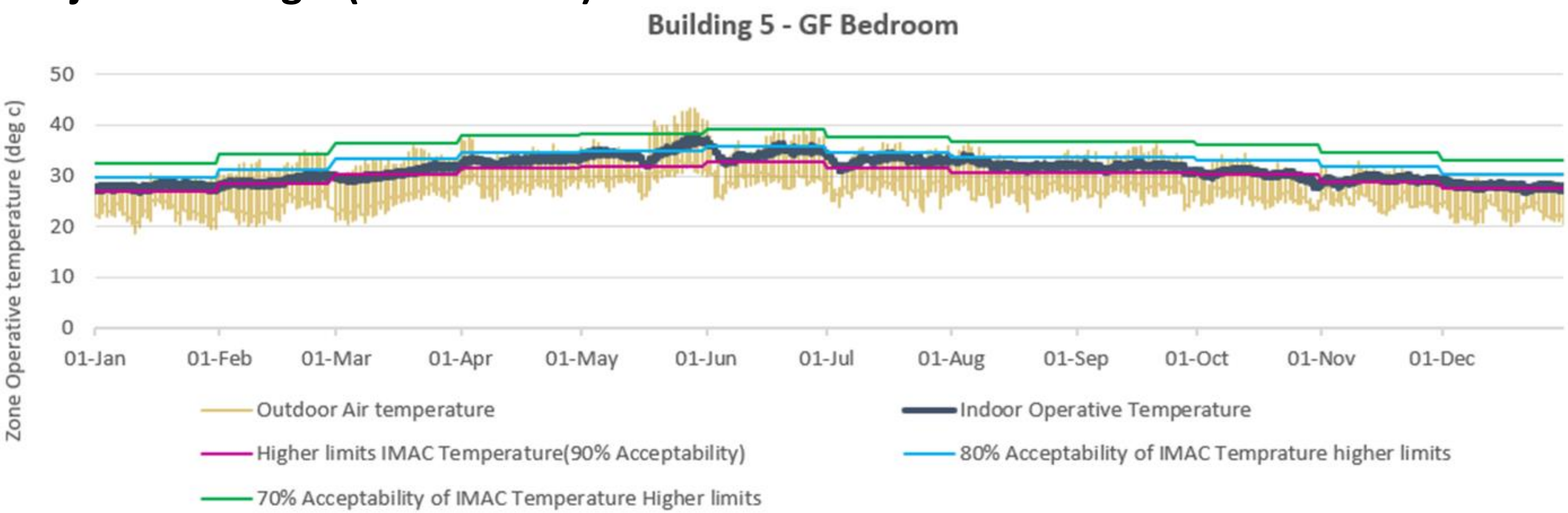
LHP Project Building 1 (North - South)

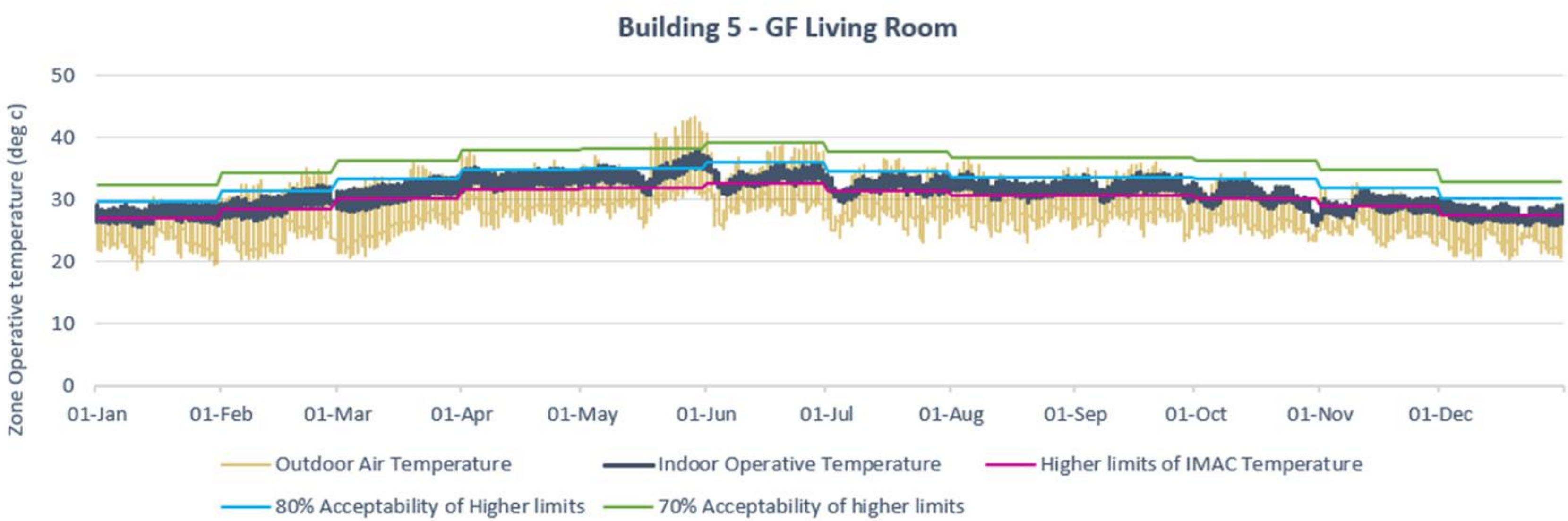




Case Study : Light House Project (LHP), Chennai

LHP Project Building 5 (East - West)





Thermal Comfort Improvement through Passive Measures

1. Large Window opening size
2. Cross ventilation
3. Shading for windows
4. Ventilator above Main door
5. EPS insulation – Under deck (At least 25 mm Thick)

LHP Site Thermal Improvements

- Dwelling units have two panel sliding window system for Living, Bedroom & kitchen openings
- Sliding windows open up only to 50% of Openable area

- Instead of using Sliding windows, **Casement windows** can provide opening up to 90% of Openable area
- This increase the quantity of fresh natural air comes into the space & aids to thermal comfort of occupants

DHP Dubrayapet, Puducherry

Introduction to Dubrayapet Project

Location of Dubrayapet site in Google map (11°55'7.87"N,79°49'49.01"E)

Location of Dubrayapet Site

- The project proposal involves development of 80 low-income housing units in a plot area of 1950Sqm adhering to the various norms of the government.
- The main road is around 450 meters from the site.
- In the proposed site the building covers the plinth area /plot coverage of 31.4%. The FAR (floor Area Ratio) achieved for the said 80 dwelling units project is 1.56 which is within the permissible limit of Puducherry Planning Authority bye- law.
- The said dwelling units fulfill all present bye laws of the line departments such Electricity, fire, Public Works department, municipality, traffic etc
- The petty shops within the premises are accomplished for the benefits of the occupants and nearby communities. Effective disposal of greywater to the Sewage treatment plant present in close proximity.
- The accumulated household wise waste is segregated with separate collecting units at source.

Project Needs

- Necessitate low-income housing for 80-90 families to have a safe all weather withstanding dwelling unit. With the possibilities to harness renewable energy through solar rooftop for the high-rise structure.
- Provide a Pucca dwelling unit for the habitants with below poverty level without need to spend for retrofitting pre and post monsoon seasons.
- To provide individual toilets to all dwelling units to improve sanitation levels by routing grey water to the nearby Sewage Treatment Plant.
- Precise day to day segregation and disposal of garbage and solid wastes of all dwelling units at the proposed site.

S.NO	STAKEHOLDER	ROLE
1.	Ministry of Housing and Urban Affairs (MoHUA)	Provision of funding for CITIIS projects
2.	National Institute of Urban Affairs (NIUA)	Handholding and rolling out of CITIIS Challenge Initiative and appointment of mentors
3.	Puducherry Smart City Development Limited (PSCDL)	Nodal Agency , Tender Inviting and Tender Receiving Authority and Project Executing Authority
4.	Technical Committee	Review and approval of Tender Documents

Key Stakeholders in the Dubrayapet project

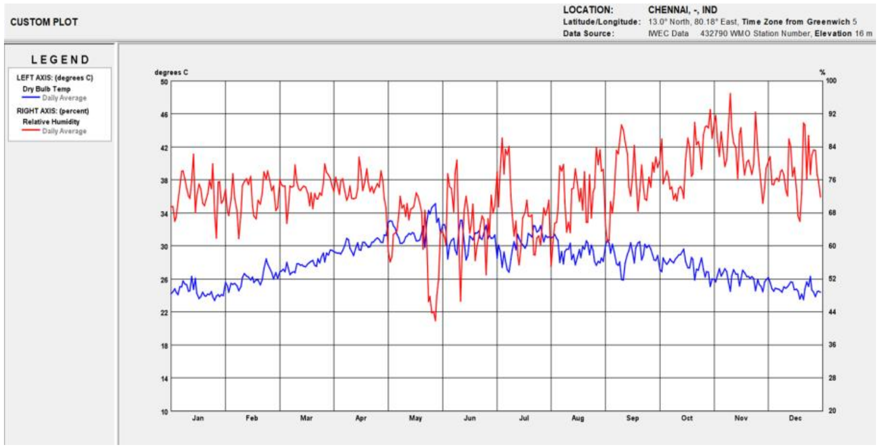
Eco Niwas Samhita (ENS) - Part 1

Eco Niwas Samhita (ENS) (Part I: Building Envelope) is a residential energy code that has been prepared to set minimum building envelope performance standards to limit heat gains (for cooling dominated climates) and to limit heat loss (for heating-dominated climates), as well as for ensuring adequate natural ventilation and daylighting potential.

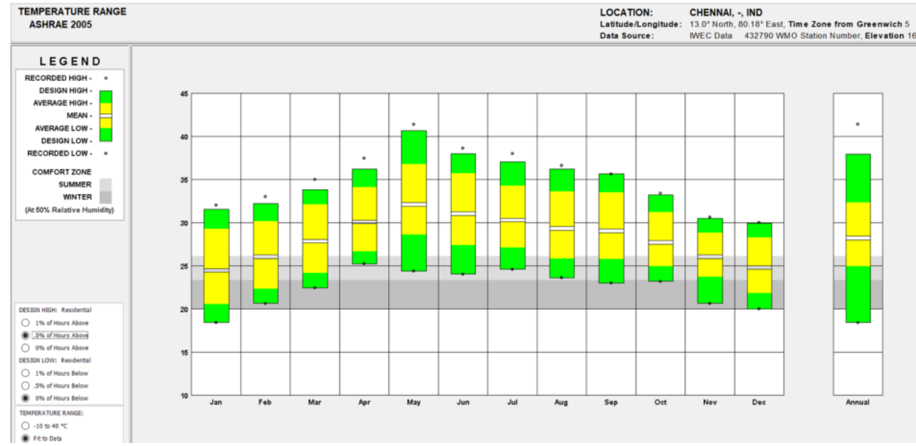
ENS Compliance Parameters	Achieved Base Case: Building 1 & 2	ENS Requirement	Compliance Status
Openable Window to Floor Area Ratio (WFR_{op})	8.37 %	≥ 16.66 %	**Not Complied**
Visible Light Transmittance (VLT)	0.51	≥ 0.27	**Complied**
Thermal Transmittance of Roof (U_{roof})	2.59 $W/m^2.K$	≤ 1.2 $W/m^2.K$	**Not Complied**
Residential Envelope Transmittance Value (RETV)	18.48 $W/m^2.K$	≤ 15 $W/m^2.K$	**Not Complied**

ENS compliance for Dubrayapet project

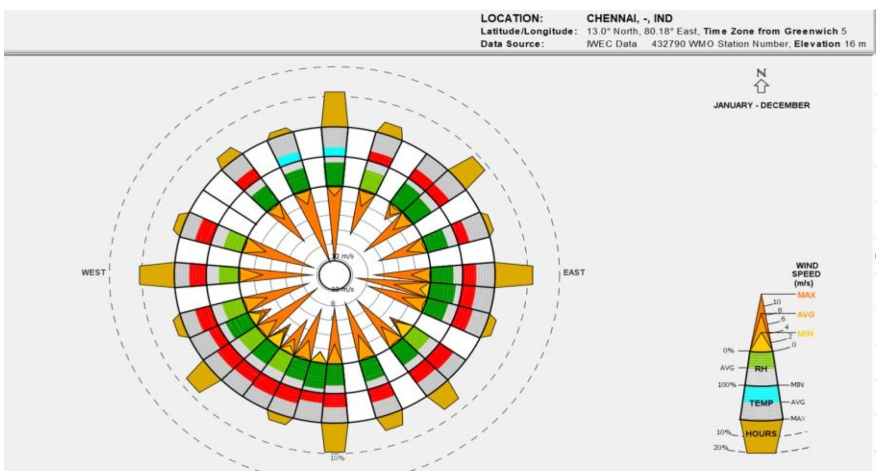
Climate Analysis - Puducherry



Temperature and Relative Humidity



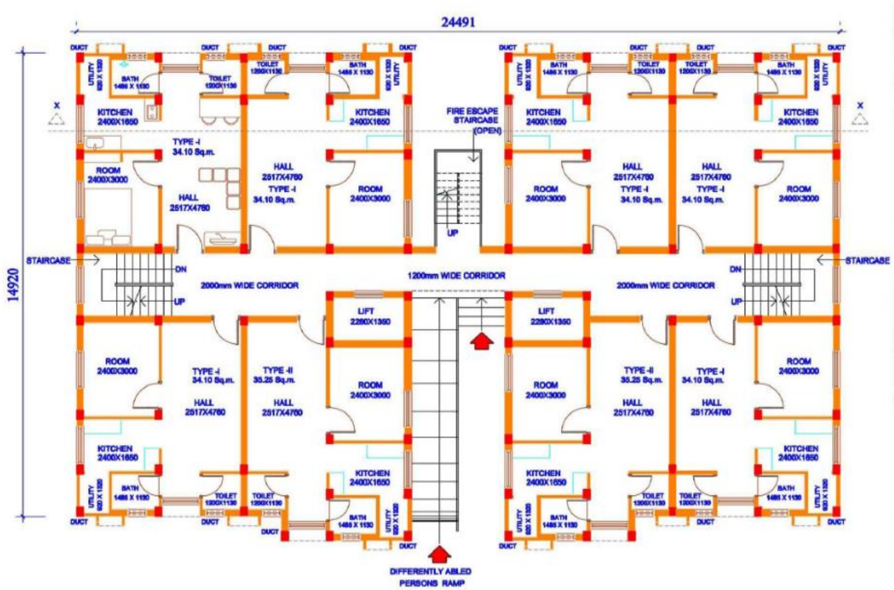
Monthly Dry Bulb Temperature (DBT) distribution



Wind Wheel

- Puducherry is placed at an altitude of 3 m.
- The Wind Wheel figure shows the wind direction is predominant in East-West at a maximum speed of 8-10 m/s, so adequate openings in this direction building should be proposed for good natural ventilation.

Building Description & Floor Plan



Floor Plan of Dubrayapet project

- This project has 2 Buildings. Each building has typical 1 BHK unit. Each 1 BHK unit has 1 bedroom, 1 toilet, Hall, Bath, kitchen and a Utility. Each tower has a total of G + 4 floors. On each floor, there are 8 units.
- The building is constructed Conventional construction with Brick wall and 18mm claY tiles for roof and Lime concrete for roof RCC roof, Single glazed units with wooden frames for building is constructed Conventional construction with Brick wall and 18mm clay tiles for roof and Lime concrete for roof RCC roof, Single glazed units with wooden frames for windows.

Cases selected for Simulation

- The project was analysed for 4 cases (Case 1, Case 2, Case 3 and Case 4) apart from the proposed construction as mentioned in the Detailed Project Report (DPR). This case is considered as the Base case.
- **Case 1:** Wall – AAC blocks; Window – Casement; Roof – Same as Base case
- **Case 2:** Wall – AAC blocks; Window – Casement window-sized modified to suit WFR requirements; Roof – Addition of 25mm EPS insulation
- **Case 3:** Wall – AAC blocks; Window – Casement + ventilators on top of windows, Glass – Single Glazed Unit with lower SHGC, Shading – Addition of vertical fins on E & W windows; Roof – Addition of 25mm EPS insulation
- **Case 4:** Wall – AAC blocks + double layer external plaster; Window – Casement + ventilators on top of windows, Glass – Single Glazed Unit with lower SHGC, Shading – Addition of vertical fins on E & W windows; Roof – Addition of 25mm EPS insulation

Building Envelope Construction Details

Envelope Type	Base Case (As per existing DPR)	Case 1	Case 2	Case 3	Case 4
Wall	Internal Cement Mortar (12 mm) + Brick wall (230mm) + External Cement Mortar (15 mm)	Internal Cement Mortar (12 mm) + AAC wall (200mm) + External Cement Mortar (15 mm)	Internal Cement Mortar (12 mm) + AAC wall (200mm) + External Cement Mortar (15 mm)	Internal Cement Mortar (12 mm) + AAC wall (200mm) + External Cement Mortar (15 mm)	Internal Cement Mortar (12 mm) + AAC wall (200mm) + External Cement Mortar (15 mm) + External Cement Mortar (10 mm)
Roof	18mm Clay tile + 25 mm Lime concrete mortar + 150mm RCC slab + 12 mm plaster thickness	18mm Clay tile + 25 mm Lime concrete mortar + 150mm RCC slab + 12 mm plaster thickness	18mm Clay tile + 25 mm Lime concrete mortar + 25 mm EPS insulation+ 150mm RCC slab + 12 mm plaster thickness	18mm Clay tile + 25 mm Lime concrete mortar + 25 mm EPS insulation+ 150mm RCC slab + 12 mm plaster thickness	18mm Clay tile + 25 mm Lime concrete mortar + 25 mm EPS insulation+ 150mm RCC slab + 12 mm plaster thickness
Fenestration & Glazing	Wood Frame SGU with 6mm glass thickness, SHGC = 0.84, VLT = 0.89; Sliding Windows	Wood Frame SGU with 6mm glass thickness, SHGC = 0.84, VLT = 0.89; Casement Windows	Wood Frame SGU with 6mm glass thickness, SHGC = 0.84, VLT = 0.89; Casement Windows size changed, bedroom window (1.65m*1.3m)	Wood Frame SGU with 6mm glass thickness, SHGC = 0.43, VLT = 0.37; Casement Windows with Base case windows added with ventilators above window	Wood Frame SGU with 6mm glass thickness, SHGC = 0.43, VLT = 0.37; Casement Windows with Base case windows added with ventilators above window
Shading	600 mm horizontal shading device on all windows.	600 mm horizontal shading device on all windows	600 mm horizontal shading device on all windows.	600 mm horizontal shading device on all windows + vertical fins on East and West windows	600 mm horizontal shading device on all windows + vertical fins on East and West windows

Project evaluation as per ENS compliance requirements

Openable Window to Floor Area Ratio (WFR_{op})

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

Openable area to Floor Ratio (WFR)				
	Openable Area (m2)	Floor Area (m2)	WFR	Minimum requirement
Base case (Sliding Window)	2.7	32.26	8.37%	16.66%
Case 1 (Casement Window)	4.86	32.26	15.07%	
Case 2 (Casement window - Bedroom size modified)	5.3865	32.26	16.70%	
Case 3,4 (Casement+Ventilators)	5.94	32.26	18.41%	

Window to Floor Area Ratio (WFR)

Climate Zone	Minimum WFR_{op} (%)
Composite	12.5
Hot-Dry	10
Warm-Humid	16.66
Temperate	12.5
Cold	8.33

minimum requirement of WFRop as per ENS code

Project evaluation as per ENS compliance requirements

Visible Light Transmittance (VLT)

Visible light transmittance (VLT) of non-opaque building envelope components (transparent/translucent panels in windows, doors, ventilators, etc.), indicates the potential of using daylight. Ensuring minimum VLT helps in improving daylighting, thereby reducing the energy required for artificial lighting. The VLT requirement is applicable as per the window-to-wall ratio (WWR) of the building. WWR is the ratio of the area of non-opaque building envelope components of dwelling units to the envelope area (excluding the roof) of dwelling units.

	WWR	Minimum VLT requirement	VLT
Basecase	0.15	0.27	**0.89**
Case 1,2	0.15	0.27	**0.89**
Case 2,3	0.18	0.27	**0.51**

Window to Wall area Ratio

Window to Wall Ratio (WWR)	Minimum VLT
0-0.3	0.27
0.31-0.4	0.2
0.41-0.5	0.16
0.51-0.6	0.13
0.61-0.7	0.11

Minimum visible light transmittance (VLT) requirement

Project evaluation as per ENS compliance requirements

Thermal Transmittance of Roof

Thermal transmittance (U_{roof}) characterizes the thermal performance of the roof of a building. Limiting the U_{roof} helps in reducing heat gains or losses from the roof, thereby improving the thermal comfort and reducing the energy required for cooling or heating. Thermal transmittance of the roof shall comply with the **maximum U_{roof} value of 1.2 W/m^2. K.**

Base Case	Outside to Inside	Thickness (m)	Specific Heat (kJ/kg K)	Density (kg/m3)	Conductivity (W/mK)	R - Value (m2 K / W)	U - Value (W/m2 K)
Roof	Brick tile	0.018	0.88	1890	0.8	0.0225	2.640234
	Lime concrete	0.025	0.84	1762	0.721	0.03467406	
	RCC slab	0.15	0.88	2288	1.58	0.09493671	
	Cement plaster	0.012	0.84	1762	0.721	0.01664355	
	Rsi					0.17	
	Rse					0.04	
	Assembly (Total)					**0.37875432**	

Thermal Transmittance of Roof for Base Case

Case 4	Outside to Inside	Thickness (m)	Specific Heat (kJ/kg K)	Density (kg/m3)	Conductivity (W/mK)	R - Value (m2 K / W)	U - Value (W/m2 K)
Roof	Brick Tile	0.018	0.88	1890	0.8	0.0225	
	Lime Concrete	0.025	0.84	1792	0.721	0.03467406	0.91488
	25 mm EPS insulation	0.025	1.34	24	0.035	0.71428571	
	Cement plaster	0.012	0.84	1762	0.721	0.01664355	
	RCC slab	0.15	0.88	2288	1.58	0.09493671	
	Rsi					0.17	
	Rse					0.04	
	Assembly (Total)					**1.09304004**	

Thermal Transmittance of Roof for Proposed Case

Project evaluation as per ENS compliance requirements

Thermal Transmittance of Roof

	U- Value in W/m2 K	U- Value in W/m2 K -Basecase	U- Value in W/m2 K - Case 1	U- Value in W/m2 K Case 2	U- Value in W/m2 K - Case 3	U- Value in W/m2 K - Case 4
Thermal Transmittance of Roof	1.2	**2.64**	**2.64**	0.92	0.92	0.92

U roof for all the Cases

The current project has its roof configuration common to all buildings. **The project has attained U-value of 2.64 W/m². K** which is higher than the prescribed limit. **Hence the building's roof configuration not complies with the ENS requirement.** A roof insulation of 25mm EPS insulation is proposed to achieve the desired thermal transmittance value. Roof insulation helps in a greater extent to reduce the heat ingress in a Warm & Humid Climate.

Project evaluation as per ENS compliance requirements

Residential Envelope Transmittance Value (RETV)

Residential envelope heat transmittance (RETV) is the net heat gain rate (over the cooling period) through the building envelope (excluding the roof) of the dwelling units divided by the area of the building envelope (excluding the roof) of the dwelling units.

RETV formula takes into account the following:

- Heat conduction through opaque building envelope components.
- Heat conduction through non-opaque building envelope components.
- Solar radiation through non-opaque building envelope components.

The RETV for the building envelope (except the roof) for four climate zones, namely, Composite Climate, Hot-Dry Climate, Warm-Humid Climate, and Temperate Climate, shall comply with the **maximum RETV of 15 W/m^2**

Project evaluation as per ENS compliance requirements

Residential Envelope Transmittance Value (RETV)

Residential Envelope Transmittance Value (RETV)

Levels	Wall						Glass											RETV (W/m2 K)	
	Properties		Net Area (m2)					Effective SHGC						Window Area (m2)					
		U value	North	East	South	West	SHGC	North	East	South	West	U value	VLT	North	East	South	West	Standard	Achieved
Basecase	Solid Burnt Clay Brick	2.07	14.25	16.50	0.00	0.00	0.84	0.73	0.63	0.00	0.00	5.8	0.89	2.28	3.12	0.00	0.00	15	18.48
Case 1	AAC Block Masonry	0.77	14.25	16.50	0.00	0.00	0.84	0.73	0.63	0.00	0.00	5.8	0.89	2.28	3.12	0.00	0.00	15	12.23
Case 2	AAC Block Masonry	0.77	14.25	15.92	0.00	0.00	0.84	0.73	0.63	0.00	0.00	5.8	0.89	2.28	3.71	0.00	0.00	15	13.01
Case 3	AAC Block Masonry	0.77	0.00	0.00	13.65	15.90	0.56	0.00	0.00	0.46	0.43	5.6	0.51	0.00	0.00	2.88	3.72	15	10.90
Case 4	AAC Block + Double layer plaster	0.760	0.00	15.90	13.65	0.00	0.56	0.00	0.43	0.46	0.00	5.6	0.51	0.00	3.72	2.88	0.00	15	8.96

RETV for all Cases

The RETV value attained for the conventional case is 18.48 W/m2K and with AAC masonry wall (12.23 W/m2K), reduces the thermal transmittance through the envelope to a greater extent.

Thermal Comfort Analysis

The project is a 1BHK house with G+4 floors. Energy simulation is carried out in Design Builder software and detailed modelling is carried out in the Energy Plus engine. The modelling is carried out for the Ground Floor, Middle Floor and Top floor units for NE, NW, SE, SW dwelling units. Detailed inputs in terms of number floors, building geometry, Envelope details, internal loads and active systems are provided in the simulation software. Detailed natural ventilation modeling is carried out in Energy plus.

The modelling methodology is adopted based on IMAC - R (Indian Model for Adaptive thermal Comfort - Residential). In the 1BHK dwelling the rooms are considered to run on 100% natural ventilation. Window operation condition is that the window opens when the Zone Operative Temperature is greater than or equal to IMAC - R Neutral Temperature (T nuet) and Outside air Temperature equal to less than Neutral Temperature or the window opens when the Zone Operative Temperature is less than Minimum IMAC (90% Acceptability) and Outside air temperature is greater than Minimum IMAC Temperature to facilitate maximum indoor thermal comfort in affordable housing.

Thermal Comfort Analysis

Level of discomfort												
	MF NW Dwelling unit			MF SW Dwelling unit			TF NW Dwelling unit			TF SW Dwelling unit		
Levels	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average
Basecase	8760	8691	**8717**	8759	8666	**8701**	8743	8663	**8693**	8745	8684	**8707**
Case-1	4111	3610	**3798**	4033	3110	**3457**	6983	8380	**7855**	6950	6174	**6466**
Case-2	4112	3607	**3797**	4037	3110	**3459**	5480	8548	**7395**	5331	4385	**4741**
Case-3	3175	3172	**3173**	3035	2861	**2926**	4745	6467	**5820**	4921	4150	**4440**
Case-4	3144	3114	**3125**	2978	2788	**2859**	4749	6414	**5788**	4925	4137	**4433**

Annual Level of Discomfort hours for select Dwelling Units

Percentage of Discomfort hours												
	MF NW Dwelling unit			MF SW Dwelling unit			TF NW Dwelling unit			TF SW Dwelling unit		
Levels	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average
Basecase	100%	99%	**100%**	100%	99%	**99%**	100%	99%	**99%**	100%	99%	**99%**
Case-1	47%	41%	**43%**	46%	36%	**39%**	80%	96%	**90%**	79%	70%	**74%**
Case-2	47%	41%	**43%**	46%	36%	**39%**	63%	98%	**84%**	61%	50%	**54%**
Case-3	36%	36%	**36%**	35%	33%	**33%**	54%	74%	**66%**	56%	47%	**51%**
Case-4	36%	36%	**36%**	34%	32%	**33%**	54%	73%	**66%**	56%	47%	**51%**

Annual Percentage of Discomfort hours for select Dwelling Units

Thermal Comfort Analysis

Level of discomfort												
	MF NW Dwelling unit			MF SW Dwelling unit			TF NW Dwelling unit			TF SW Dwelling unit		
Levels	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average
Basecase	4392	4392	**4392**	4392	4392	**4392**	4392	4392	**4392**	4392	4392	**4392**
Case-1	3389	3041	**3172**	3128	2661	**2837**	4172	4347	**4281**	4119	3903	**3984**
Case-2	3390	3039	**3171**	3129	2661	**2837**	4046	4387	**4259**	3800	3462	**3589**
Case-3	2726	2639	**2672**	2438	2377	**2400**	3666	4181	**3987**	3521	3161	**3296**
Case-4	2720	2621	**2658**	2414	2357	**2378**	3707	4118	**3963**	3582	3220	**3356**

Summer Months (Apr - Sept) Level of Discomfort Hours for select Dwelling Units

Percentage of Discomfort hours												
	MF NW Dwelling unit			MF SW Dwelling unit			TF NW Dwelling unit			TF SW Dwelling unit		
Levels	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average	Bedroom	Living Room	Area weighted average
Basecase	50%	50%	**100%**	50%	50%	**100%**	50%	50%	**100%**	50%	50%	**100%**
Case-1	39%	35%	**72%**	36%	30%	**65%**	48%	50%	**97%**	47%	45%	**45%**
Case-2	39%	35%	**72%**	36%	30%	**65%**	46%	50%	**97%**	43%	40%	**41%**
Case-3	31%	30%	**61%**	28%	27%	**55%**	42%	48%	**91%**	40%	36%	**38%**
Case-4	31%	30%	**61%**	28%	27%	**54%**	42%	47%	**90%**	41%	37%	**38%**

Summer Months (Apr - Sept) Percentage of Discomfort Hours for select Dwelling Units

Thermal Comfort Analysis

Inference

From the Discomfort hours and percentage, it is clearly understood that for a Warm & Humid climate the following passive design recommendations needs to be considered

- Envelope with lower Thermal conductivity, Higher thermal mass for walls, double plastering, Higher WWR
- Higher window openable area (WFR), Ventilators on top of Windows to facilitate stack ventilation and promote cross ventilation
- Roof with lower thermal conductivity by adding adequate insulation

Cost Implication

Cost for construction for Base Case: INR 56,24,385

Base Case						
	Unit	**Specification**	**Quantity**	**Unit cost (Rs./-)**	**Costing/block (Rs./-)**	**Source**
Wall	cum	230mm brick	369.84	₹ 6,184.12	₹ 22,87,134.94	DPR Serial No:26
Plaster	sqm	15mm external	1608	₹ 271.42	₹ 4,36,443.36	DPR Serial No:48
Plaster	sqm	12mm internal	1608	₹ 179.60	₹ 2,88,796.80	DPR Serial No:49
Window (glass)	sqm	Sliding Windows, SGU; SHGC = 0.84	216	₹ 537.00	₹ 1,15,992.00	CPWD SOR
Roof finishing	sqm	Bitumen Paint + 18mm Clay brick tiles+25mm Lime Mortar	332		₹ 21,41,650.00	DPR Serial No:VIII
Shading device	sqm	Horizontal shading device	634	₹ 558.94	₹ 3,54,367.96	CPWD SOR
Total Material Cost (Rs./-)					**₹ 56,24,385.06**	

Cost Implication

Cost for construction for Case 1: INR 51,71,657

		Case-1				
	Unit	Specification	Quantity	Unit cost (Rs./-)	Costing/block (Rs./-)	Source
Wall	cum	200 mm AAC	369.84	₹ 4,960.00	₹ 18,34,406.40	CPWD SOR
Plaster	sqm	15mm external	1608	₹ 271.42	₹ 4,36,443.36	DPR Serial No:48
Plaster	sqm	12mm internal	1608	₹ 179.60	₹ 2,88,796.80	DPR Serial No:49
Window (glass)	sqm	Casement Windows, SGU; SHGC = 0.84	216	₹ 537.00	₹ 1,15,992.00	CPWD SOR
Roof finishing	sqm	Bitumen Paint + 18mm Clay brick tiles+25mm Lime Mortar	332		₹ 21,41,650.00	DPR Serial No:VIII
Shading device	sqm	Horizontal shading device	634	₹ 558.94	₹ 3,54,367.96	CPWD SOR
Total Material Cost (Rs./-)					**₹ 51,71,656.52**	

Cost Implication

Cost for construction for Case 2: INR 53,30,604

		Case-2				
	Unit	**Specification**	**Quantity**	**Unit cost (Rs./-)**	**Costing/block (Rs./-)**	**Source**
Wall	cum	200 mm AAC	369.84	₹ 4,960.00	₹ 18,34,406.40	CPWD SOR
Plaster	sqm	15mm external	1608	₹ 271.42	₹ 4,36,443.36	DPR Serial No:48
Plaster	sqm	12mm internal	1608	₹ 179.60	₹ 2,88,796.80	DPR Serial No:49
Window (glass)	sqm	Casement Windows, SGU; SHGC = 0.84; Bedroom window (1.65m*1.3m)	252	₹ 537.00	₹ 1,35,324.00	CPWD SOR
Roof finishing	sqm	Bitumen Paint + 18mm Clay brick tiles+25mm Lime Mortar + 25 mm EPS insulation	332	368 (Unit cost of EPS insulation)	₹ 22,63,826.00	DPR Serial No:VIII
Shading device	sqm	Horizontal shading device + Vertical fins for 2 windows Bedroom and Kitchen (E&W) windows (0.3*1.3m)	665.2	₹ 558.94	₹ 3,71,806.89	CPWD SOR
Total Material Cost (Rs./-)					**₹ 53,30,603.45**	

Cost Implication

Cost for construction for Case 3: INR 53,31,892

		Case-3				
	Unit	**Specification**	**Quantity**	**Unit cost (Rs./-)**	**Costing/block (Rs./-)**	**Source**
Wall	cum	200 mm AAC	369.84	⍰ 4,960.00	⍰ 18,34,406.40	CPWD SOR
Plaster	sqm	15mm external al	1608	⍰ 271.42	⍰ 4,36,443.36	DPR Serial No:48
Plaster	sqm	12mm internal	1608	⍰ 179.60	⍰ 2,88,796.80	DPR Serial No:49
Window (glass)	sqm	Casement Windows, SGU; SHGC = 0.56 + ventilators on top of two windows; Bedroom and Living room window (0.5*1.2m)	254.4	⍰ 537.00	⍰ 1,36,612.80	CPWD SOR
Roof finishing	sqm	Bitumen Paint + 18mm Clay brick tiles+25mm Lime Mortar + 25 mm EPS insulation	332	368 (Unit cost of EPS insulation)	⍰ 22,63,826.00	DPR Serial No:VIII
Shading device	sqm	Horizontal shading device + Vertical fins for 2 windows Bedroom and Kitchen (E&W) windows (0.3*1.3m)	665.2	⍰ 558.94	⍰ 3,71,806.89	CPWD SOR
Total Material Cost (Rs./-)					**⍰ 53,31,892.25**	

Cost Implication

Cost for construction for Case 4: INR 56,20,689

		Case-4				
	Unit	**Specification**	**Quantity**	**Unit cost (Rs./-)**	**Costing/block (Rs./-)**	**Source**
Wall	cum	200 mm AAC	369.84	₹ 4,960.00	₹ 18,34,406.40	CPWD SOR
Plaster	sqm	15mm external + 10mm external	1608	₹ 451.02	₹ 7,25,240.16	DPR Serial No:48
Plaster	sqm	12mm internal	1608	₹ 179.60	₹ 2,88,796.80	DPR Serial No:49
Window (glass)	sqm	Casement Windows, SGU; SHGC = 0.56 + ventilators on top of two windows; Bedroom and Living room window (0.5*1.2m)	254.4	₹ 537.00	₹ 1,36,612.80	CPWD SOR
Roof finishing	sqm	Bitumen Paint + 18mm Clay brick tiles+25mm Lime Mortar + 25 mm EPS insulation	332	368 (Unit cost of EPS insulation)	₹ 22,63,826.00	DPR Serial No:VIII
Shading device	sqm	Horizontal shading device + Vertical fins for 2 windows Bedroom and Kitchen (E&W) windows (0.3*1.3m)	665.2	₹ 558.94	₹ 3,71,806.89	CPWD SOR
Total Material Cost (Rs./-)					**₹ 56,20,689.05**	

Conclusion and Remarks

Cost implication of proposed Cases

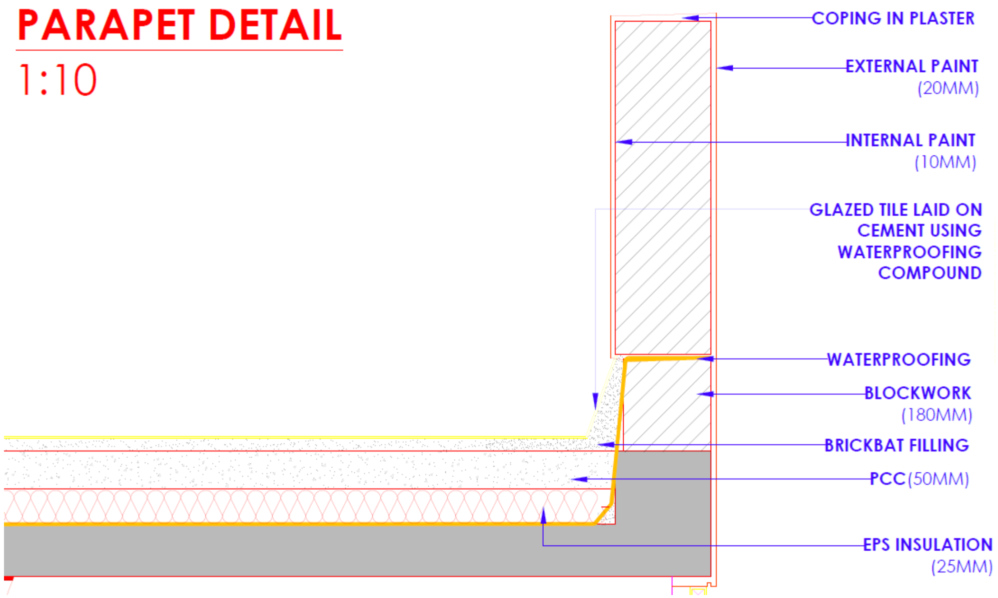
Base Case	Case 1	Case 2	Case 3	Case 4
56,24,385	51,71,657	53,30,603	53,31,892	56,20,689
NA	4,52,729	2,93,782	2,92,493	3,696
NA	8.05%	5.22%	5.20%	0.07%

- It is recommended to go for Case 2;
    - AAC wall
    - 25 mm EPS roof insulation
    - Casement windows with an increase in the size of the bedroom window

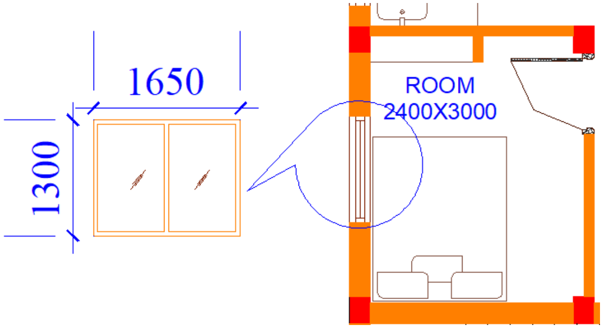
Conclusion and Remarks

- AAC wall

- 25 mm EPS roof insulation



- Casement windows with an increase in the size of the bedroom window



Life Cycle Cost

Life Cycle Analysis

Life cycle analysis (LCA) is a method used to evaluate the environmental impact of a product through its life cycle encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling, and final disposal.

Life-cycle analysis (LCA) is a primary tool used to support decision-making for sustainable development. Crucially, an LCA is a comprehensive method for assessing all **direct and indirect environmental impacts** across the full life cycle of a product system, from materials acquisition, to manufacturing, to use, and to final disposition (disposal or reuse).

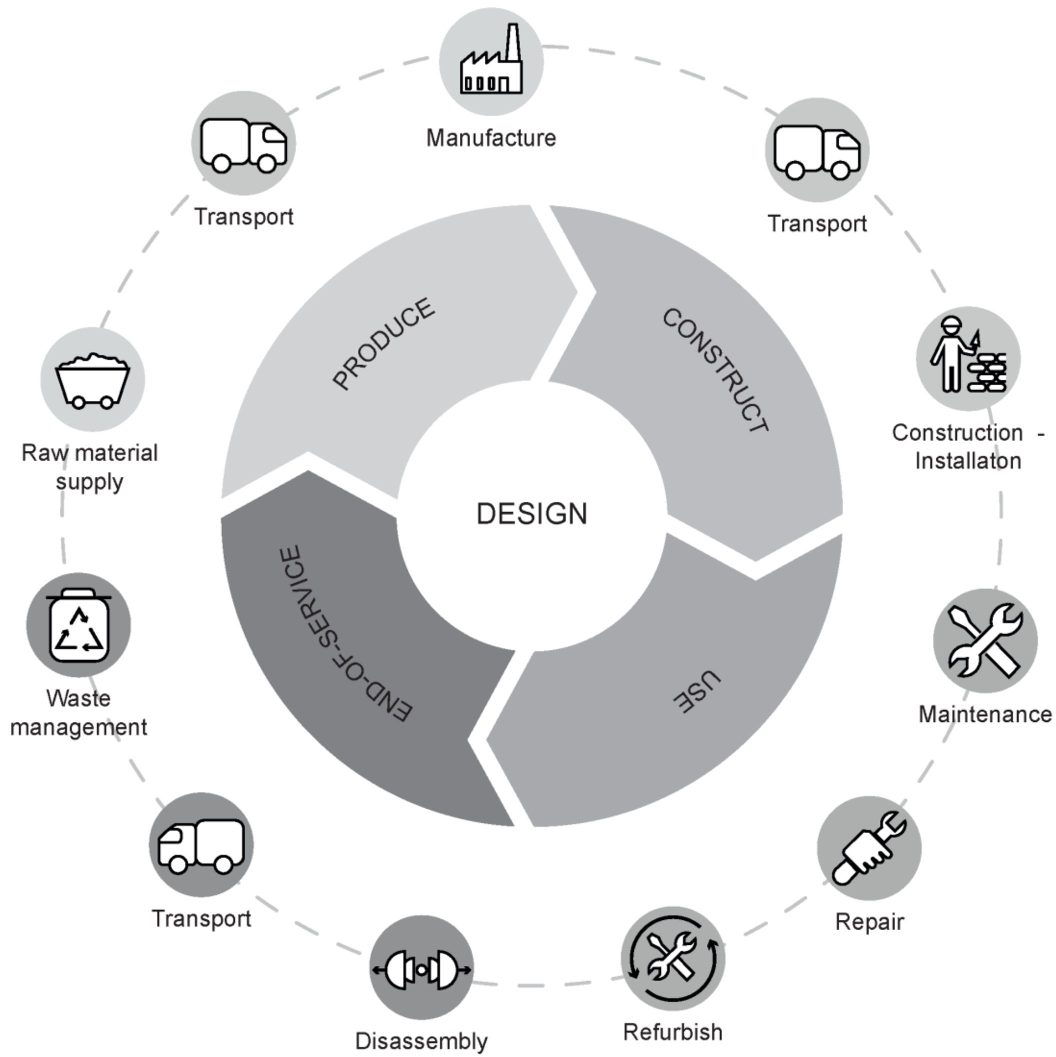
Life Cycle Cost

Life cycle costing is an economic appraisal technique used to **evaluate different investment alternatives** by taking into account cost and saving associated with each investment alternative along a period of analysis often determined by a period of commercial interest. In the construction sector, it is used to compare different design alternatives for a building, or a system considering the life cycle cost and saving associated with each design option

Life cycle costing for building is a method used to assess the anticipated economic performance of a building throughout its life cycle which includes:

- Design
- Construction
- Operation and Maintenance
- Disposal

Life Cycle Cost



Source: https://ocw.tudelft.nl/course-readings/3-1-2-life-cycle-of-a-building/

Session 2: Importance of Thermal comfort

Handbook – Climate Smart Buildings

COMPENDIUM OF LHP CHENNAI & RAJKOT

The compendiums capture the journey of design, planning and construction of Light House Projects at Chennai and Rajkot. It lays emphasis on the construction technologies used in the two LHPs along with the construction process, the project management & monitoring. Further, it documents the series of activities being undertaken under the Live Laboratory component of GHTC-India for disseminating the learning on use of innovative technologies for various stakeholders.

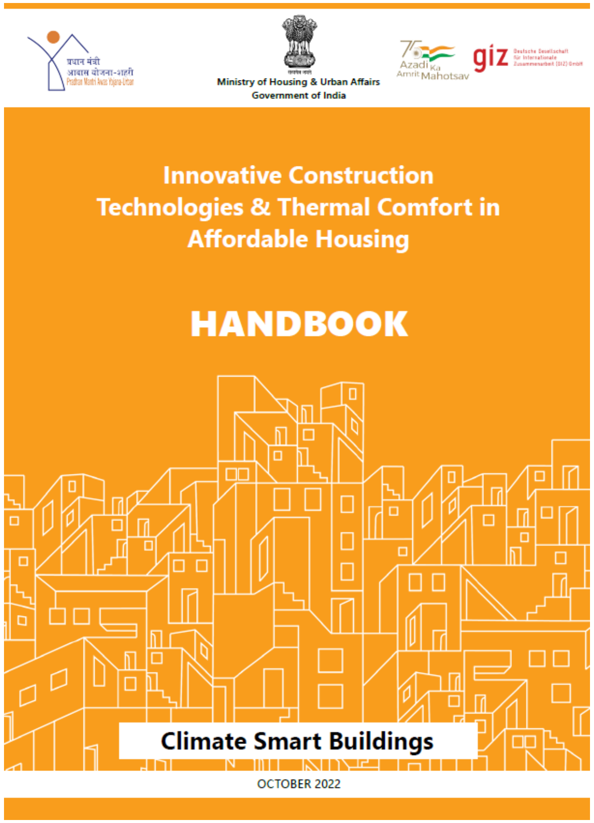
HANDBOOK ON INNOVATIVE CONSTRUCTION TECHNOLOGIES AND THERMAL COMFORT IN AFFORDABLE HOUSING

The handbook is a comprehensive resource material on thermal comfort fundamentals and detailed exploration on innovative construction technologies. The handbook will equip the readers with theoretical knowledge, and with tools that will enhance their skills on mainstreaming thermal comfort in affordable housing.

Handbook – Climate Smart Buildings

"This One-Word, in the context of climate, can become the basic foundation of One World. This is a word- LIFE...L, I, F, E, i.e. Lifestyle For Environment Today, there is a need for all of us to come together, together with collective participation, to take Lifestyle For Environment (LIFE) forward as a campaign. This can become a mass movement of Environmental Conscious Lifestyle. What is needed today is mindful and deliberate utilization, instead of Mindless and destructive Consumption. These movements together can set goals that can revolutionize many sectors such and diverse areas such as Fishing, Agriculture, Wellness, Dietary Choices, Packaging, Housing, Hospitality, Tourism, Clothing, Fashion, Water Management and Energy."

~ Narendra Modi, Hon'ble Prime Minister at COP26 Summit in Glasgow, 1st November 2021



Ministry of Housing & Urban Affairs
Government of India

Innovative Construction Technologies & Thermal Comfort in Affordable Housing

HANDBOOK

Climate Smart Buildings

OCTOBER 2022

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

Supported by

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Climate Smart Buildings (IGEN-CSB),
B-5/5, Safdarjung Enclave, New Delhi 110029, India

Knowledge Partner

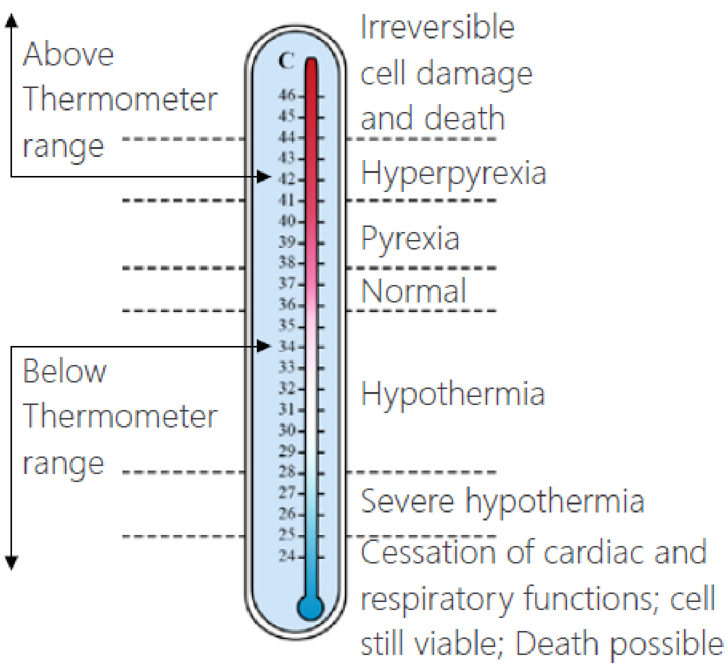
CEPT Research and Development Foundation (CRDF)
CEPT University, K.L. Campus, Navrangpura,
Ahmedabad 380009, India

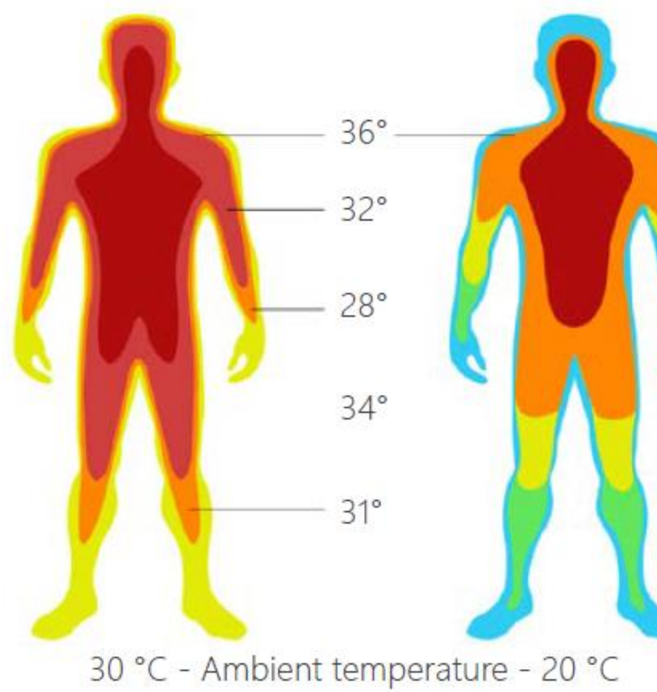
Development Team

Prof. Rajan Rawal, Ph.D., CRDF, CEPT University
Bhavya Pathak, CRDF, CEPT University
Prof. Yash Shukla, Ph.D., CRDF, CEPT University
Dr. Shailesh Kr. Agrawal, BMTPC
Manish Kumar, Consultant, MoHUA
S Vikash Ranjan, GIZ
Govinda Somani, GIZ
Prof. Rashmin Damle, CEPT University
Palak Patel, CRDF, CEPT University

Thermal comfort & Cooling Demand

Thermal Condition of Human Body





Comfort Band

Skin surface temperature

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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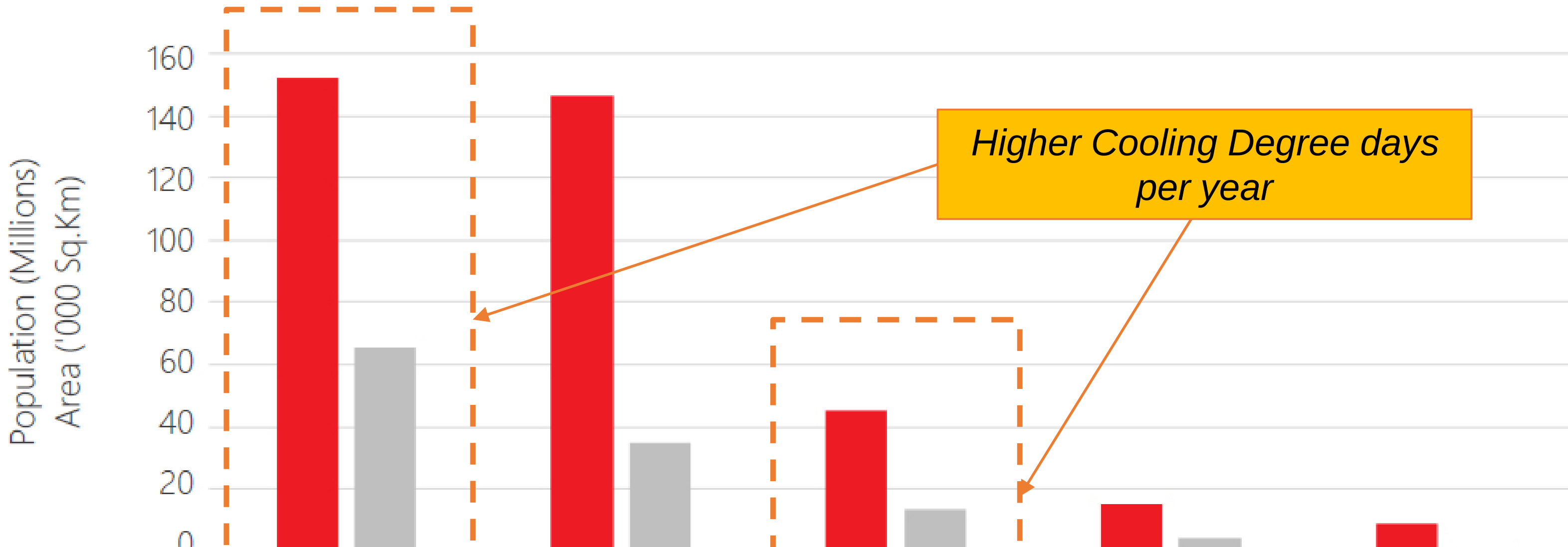
Cooling Demand in India



	Warm-humid	Composite	Hot-Dry	Cold	Temperate
Population	152.2	147.0	45.8	15.3	9.5
Area	65.8	35.5	13.6	4.6	1.0

Population (Millions) Area (in '000 sq. km.)

Climate zone wise area & population distribution in India

Sources: Senses 2011, GoI

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

GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA

Ministry of Housing and Urban Affairs
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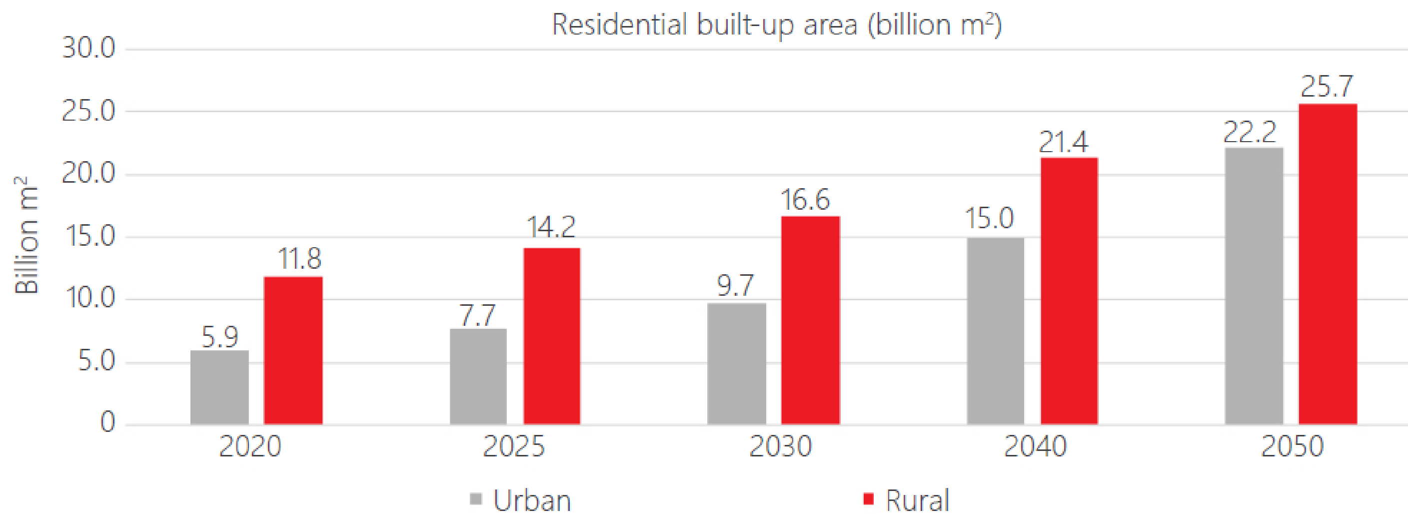
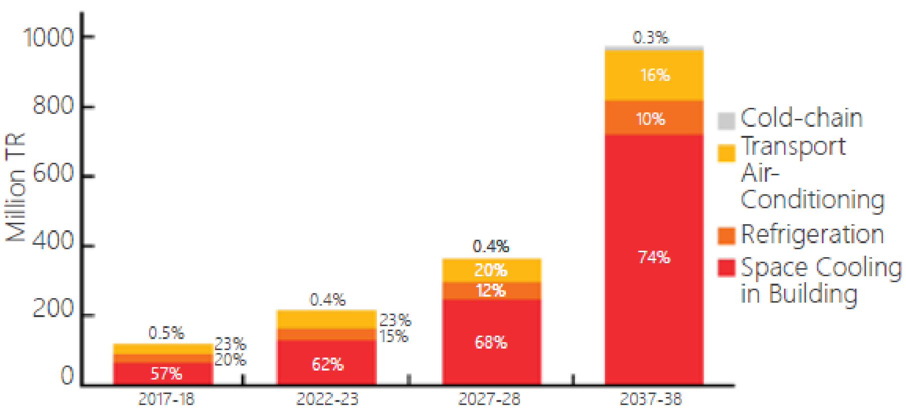
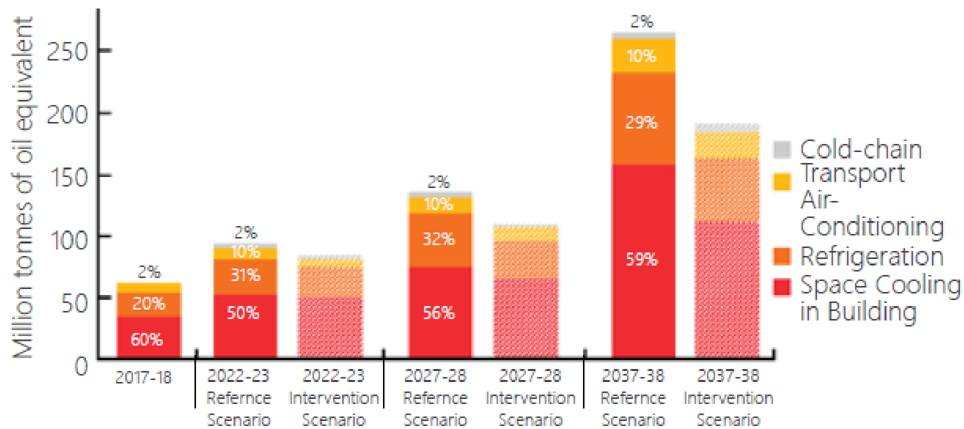
Cooling Demand in India



Projected increase in residential built up area in rural & urban India

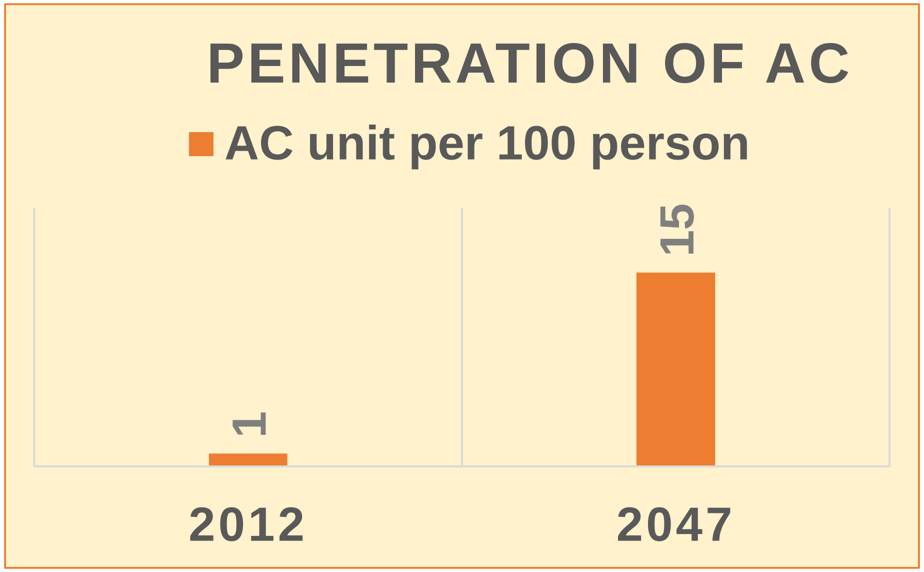


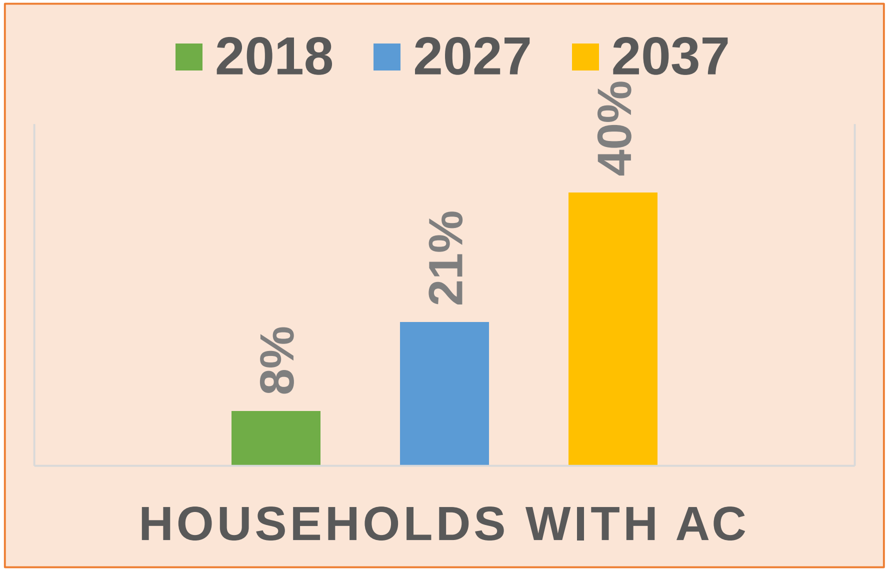


Sector wise growth in cooling demand in India - ICAP

Increase in AC demand in the Residential Sector

In 2017, approximately 272 million households were estimated in India which will increase to 328 and 386 million in 2027 and 2037 respectively.





Source: Ministry of Environment, Forest & Climate Change. (2019). India Cooling Action Plan & NITI Aayog 2015

Factors affecting Thermal comfort & Cooling Demand

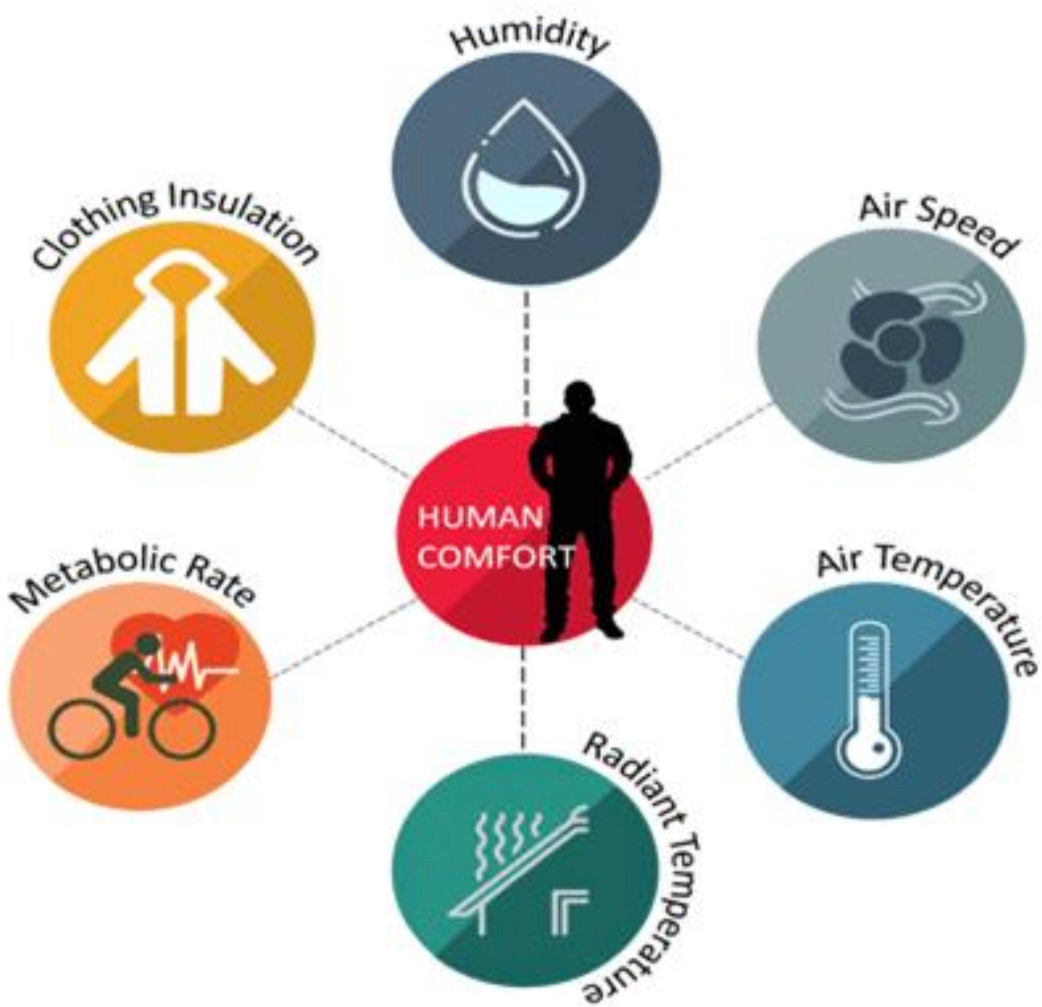
Thermal Comfort – Definition

It is defined as "that condition of mind which expresses satisfaction with the thermal environment." This condition is also some times called as "neutral condition", though in a strict sense, they are not necessarily same for everyone.

Internationally Engineers & designers look up to following standards for thermal comfort conditions:

- **ASHRAE 55** (American Society of Heating, Refrigerating, and Air Conditioning Engineers)
- **ISHRAE** (Indian Society of Heating, Refrigerating, and Air Conditioning Engineers)
- **IMAC** (Indian Model for Adaptive Thermal Comfort)

Thermal Comfort – Indices



Source: https://www.simscale.com/blog/2019/08/what-is-ashrae-55-thermal-comfort/

Thermal Comfort Indices – Metabolic Rate

Source: https://www.simscale.com/blog/2019/08/what-is-ashrae-55-thermal-comfort/

Thermal Comfort Indices – Clothing Insulation

- The clothing factor used to represent the thermal insulation from clothing
- The unit for measuring the resistance offered by clothes is called as "clo"

  - Radiation heat loss/gain
  - Convection heat loss/gain
  - Surface area exposed

  - 1 clo : 0.155 m^2K/W
  - Winter clothing : 1.0 clo
  - Summer clothing : 0.5 clo

Trouser+ Half Sleeves	Jeans + Blazer	Woollen Clothes

0.6 clo	1.0 clo	1.5 clo

Thermal Comfort – Impact of Radiant Temperature

The mean radiant temperature accounts for the radiant heat transferred from the surfaces of an enclosure to a point in space.

It is dependent on the ability of a surface to emit the incident heat, also known as emissivity of the material.

The MRT is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure.

It is calculated using globe temperature (Tg) measured using a globe thermometer and air temperature (Ta).

The average of mean radiant and ambient air temperatures, weighted by their respective heat transfer coefficients is termed indoor operative temperature (ASHRAE, 2021)

Thermal Comfort Indices – Environmental Factors

Indices	Air Speed	Humidity	Air Temperature
Definitions	Rate of Air Movement	Percentage of the amount of moisture the air could possibly hold	Average temperature of air surrounding an occupant
Controls	Fan Speed Wind speed Window Opening	Humidifier Dehumidifier	Insulated Envelope Heat Ingress/Egress
Heat Influence	Convective Evaporative	Evaporation	Convective Evaporative

Thermal Comfort Indices – Environmental Factors

Problems due to High Humid Conditions

- ❑ Stuffy air
- ❑ Condensation on windows and walls
- ❑ Mold spots or water stains
- ❑ Musty smells
- ❑ Allergies
- ❑ Skin problems
- ❑ Swollen woods
- ❑ Moist fabrics

Problems due to Low Humid Conditions

- ❑ Dry air
- ❑ Allergies
- ❑ Vulnerable to Cold
- ❑ Infections
- ❑ Itchy & Dry Skin
- ❑ Damage to wood furniture & paints
- ❑ Increased static electricity
- ❑ Electronics damage

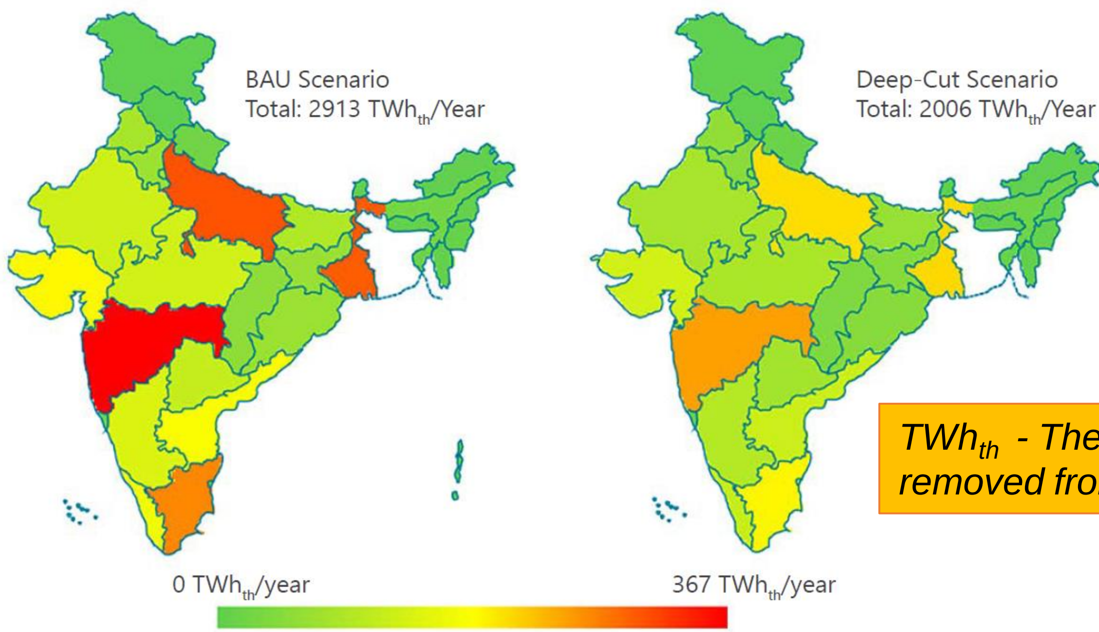
Contemporary Approaches

Contemporary approaches to reduce demand

Deep cut scenarios

Proposition of implementing aggressive measures

- Improved building technologies & cooling technologies
- Target values for Residential Envelope Transmittance Value (RETV)
- Target values for Roof thermal conductivity
- Improved COP targets



TWh$_{th}$ - Thermal energy to be removed from space

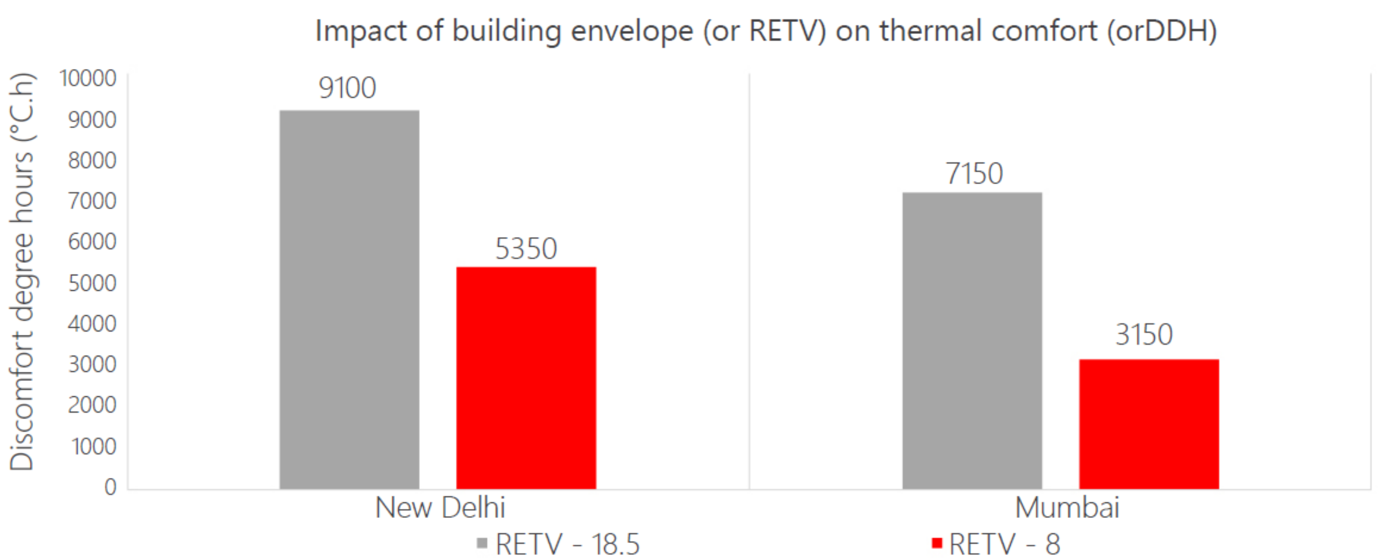
Urban residential space cooling energy requirement in 2050

Contemporary approaches to reduce demand

Impact of Building Envelope

Lock-in period & retrofit

- Building life span – 50 to 60 years
- Lock in period for Lighting systems – 2 to 5 years
- Lock in period for HVAC systems – 7 to 12 years
- **Lock in period/Retrofit for Envelope – 12 to 20 years** (*Leads to higher energy & environmental cost*)



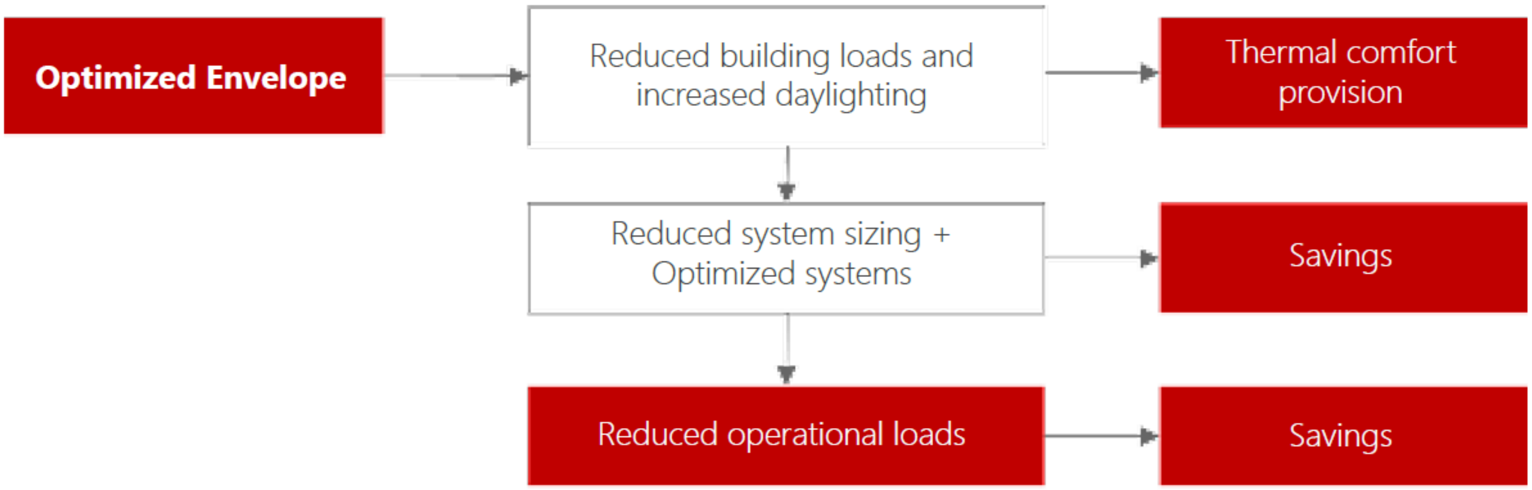
DDH is a measure of the degree of heating or cooling needed to obtain thermally comfortable indoor environment

Contemporary approaches to reduce demand

Provision in Codes

Minimum Energy Performance

- Energy Conservation Building Code 2007 & 2017 – Commercial buildings
- Eco Niwas Samhita Part 1 2018 – Building Envelope
- Eco Niwas Samhita Part 2 2021 – Building Systems
- **Thermal comfort provision**

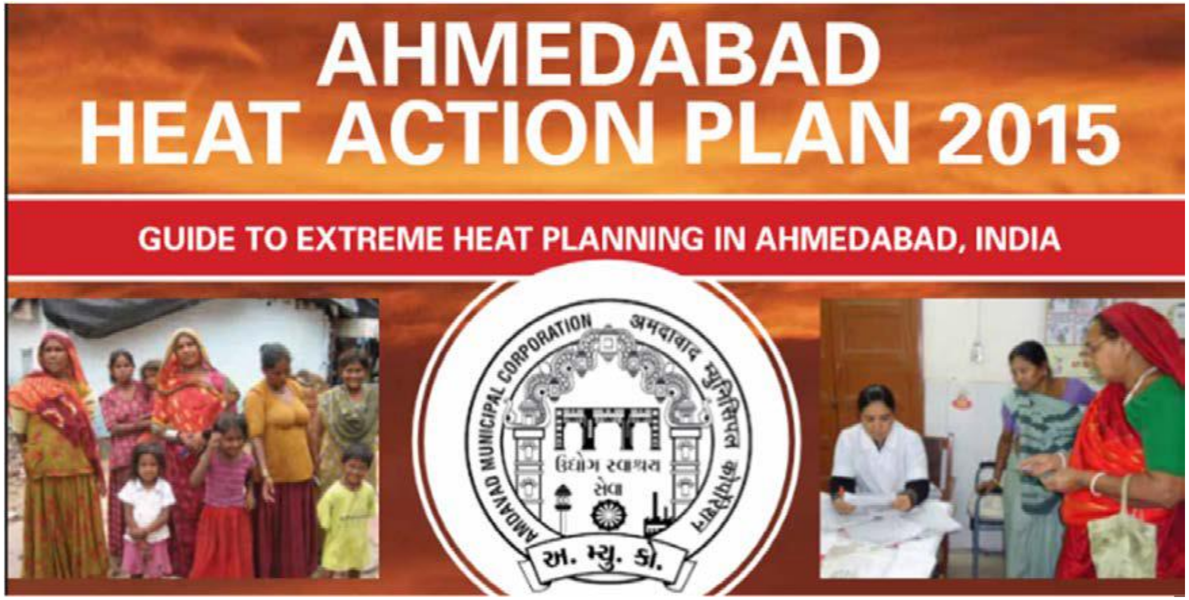


Contemporary approaches to reduce demand

Heat Action Plan

Frameworks for extreme climate

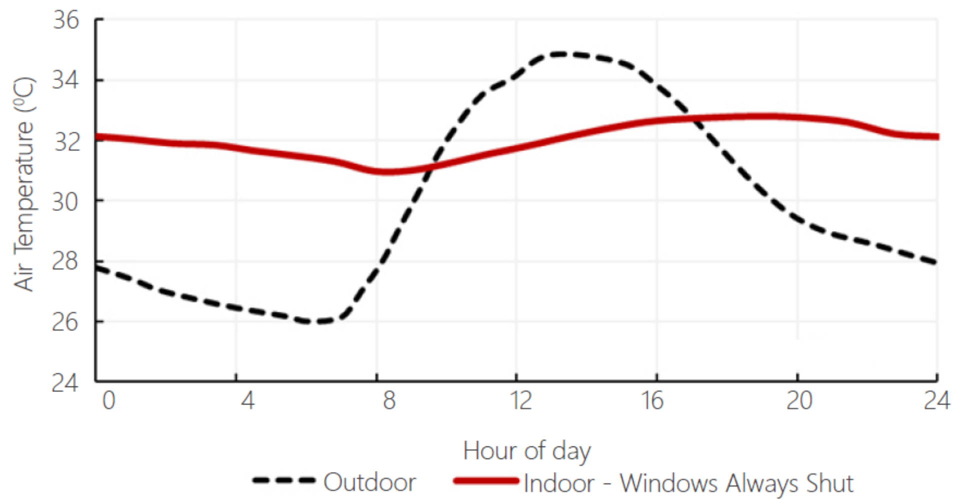
- Ahmedabad Heat Action Plan 2015
- India Cooling Action Plan
- TN Climate Change Action PLan



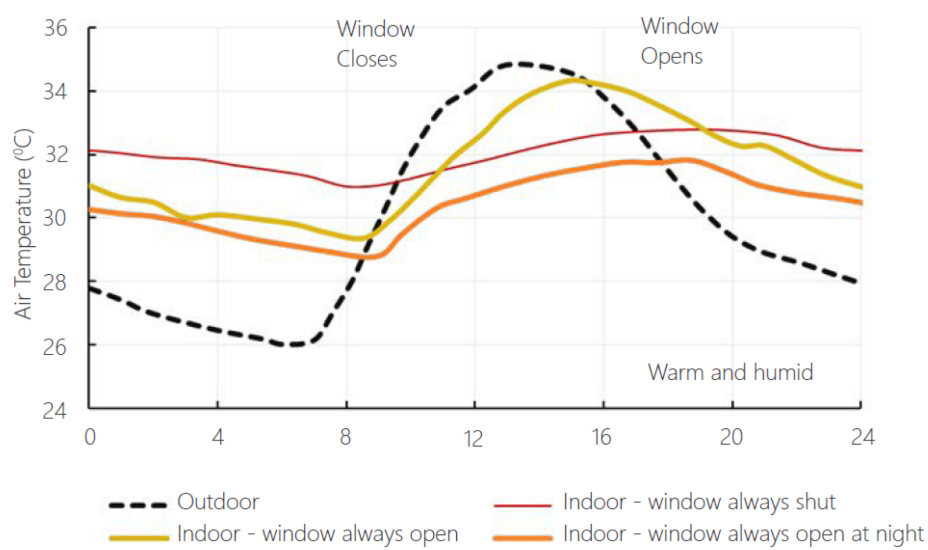
Thermal comfort Metrics

Spatial Characteristics

Impact on Heat Gains due to reduced convections



Impact on Heat Gains due to measured convections



Impact of design strategies

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

V. Low   Low   Neutral   High   V. High

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

Impact of design strategies on heat transfer through building envelope in different climates

Metrics for building envelope elements

Source: Rawal, R., 2021. Heat Transfer And Your Building Envelope, Solar Decathlon India

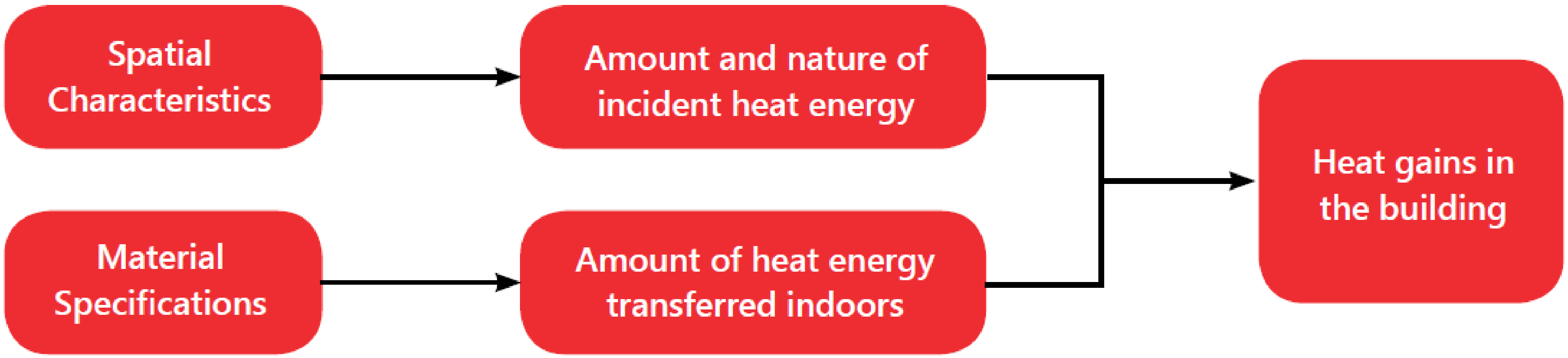
Parameter	Metric	Building envelope element
Thermal Conductivity	R value – U value	Walls • Internal • **External**
Thermal Mass	Specific heat capacity	
Thermal Conductivity (Frames and Glass)	R value – U value	**Fenestration** • **Windows** • Skylights • Doors
Solar Gains	Solar Heat Gain Coefficient	
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

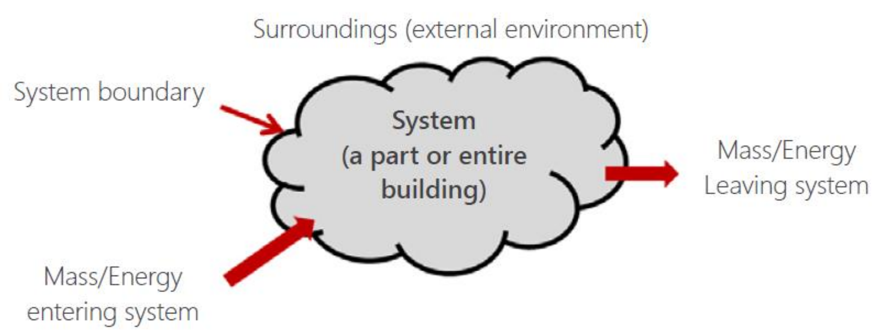
Session 3: Building Physics & Fundamentals of Thermal comfort

Thermal comfort & Cooling Demand

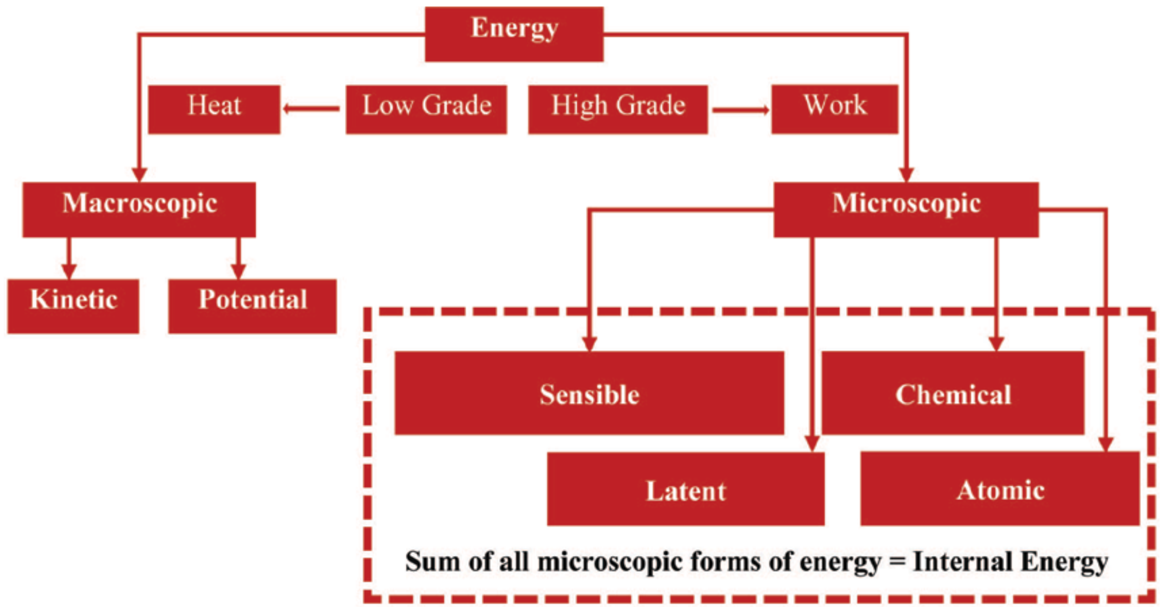
Building Physics



Role of spatial characteristics and building material in heat ingress

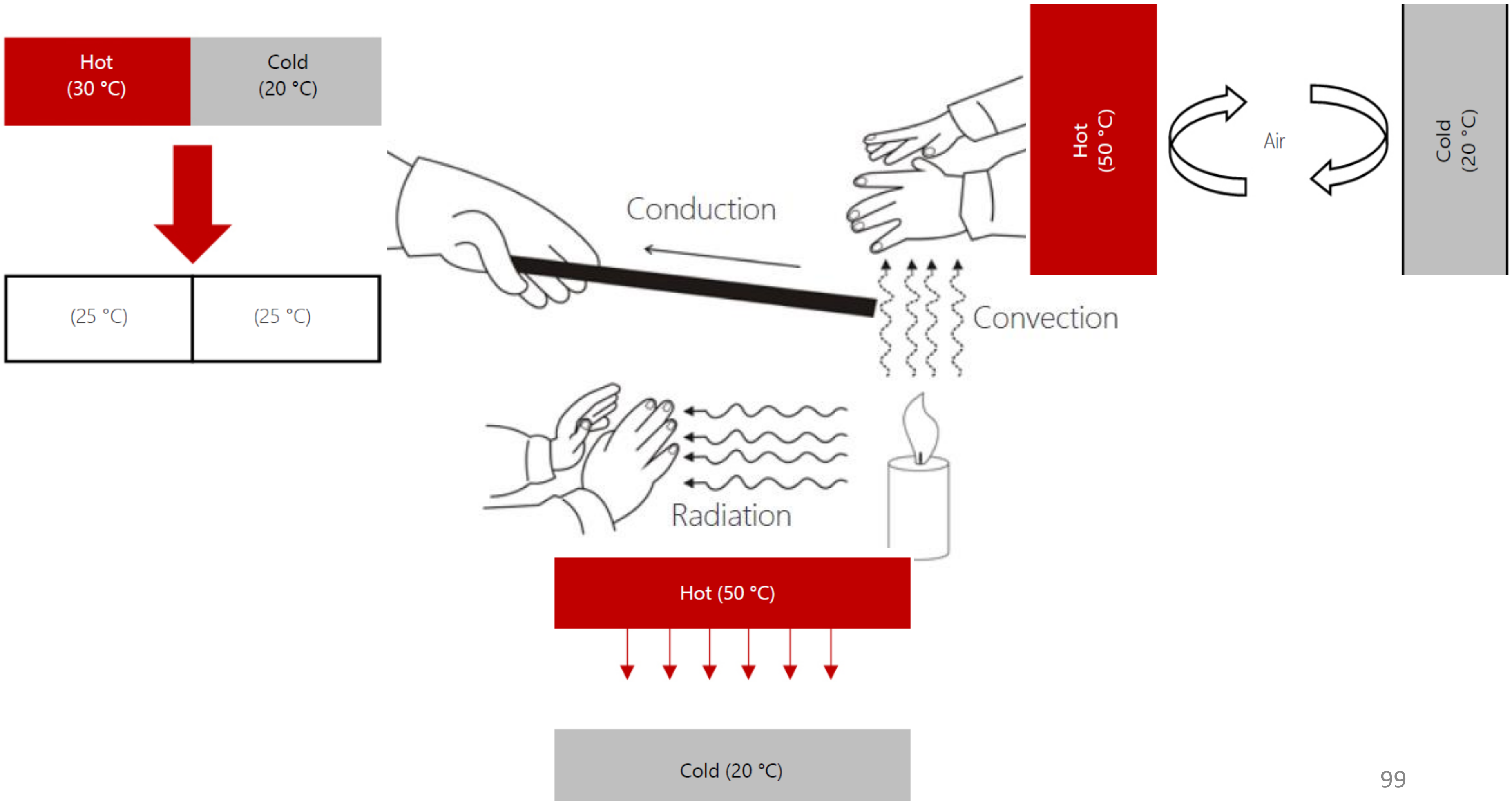


Building Physics – Forms of Energy



Sensible energy: resulting from the translational, rotational, and vibrational movement of molecules/ atoms
Latent energy: energy gained or released to change phase
Chemical energy: resulting from atomic bonds
Atomic energy: resulting from bonds within the nucleus.

Building Physics- Mode of Heat Transfer



Building Physics- Conduction

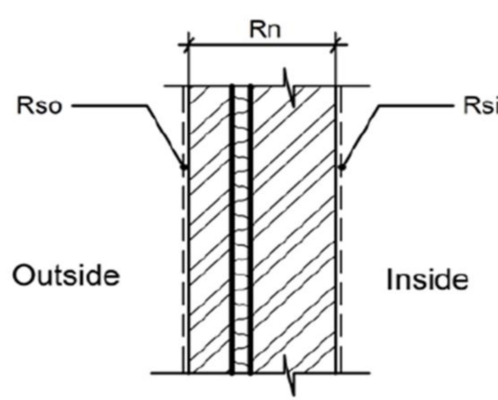
Conduction happens whenever a temperature gradient exists in a stationary medium.

Fourier Equation

$$Q_{conduction} = U.A. (T_i - T_o)$$

- $Q_{conduction}$ = Heat transfer through conduction; W
- U or U-factor = Overall heat transfer co-efficient; $W/m^2 \cdot K$
- A = Surface area; m^2

delta T = Temperature difference; $T_i - T_o$; °C



Building Physics- Conduction Through Building Envelope

The thermal conductivity of a material is a measure of its ability to conduct heat. The Unit of specific heat capacity is W/m2K

In addition to thermal conductivity, building materials also have a capacity to absorb some of the heat energy. The specific heat capacity of a material is defined as the quantity of heat (in Joules) that must be added to a unit mass (kg) of the material to raise its temperature by 1 K (or 1°C). The S.I. Unit of specific heat capacity is J/kg.K.

Materials	Density (kg/m³)	Thermal Conductivity (W/m.k)	Specific Heat Capacity (J/kg.K)
Walls			
Autoclaved Aerated Concrete Block (AAC)	642	0.184	0.794
Resource Efficient Bricks (REB)	1520	0.631	0.9951
Concrete block (25/50)	2427	1.396	0.4751
Concrete block (30/60)	2349	1.411	0.7013
Calcium Silicate Board	1016	0.281	0.8637
Cement Board	1340	0.438	0.8113
Sandstone	2530	3.009	1.5957
Stone (Jaisalmer Yellow)	3006	2.745	2.0954
Stone (Kota)	3102	3.023	2.0732
Bamboo	913	0.196	0.6351
Surface Finishes			
Plaster of Paris (POP) powder	1000	0.135	0.9536
Cement Plaster	278	1.208	0.9719
Plywood	697	0.221	0.7258

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Building Physics - Thermal Mass

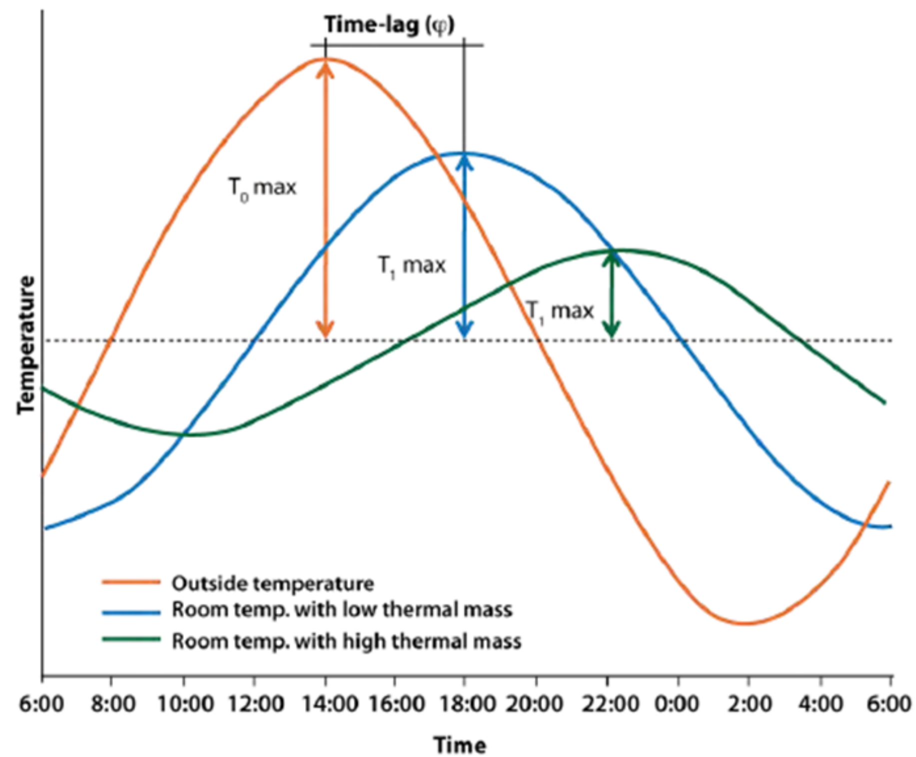
•Thermal mass (thermal capacitance or heat capacity) is the capacity of a body to store heat (J/°C or J/K)

•For a homogeneous material, thermal mass is simply the mass of material present times the specific heat capacity of that material. Specific Heat (c) values (at room temperature) for:

–Air = 1006 J/(kg.K)

–Water = 4187 J/(kg.K)

•Thermal mass provides "inertia" against temperature fluctuations, sometimes known as the TIME LAG



Building Physics - Thermal Mass

- **Thermal conductivity of walling material and thickness of the wall** are important parameters to consider during the design of climate- responsive residential architecture.

- The conductive heat gains through the wall surfaces are highly influenced by the **building material and construction methods**.

- The thermal performance of a stone wall is **more appropriate in hot and dry climate** to control the heat gain as compared to warm and humid climate.

- The specific heat capacity of natural limestone is on the higher end of the range. This means that a stone wall can **store more heat energy**. The greater the amount of heat storage in the thermal mass of the wall, the lesser is the heat transferred to the indoors.

- Similarly, a stone wall of **greater thickness** will be able to transfer less heat than a stone wall of lesser thickness.

Building Physics - Convection

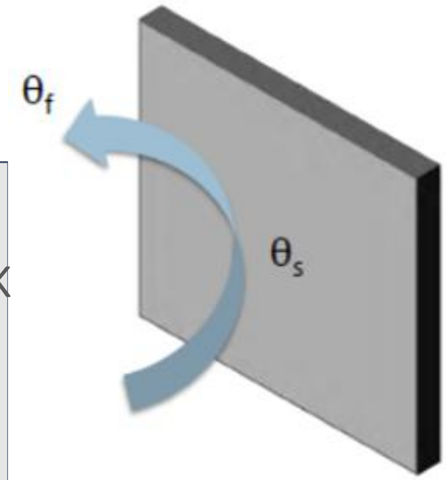
- Convection heat transfer takes place between a surface and a moving fluid, when they are at different temperatures
- Heat is transferred through two modes

–energy transfer due to molecular motion (conduction) through a fluid layer adjacent to the surface

–energy transfer by the macroscopic motion of fluid particles by virtue of an external force

$$Q_v = h_{cv} A (T_s - T_\infty)$$

Q_c = Rate of heat transfer by convection, W
h_{cv} = convective heat transfer coefficient, $W/m^2.K$
A = Surface area, m^2
T_s = Surface Temperature, K
T_∞ = temperature of fluid in free stream, K



Building Physics - Convection in Building

- Heat transfer in gases and liquids. E.g. Warm air rising (or cool air falling) on a wall's inside surface, inducing air movement
- Flux due to local temperature and density differences (natural or free convection) or due to mechanical devices (forced convection)

Convection	Heat transfer coefficient in air h_{CV} in $W/m^2{\cdot}K$
Free	3-10
Forced	10-100

Ventilation

$$Q_v = \rho \cdot V_r \cdot c \cdot \Delta T$$

Q_v = Heat transfer through ventilation; W

ρ= Density of air; (kg/m^3)

V_r= Ventilation rate; (m^3/s)

c= Specific heat of air; (J/kg.K)

ΔT= Temperature difference (T_s-T_∞); (K)

Infiltration and Ventilation Load

- **Sensible Load**

$$H_S = 1.08 \times CFM \times \Delta T$$

HS = Sensible Heat (Btu/hr)
CFM = Air Flow Rate (Cubic Feet per Minute)
ΔT = Temperature Difference (°F)

- **Latent Load**

$$H_L = 0.68 \times CFM \times \Delta W_{GR.}$$

H_L = Latent Heat (Btu/hr)
CFM = Air Flow Rate (Cubic Feet per Minute)
$\Delta W_{GR.}$ = Humidity Ratio Difference (Gr.H2O/Lb.DA)

Building Physics - Air Changes per Hour (ACH)

Air changes per hour (ACH) is a measure of how many times the air within a defined space is replaced in a hour

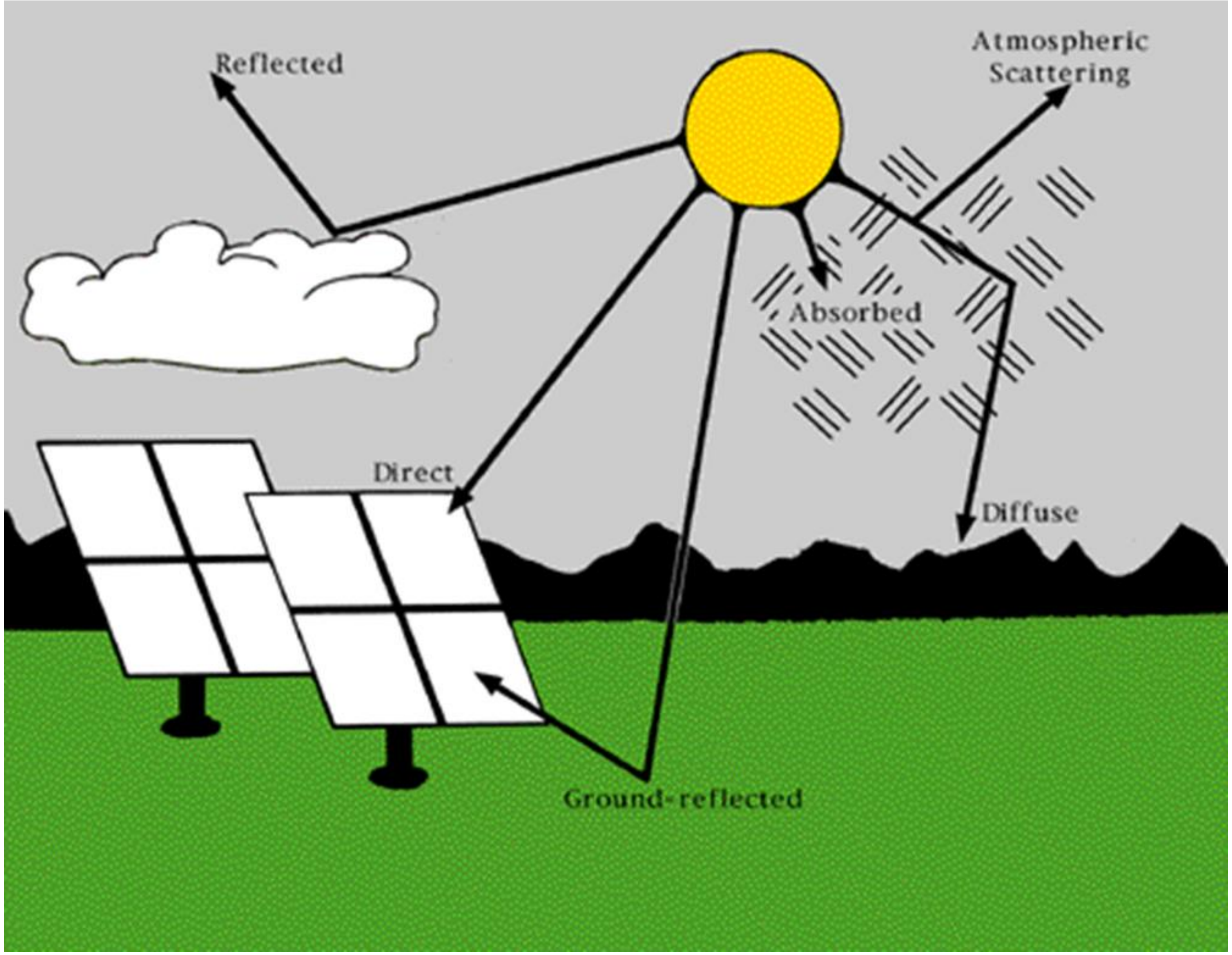
$$N = \frac{60Q}{Vol}$$

N = number of air changes per hour

Q = Volumetric flow rate of air in cubic feet per minute (cfm)

Vol = Space volume L × W × H, in cubic feet

Building Physics - Solar Radiation



Building Physics - Radiation

Radiation heat transfer does not require any medium for transmission

Energy transfer occurs due to the propagation of electromagnetic waves. All bodies due to their temperature emits electromagnetic radiation.

It is propagated with the speed of light and in straight line in vacuum

Stefan-Boltzmann's law

$$Q_r = \varepsilon.\sigma.A.T_s^4$$

Q_r = Rate of heat transfer by radiation, W

ε = Emissivity of the surface

σ = Stefan-Boltzmann's constant, 5.669 X 10^{-8} $W/m^2.K^4$

A = Surface area, m^2

T^s = Surface Temperature, K

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.

$$M\text{-}W = q_{sk} + q_{res} + S = (C + R + E_{sk}) + (C_{res} + E_{res}) + (S_{sk} + S_{cr})$$

Where M = rate of metabolic heat production, W/m^2

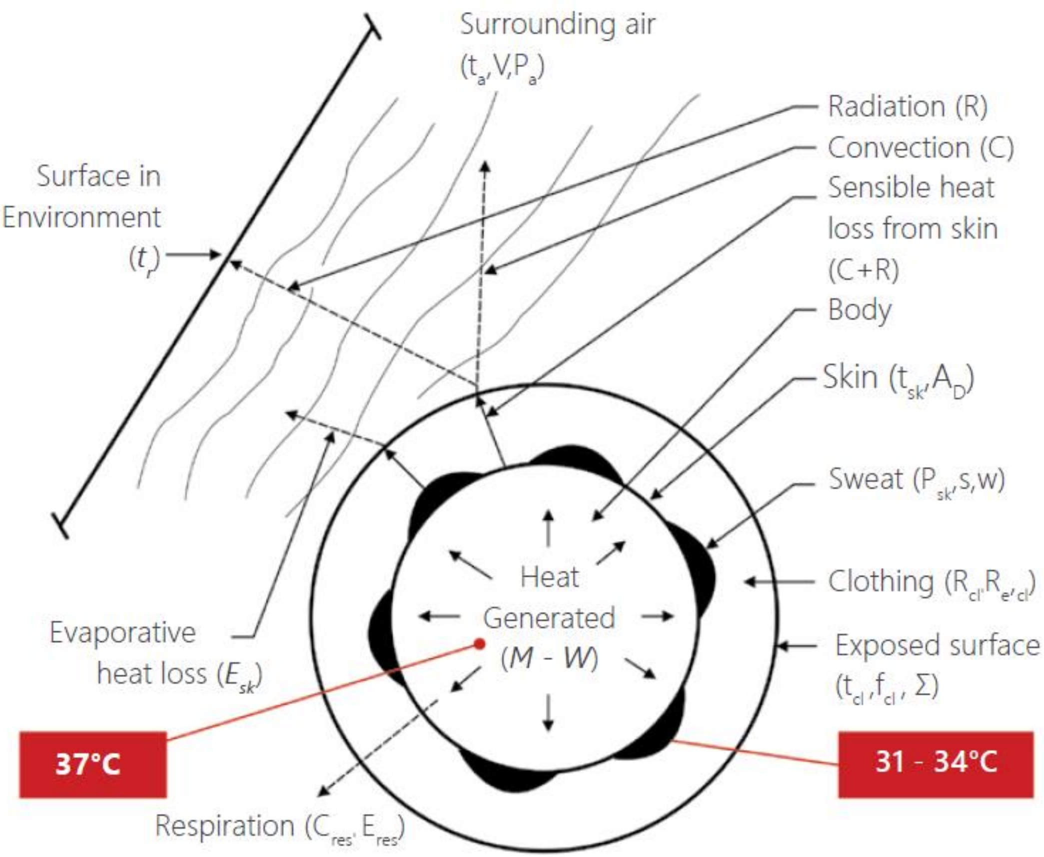
Where M is the rate of metabolic heat production, W is the rate of mechanical work accomplished; q_{sk} is the total rate of heat loss from skin; q_{res} is the total rate of heat loss through respiration; C + R is the sensible heat loss from skin; E_{sk} is the total rate of evaporative heat loss from skin; C_{res} is the rate of convective heat loss from respiration; E_{res} is the rate of evaporative heat loss from respiration; S_{sk} is the rate of heat storage in skin compartment; S_{cr} is the rate of heat storage in core compartment.

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

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.

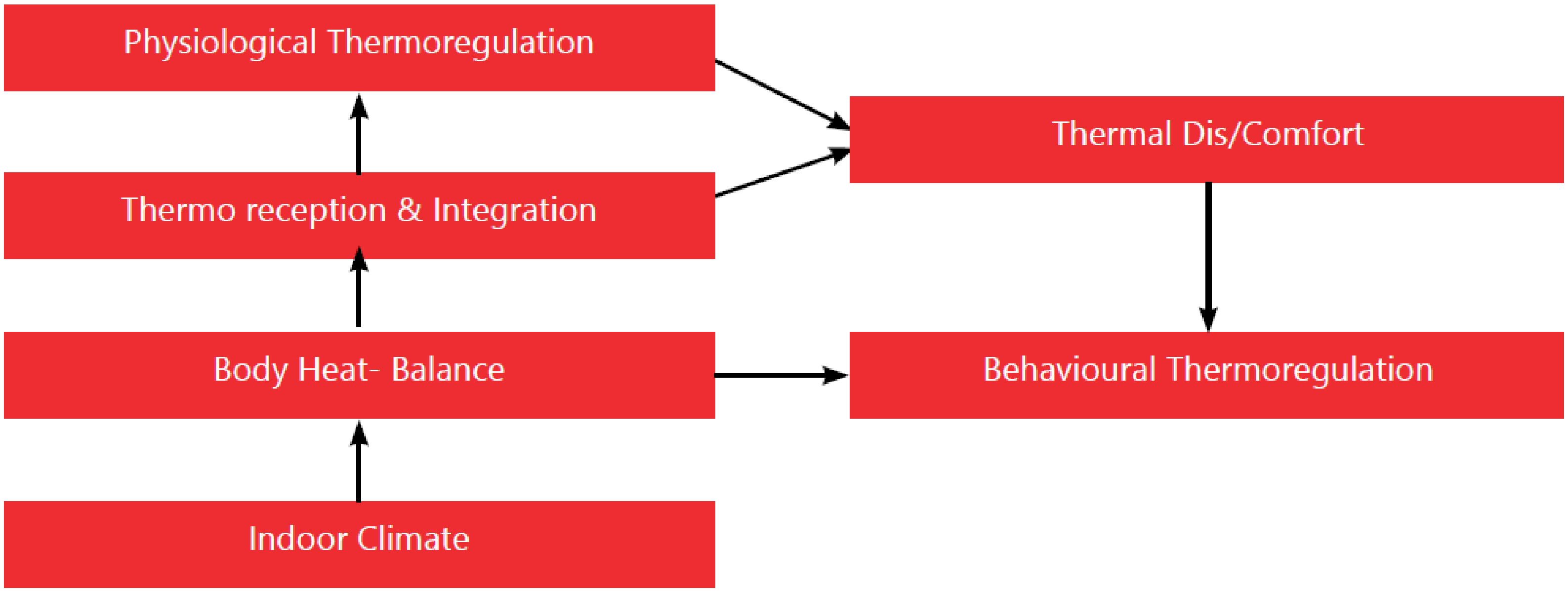


https://doi.org/10.3390/atmos10120769

Adaptive Thermal control Model

Adaptive thermal comfort model takes into consideration all three- **physiological, psychological, and behavioral aspects** of occupants and their influence on perception of thermal comfort.

It prescribes indoor set point temperature to address 90% acceptability of thermal environment among occupants at granular timescales as opposed to a static set point-based conditioning.



IMAC

The **India Model for Adaptive Comfort (IMAC**) approach addressed the prevalent five Indian climatic zones and increasing adoption of mixed mode buildings (Manu, Shukla, Rawal, Thomas, & Dear, 2016).

Surveys comprising of ventilated, mixed mode and air-conditioned buildings informed the formulation of two separate adaptive models- one for naturally ventilated and one for mixed mode buildings.

The IMAC equations were subsequently included in the National Building Code 2016. Additionally, ECBC 2017 refers to NBC as the standard for thermal comfort requirements.

Recent advancements include development of IMAC specifically for the residential sector (IMAC-R) (Rawal, et al., 2022).

Thermal Discomfort

- **Local Thermal Discomfort**

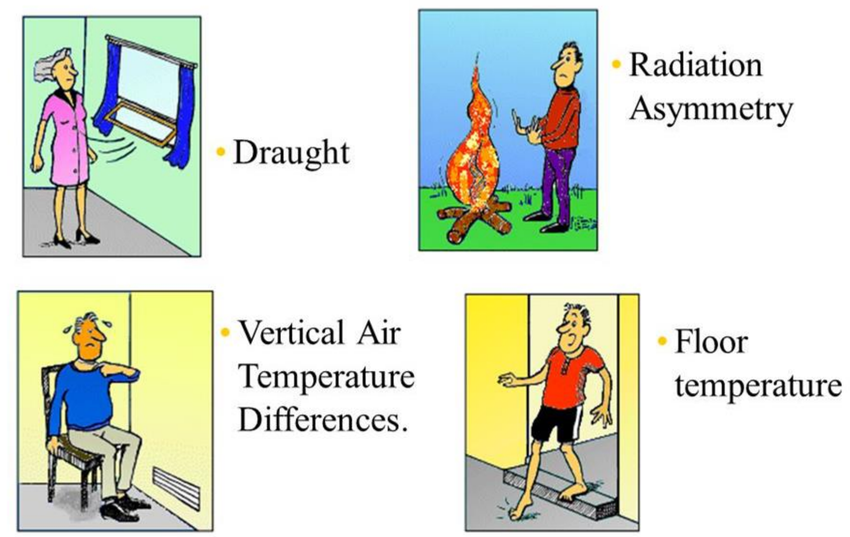
•The local thermal discomfort is **unwanted cooling or heating** on a particular part of an occupant's body

Asymmetric radiant field (Cold floor, warm wall, equipment & sunlight)

Too warm or too cold Flooring

Local convective cooling (draught)

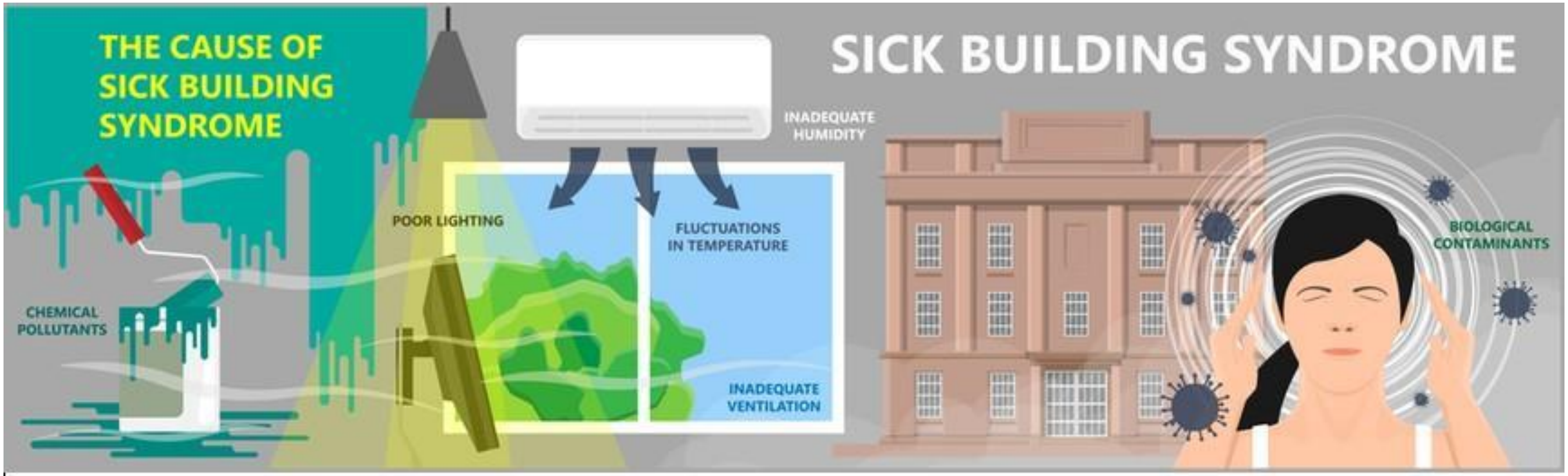
Vertical Air temperature difference (Warm air near head & Cold air near feet)



Thermal Discomfort – Sick Building Syndrome

SICK BUILDING SYNDROME

- Sick building syndrome (SBS) is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building



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Session 4: Passive Strategies & Building Materials

Passive Strategies & Building Materials

- Passive design can be explained as no or low-cost strategies that use building envelope components to maintain thermally comfortable indoor environment.
- They can help to maintain thermal comfort. This is because passive design measures either reject the heat or delay the transfer of heat from outdoors to indoors to ensure excess heat does not enter the indoor spaces.

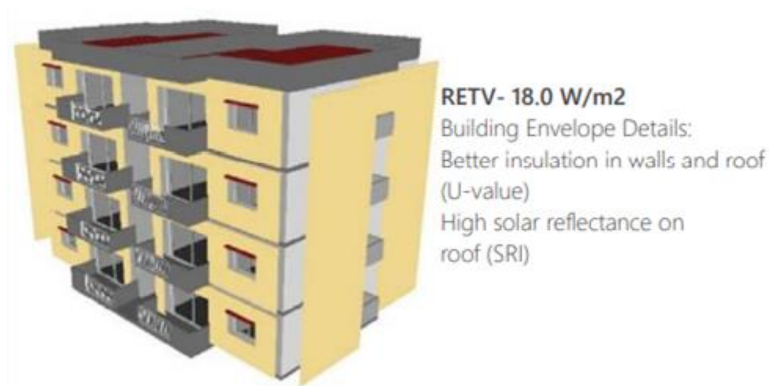
Mode of heat transfer	Passive Design strategies applicable
Conduction	Materials and Construction
Convection	Space Volume, Building form- (Roof form, plan)
Radiation	Orientation Shading/ Brise Soleil, jail etc

Passive Strategies & Building Materials

Initial Strategies

- Form and orientation
- Window-to-wall ratio
- Shading strategies
- Solar Heat Gain Coefficient (SHGC)
- Residential envelope transmittance value (RETV)
- Construction configuration
- Interaction between parameters

RETV value of typical affordable multifamily residential building

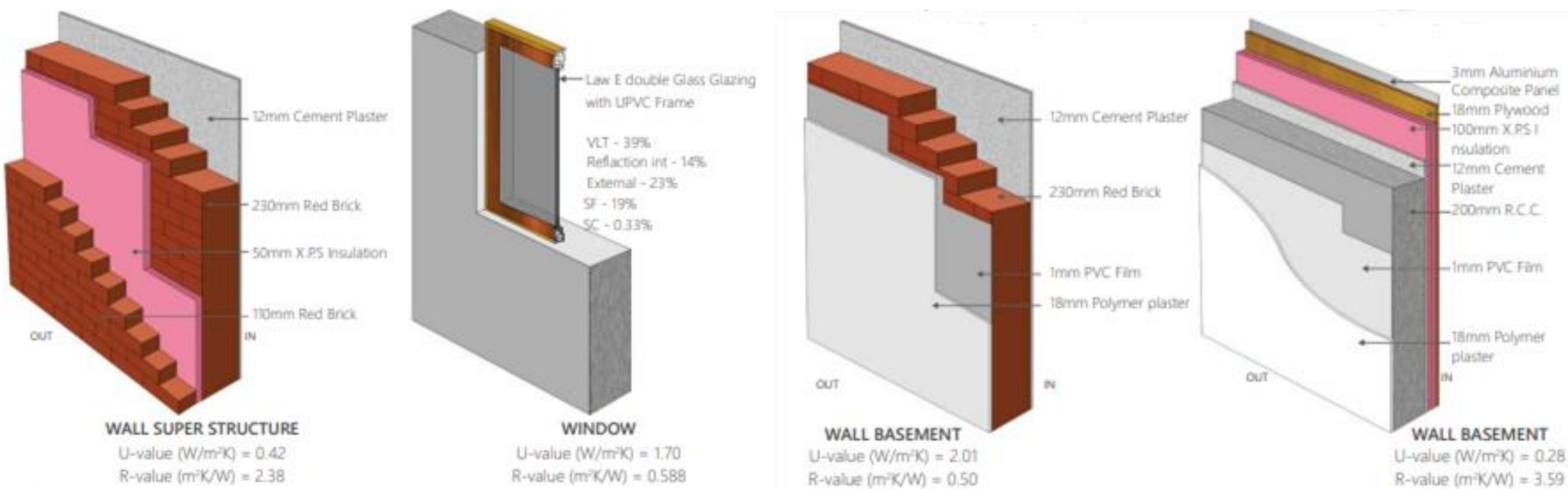


RETV value after initial envelope optimization strategies

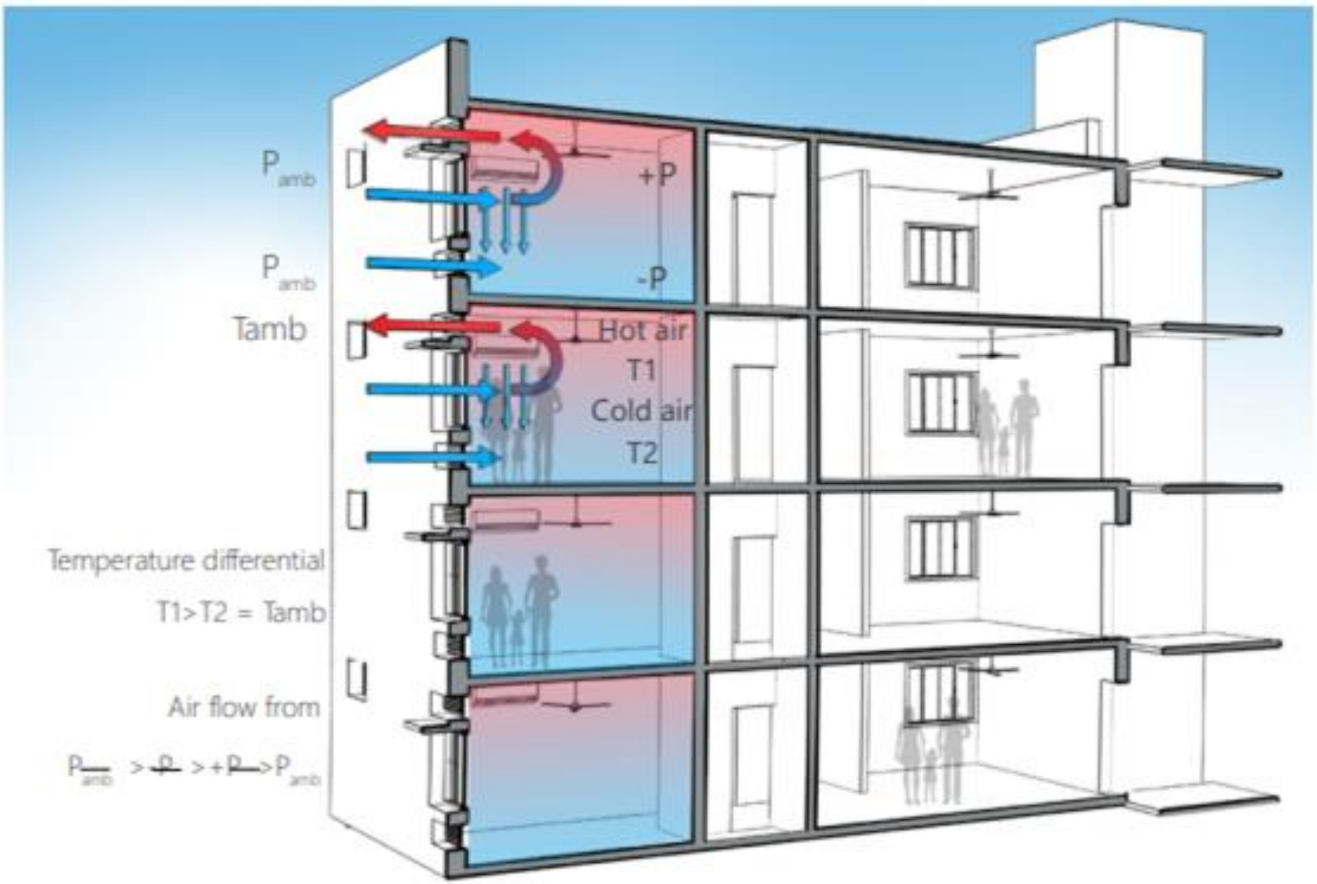
RETV value meeting ENS compliance after glazing related optimization strategies

Passive Strategies & Building Materials

Effective operation of openable elements of the building envelopes such as windows, doors, and building appliances such as fans, provide the occupants with adaptive opportunities to alter their immediate environment. Window operation is an effective adaptive measure in most Indian residences. Favourable outdoor thermal environmental conditions offer occupants the opportunity to open the windows and allow outdoor air to ventilate indoor spaces.

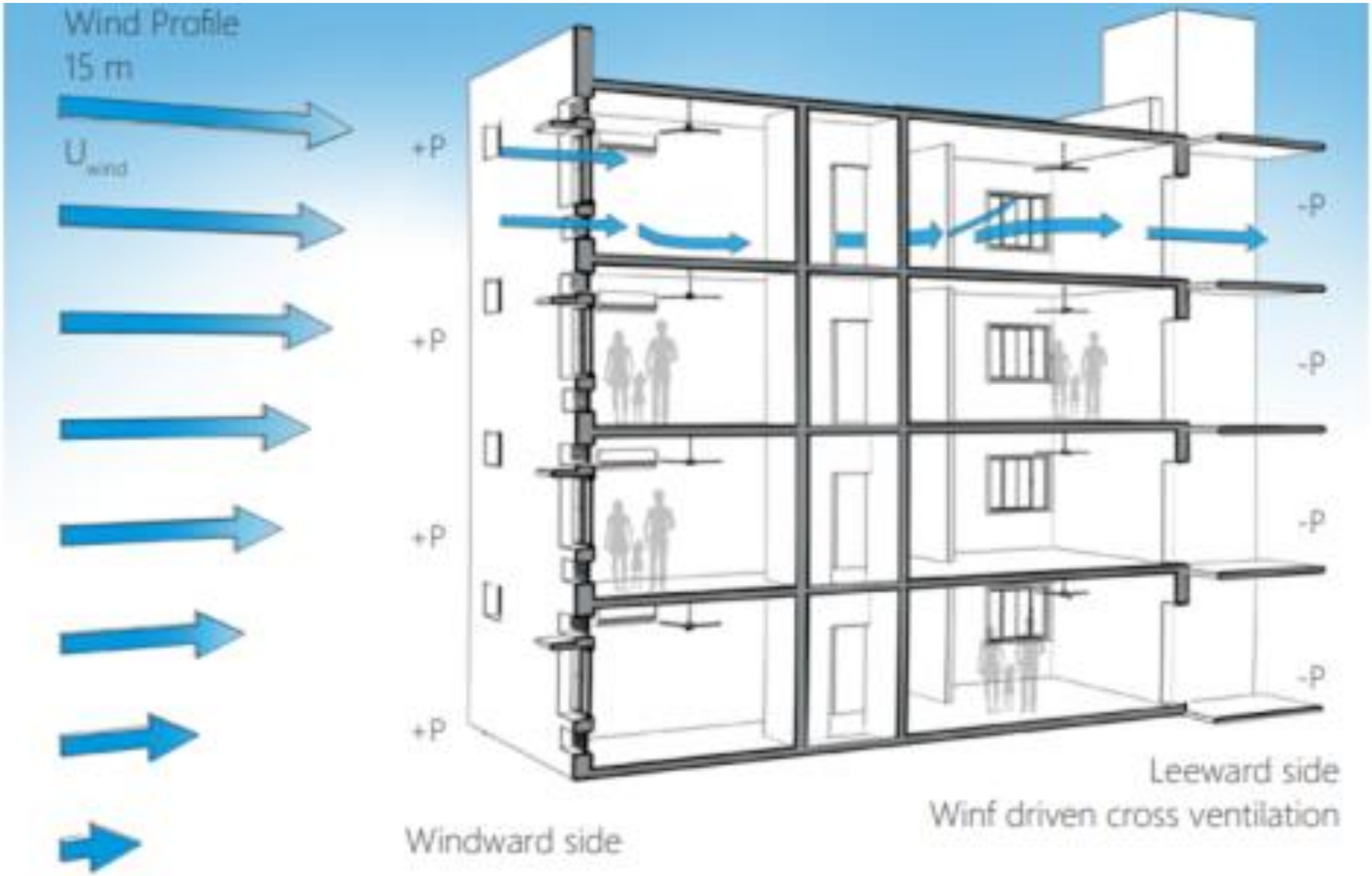


Passive Strategies & Building Materials



natural ventilation principles driven by buoyancy forces. +P denotes positive pressure regions and -P denotes negative pressure regions.
Source: (Cook, et al., 2020)

Passive Strategies & Building Materials

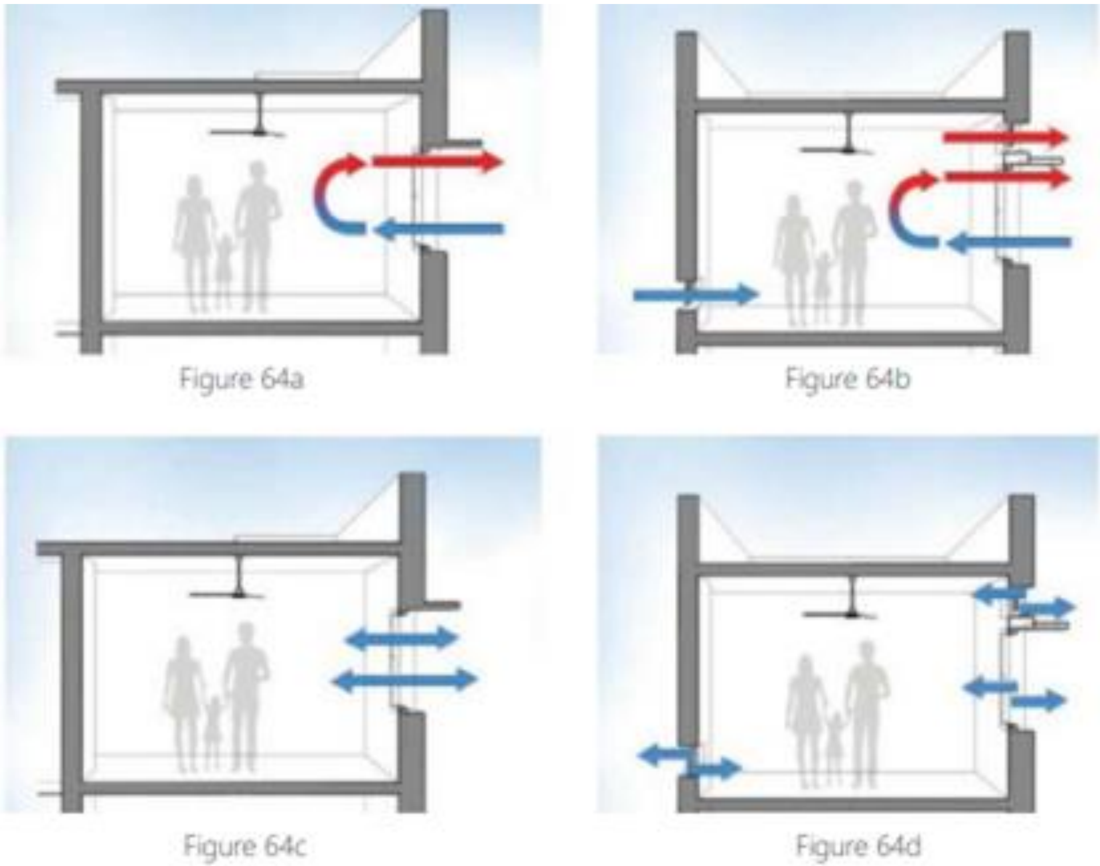


Pressure distribution outside a building and resultant ventilation flow.
Source: (Cook, et al., 2020)

Passive Strategies & Building Materials

The four most common configurations in Indian residential buildings are presented in design charts.

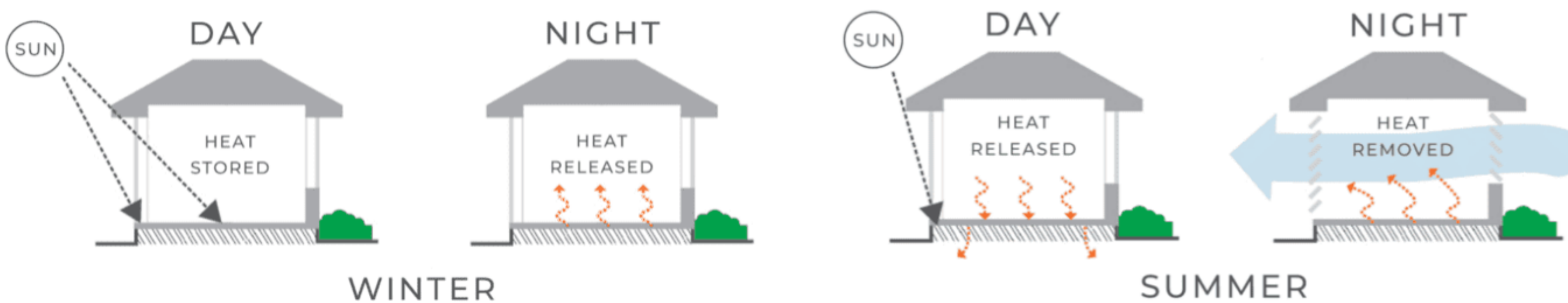
- buoyancy-driven flow; single-sided ventilation with one opening (Figure 64a)
- buoyancy-driven flow; cross ventilation with multiple openings (Figure 64b)
- wind-driven flow; single-sided ventilation with one opening (Figure 64c)
- wind-driven flow; cross ventilation with multiple openings (Figure 64d)

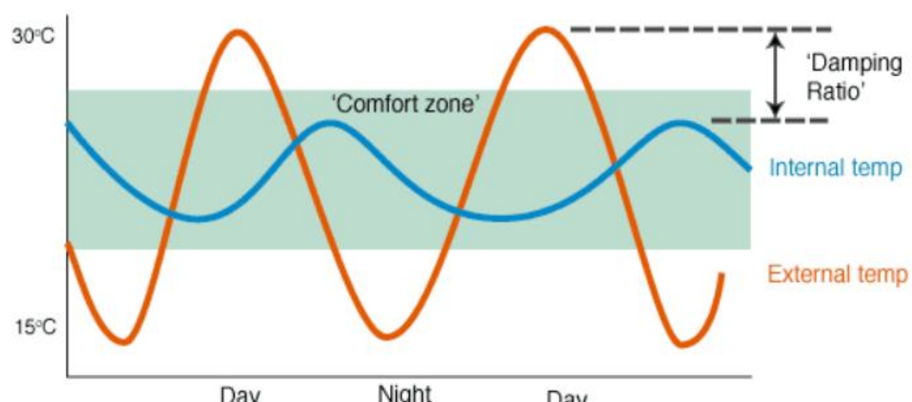


Cross-section sketches of the driving forces for the naturalventilation systems presented in the four design charts.
Source: (de Faria, et al., 2018)

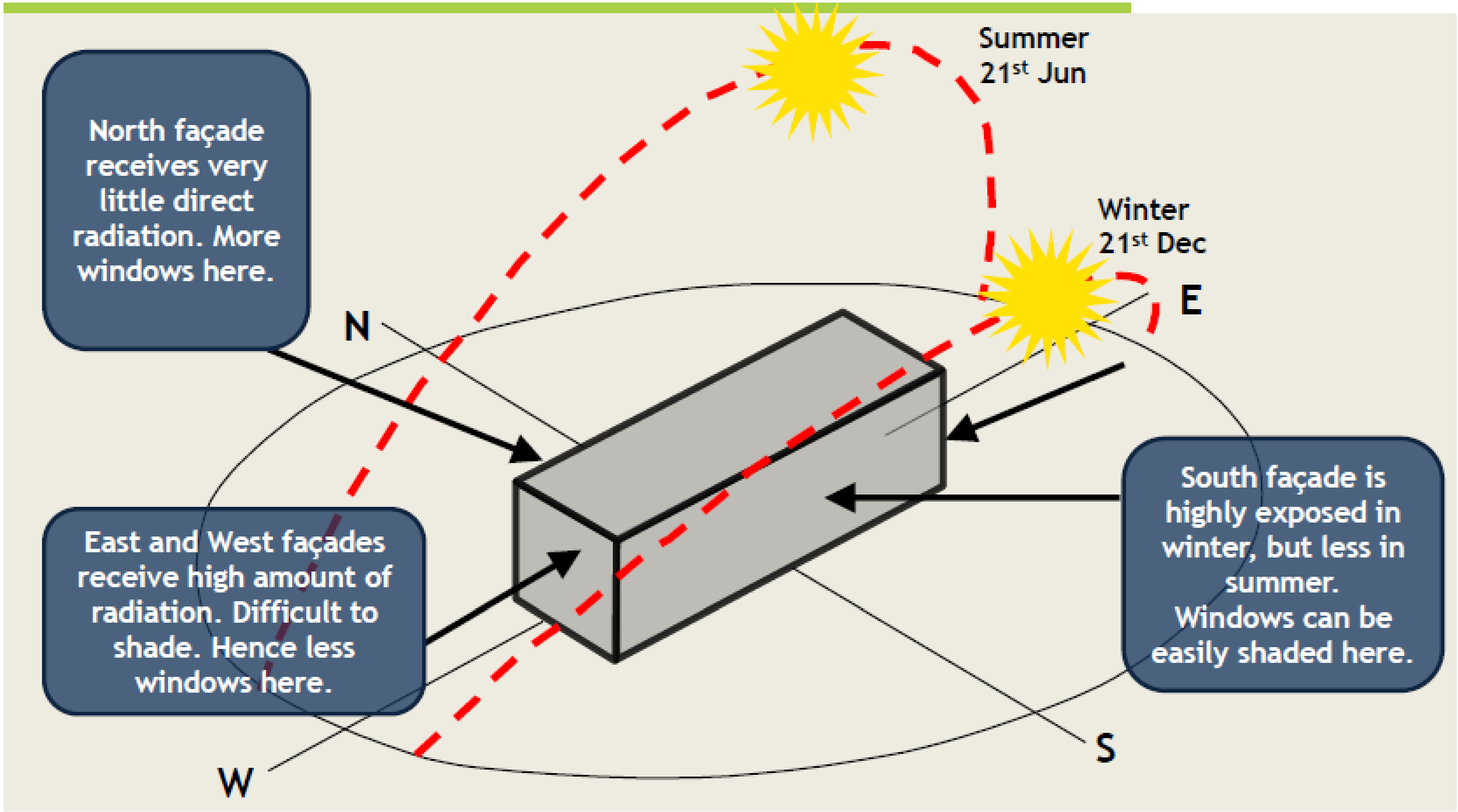
Passive Measures - Thermal Mass

- Denser thermal mass materials are more effective passive solar materials. Thus, denser the material the better it stores and releases heat.
- Integrate thermal mass with an efficient passive solar design, by considering the placement of added mass.
- Do not substitute thermal mass for insulation. It should be used in conjunction with insulation



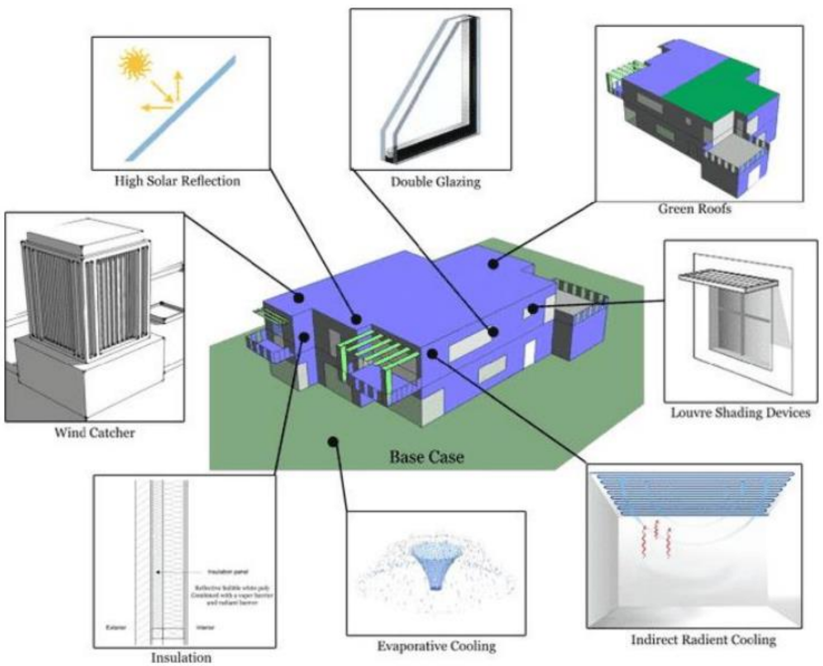


Passive Measures - Orientation



Passive Measures - Roof and Wall Materials

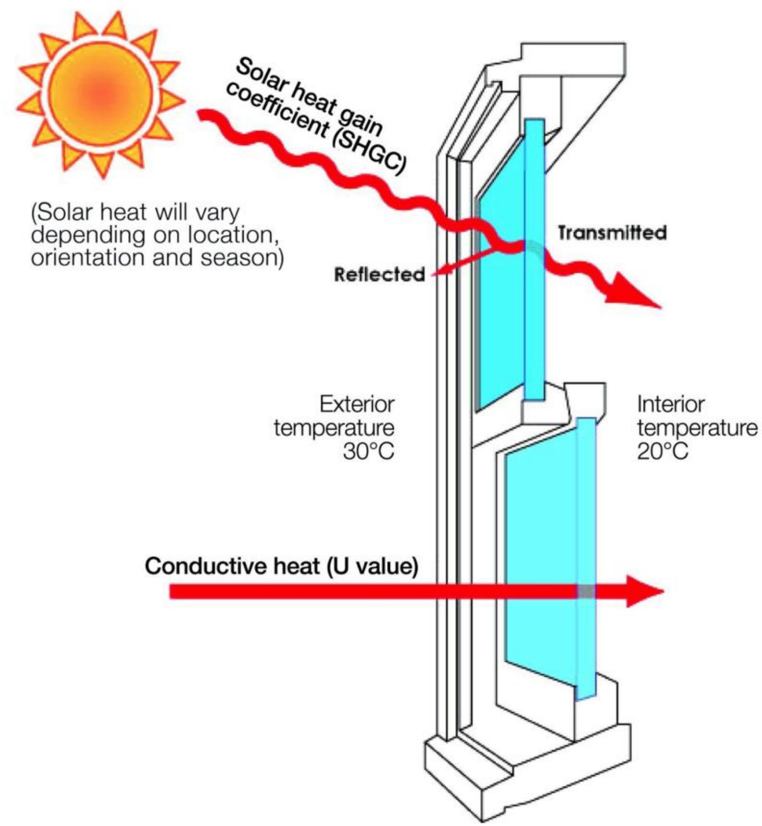
The properties of building materials act as building envelopes by resisting the external temperature and humidity, mostly influenced by indoor thermal comfort. The materials having lower thermal conductivity, thermal diffusivity, and absorptivity has the properties of less temperature swing on the inside surface of the walls compared to the materials with high thermal conductivity



- Green roofs.
- Louvre and shading devices.
- Insulation
- Low energy cooling techniques.
- Wind catchment and ventilation.
- Double glazed glass.
- High solar reflective surface.

Passive Measures - Non Opaque Material Properties

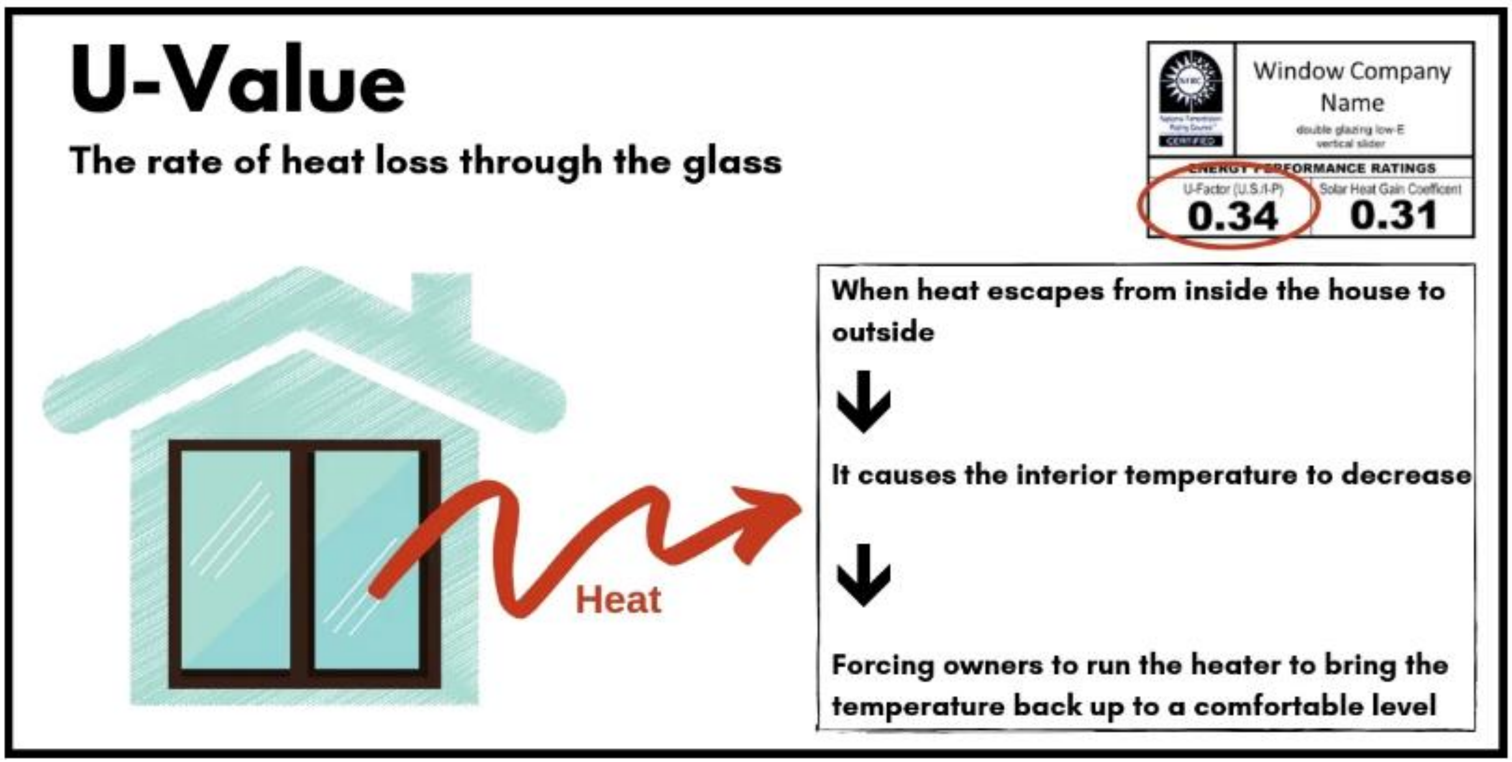
- Three of the most important properties of the materials, coatings, and constructions that make up windows, skylights, translucent panels, or other products used to let sunlight into a building include:
  - *Thermal conductance (U-value)*
  - *Solar Heat Gain Coefficient (SHGC)*
  - *Visible Light Transmittance (VT)*
- Appropriate values for glazing properties vary by climate, size, and placement of the aperture.
- It's not unusual for a single building to have three, four, or even five different kinds of glazing for apertures in different sides and at different heights on a building.



Passive Measures - Non Opaque Material Properties

Thermal conductance (U-factor)

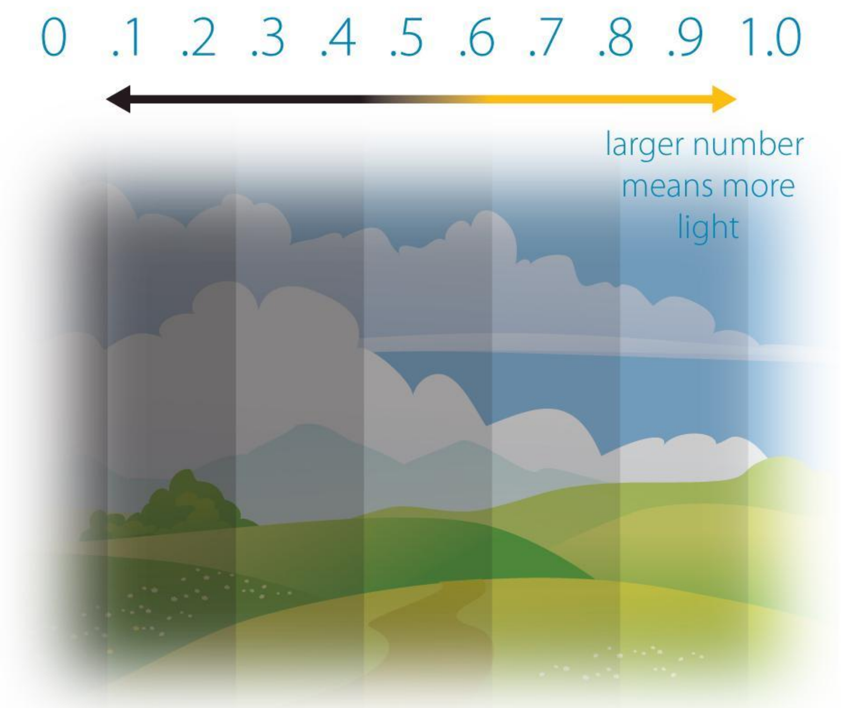
- U-factors measure thermal conductivity, the rate of heat transfer per unit area, per unit temperature difference from the hotter side to the colder side.
- The size of the air gap between glazings, the coatings on the glazings, the gas fill between glazings, and the frame construction all influence the U-factor.



Passive Measures - Non Opaque Material Properties

Visible Light Transmittance (VT)

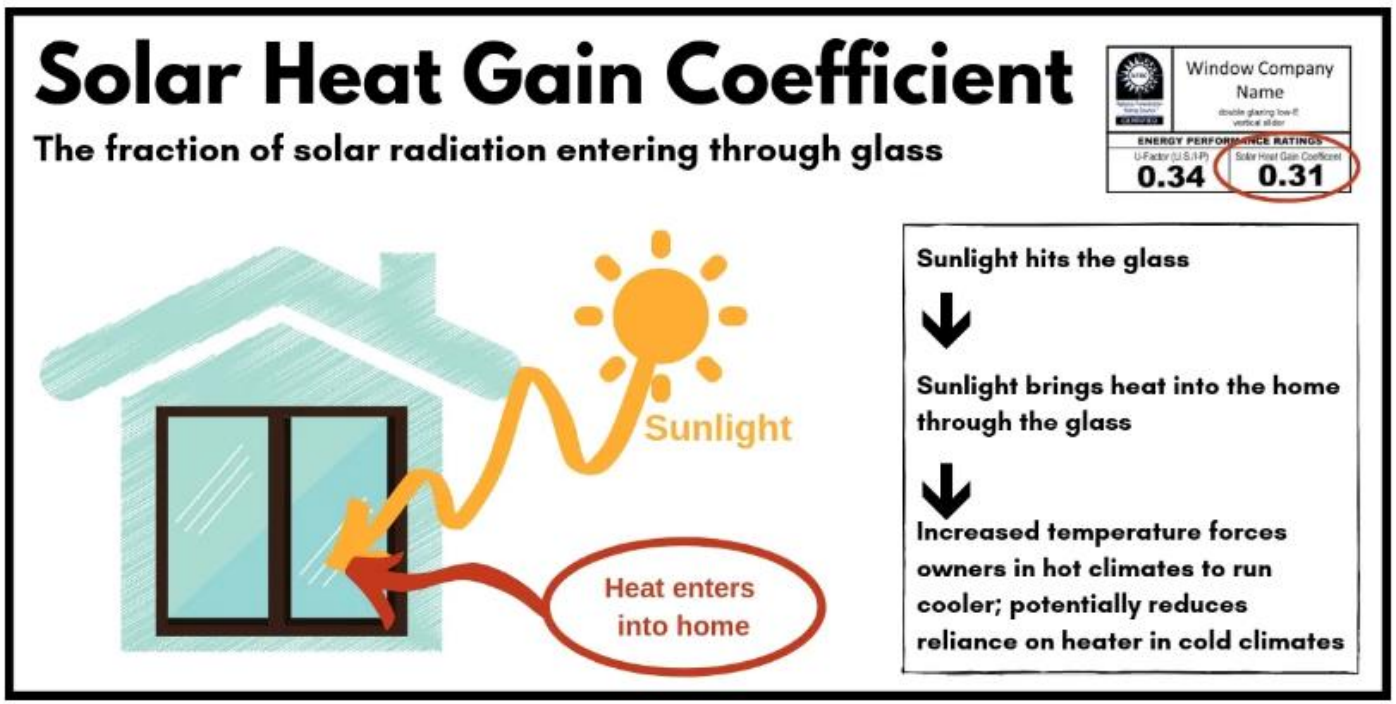
- The percentage of visible light that passes through a window or other glazing unit is called the Visible Light Transmittance (VT).
- More light is often not better, as it can cause glare and overheating. Tints, frits, and coatings can be chosen to produce any VT; common values are often 30 - 80%.
- VT is influenced by the color of the glass (clear glass has the highest VT) as well as by coatings and the number of glazings.



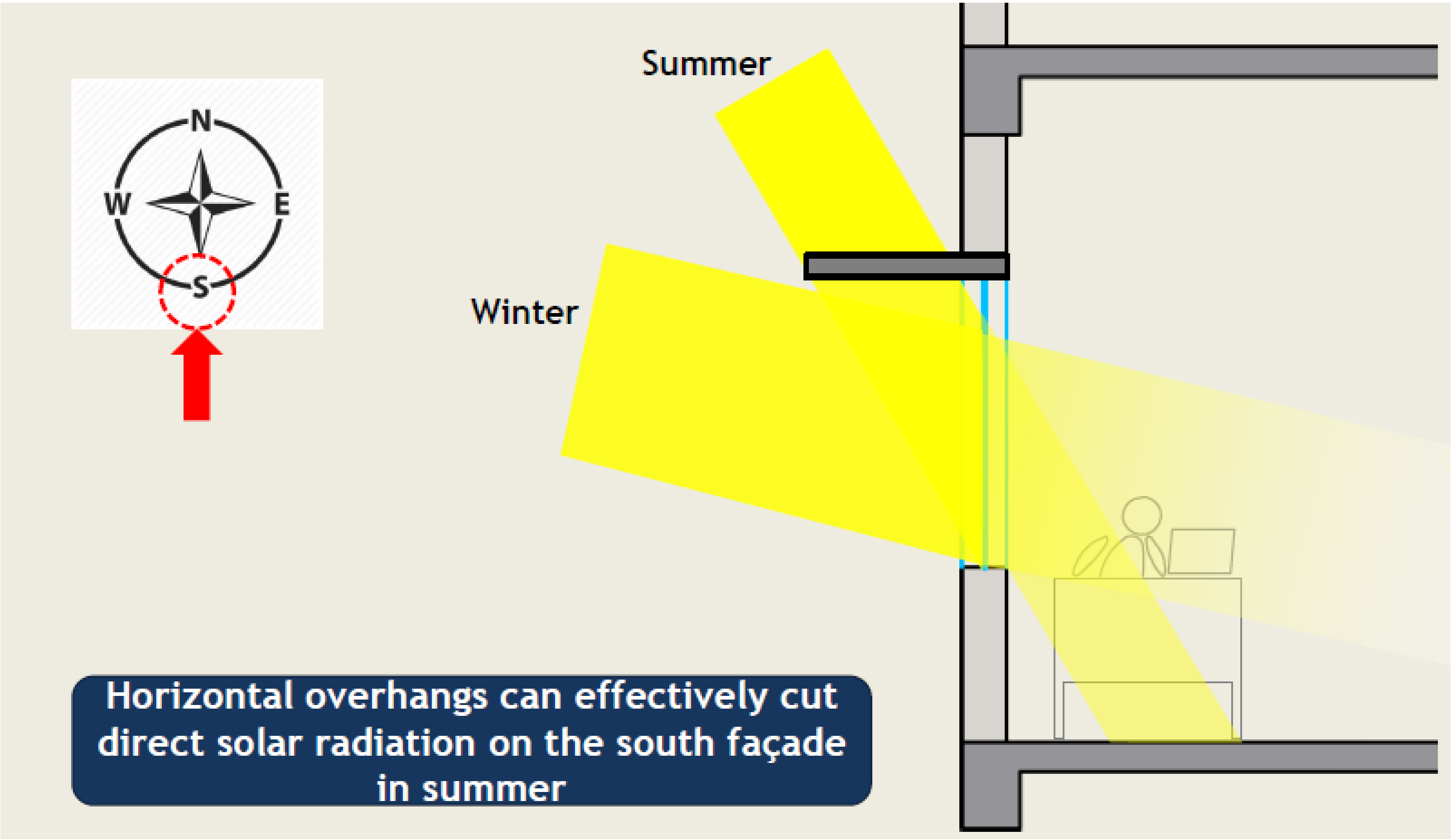
Passive Measures - Non Opaque Material Properties

Solar Heat Gain Coefficient (SHGC)

- Solar Heat Gain Coefficient (SHGC) measures how much of the incoming heat from sunlight gets transmitted into the building, versus how much is reflected away
- The SHGC is especially important in hot sunny climates (where cooling is the dominant thermal issue), and you should generally use glazing with lower SHGC. Buildings in cold climates should generally have higher SHGC to enable passive solar heating and to reduce heating loads.



Passive Measures - Shading

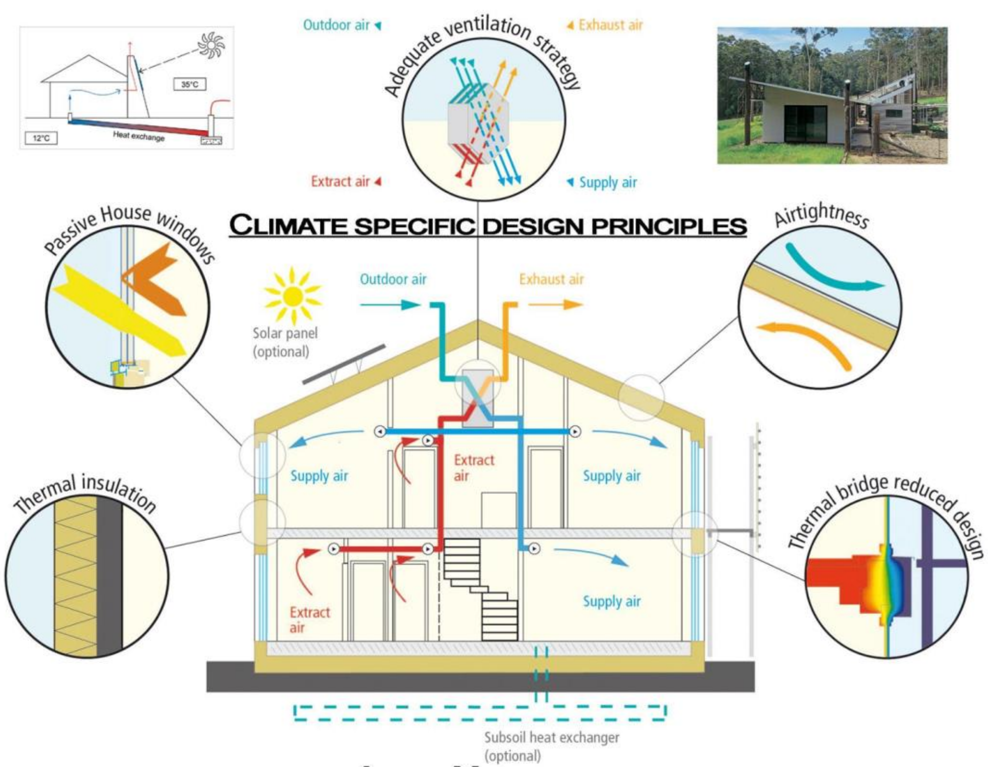


Passive Measures - Climate Specific Design Interventions

The climate responsive design refers to **the architecture that reflects the particular region-specific weather conditions of the peculiar area**. It uses data of weather patterns and factors like sun, wind, rainfall, and humidity. The building structure is built according to the same.

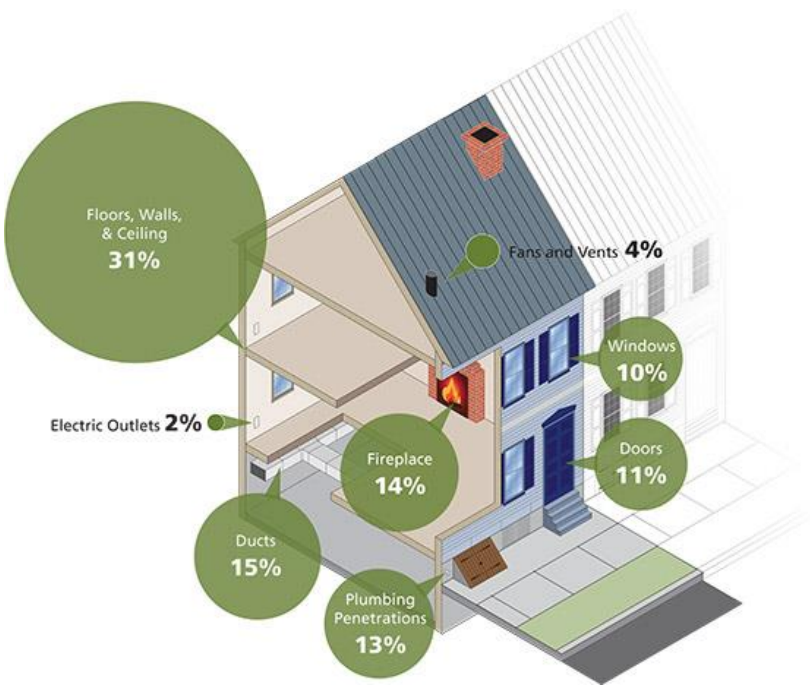
Factors Affecting Climatic Design:

- **Topography - elevation, slopes, hills and valleys, ground surface conditions.**
- Vegetation - height, mass, silhouette, texture, location, growth patterns.
- Built forms - nearby buildings, surface conditions. and ventilation heat flow.



Passive Measures - Minimal Infiltration Losses

- Infiltration is **the unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope and through use of doors for passage**. Infiltration is sometimes called air leakage.
- Reducing air infiltration is often the first action item of a weatherization plan. Caulking cracks, sealing an unused fireplace, and adding weatherstripping are simple, low-cost improvements that can reduce air infiltration.



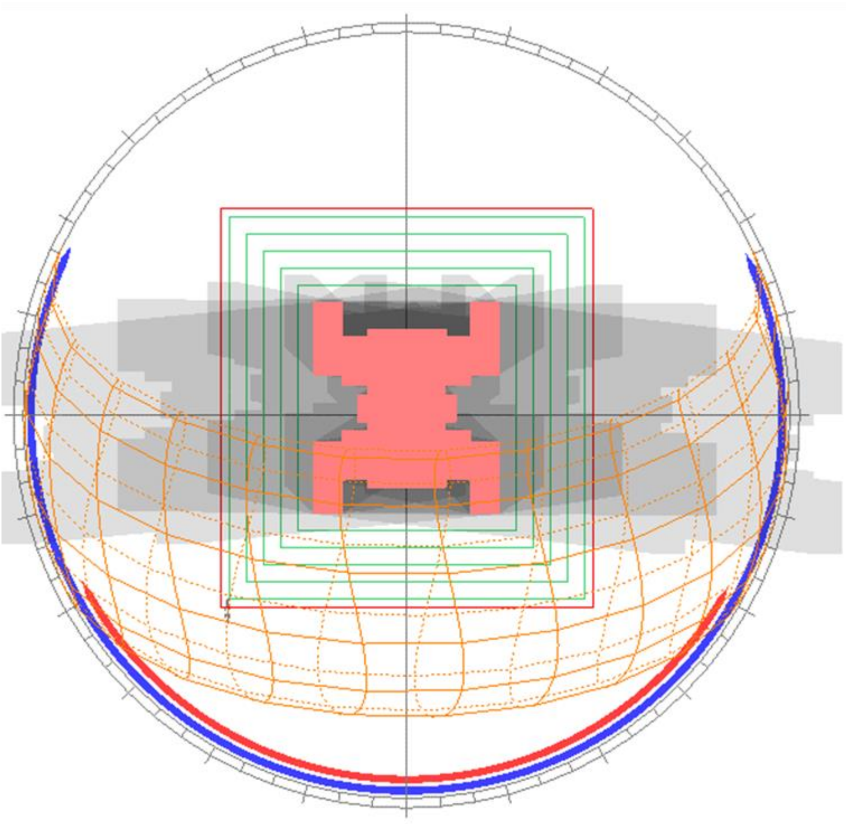
Typical places to check for air infiltration include:

- Electrical outlets, switches, and ceiling fixtures
- Operable features of windows and doors – check for a loose fit
- Window and door frames where they meet the wall
- Wall or window-mounted air conditioners
- Plumbing, electrical, cable, and telephone penetrations
- Ducts in unconditioned spaces.

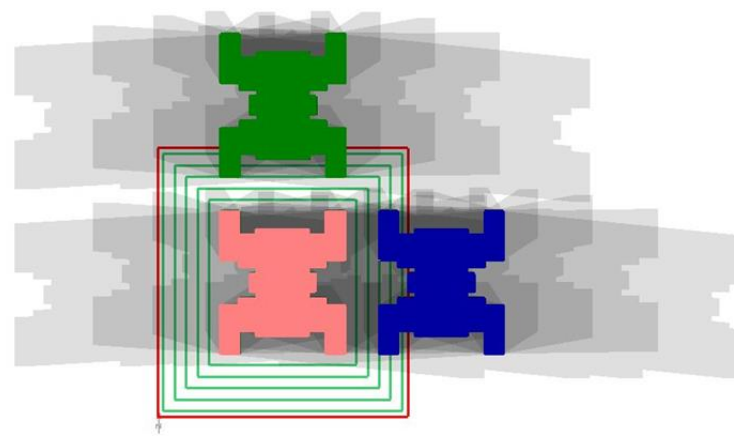
Passive Measures - Mutual Shading

Mutual Shading: June 21st

12 storey tower typology residential building



LATITUDE: 28.6°
LONGITUDE: 77.2



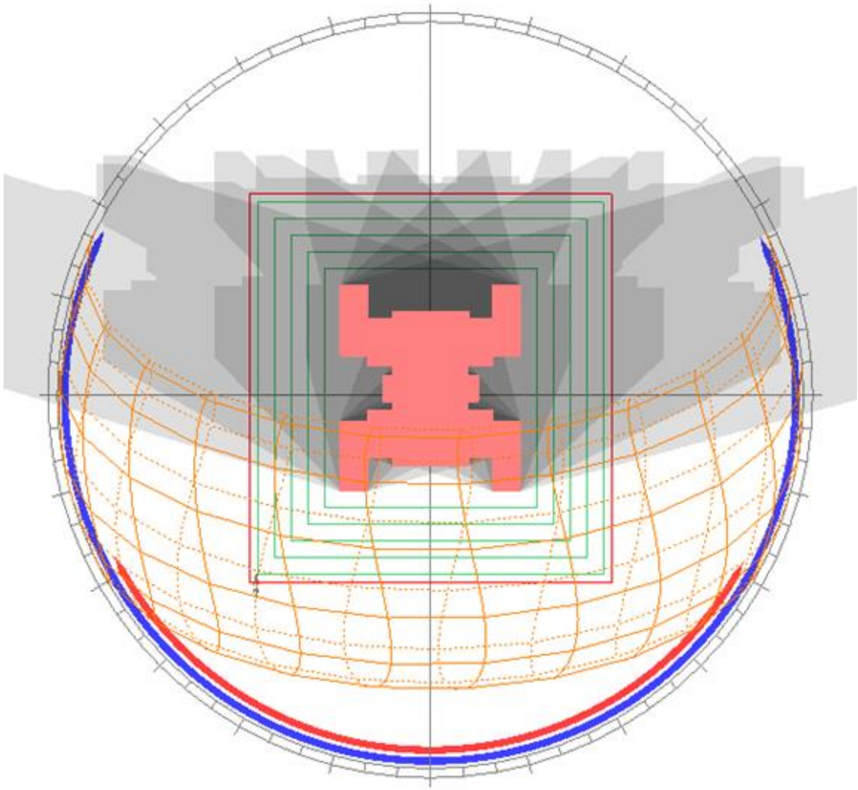
Passive Measures - Mutual Shading

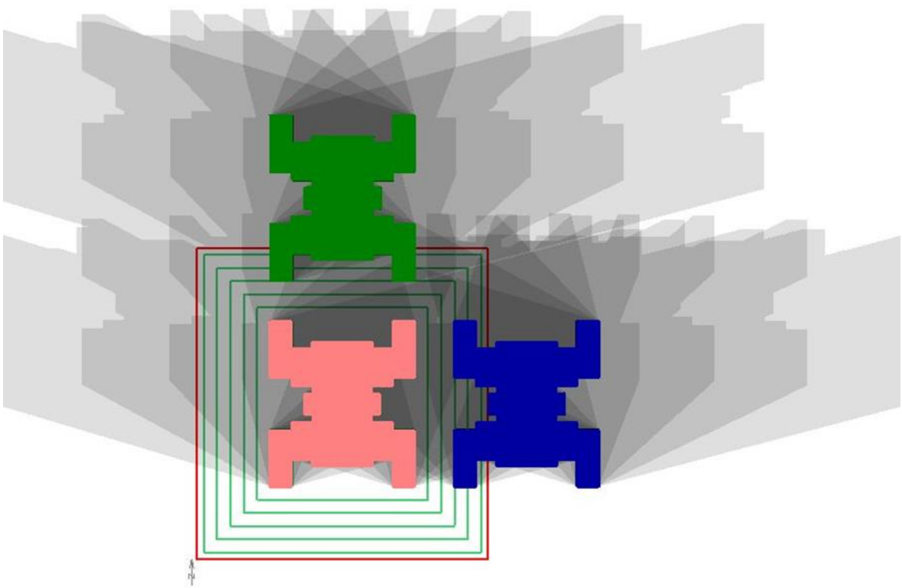
Mutual Shading: April 1st

12 storey tower typology residential building

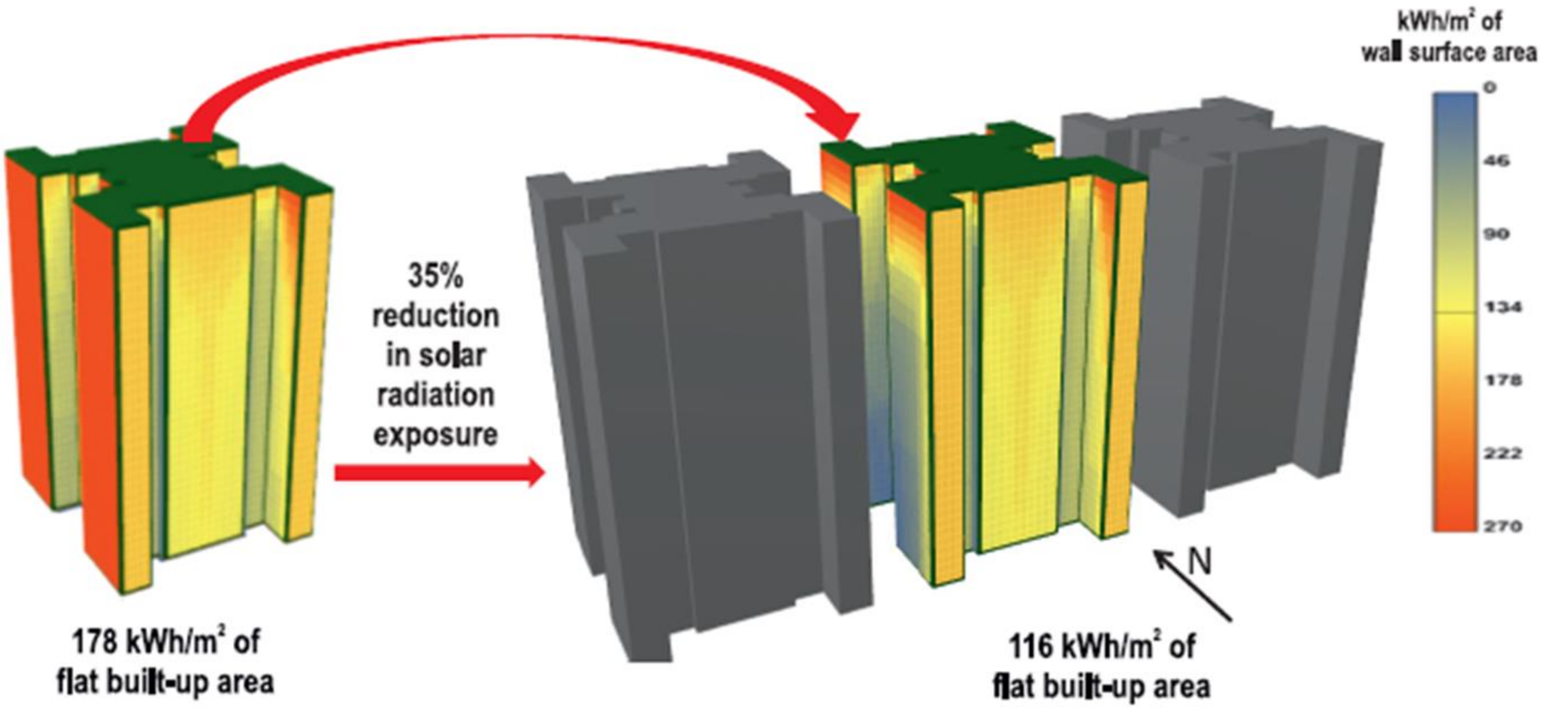
LATITUDE: 28.6°

LONGITUDE: 77.2°





Passive Measures - Quantitative Impact of Mutual Shading



Thermal Comfort Improvement through Materials

Materials without Insulation

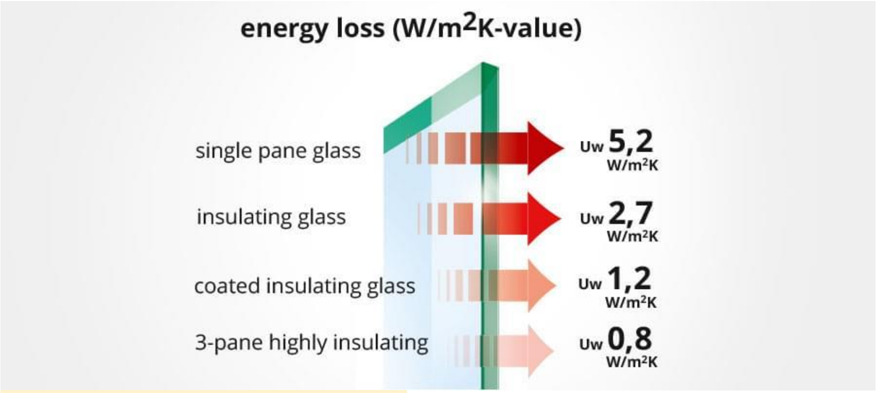
Wall materials	U Value (W/sqmK)
150 mm RCC (No plaster)	3.77
200 mm Solid Concrete Block with plaster on both sides	2.8
230 mm Brick with plaster on both sides	1.72-2.24
200 mm Autoclaved Aerated Concrete (AAC) with plaster on both side	0.77
300 mm Autoclaved Aerated Concrete (AAC) with plaster on both side	0.54

Thermal Comfort Improvement through Materials

EPS Insulation

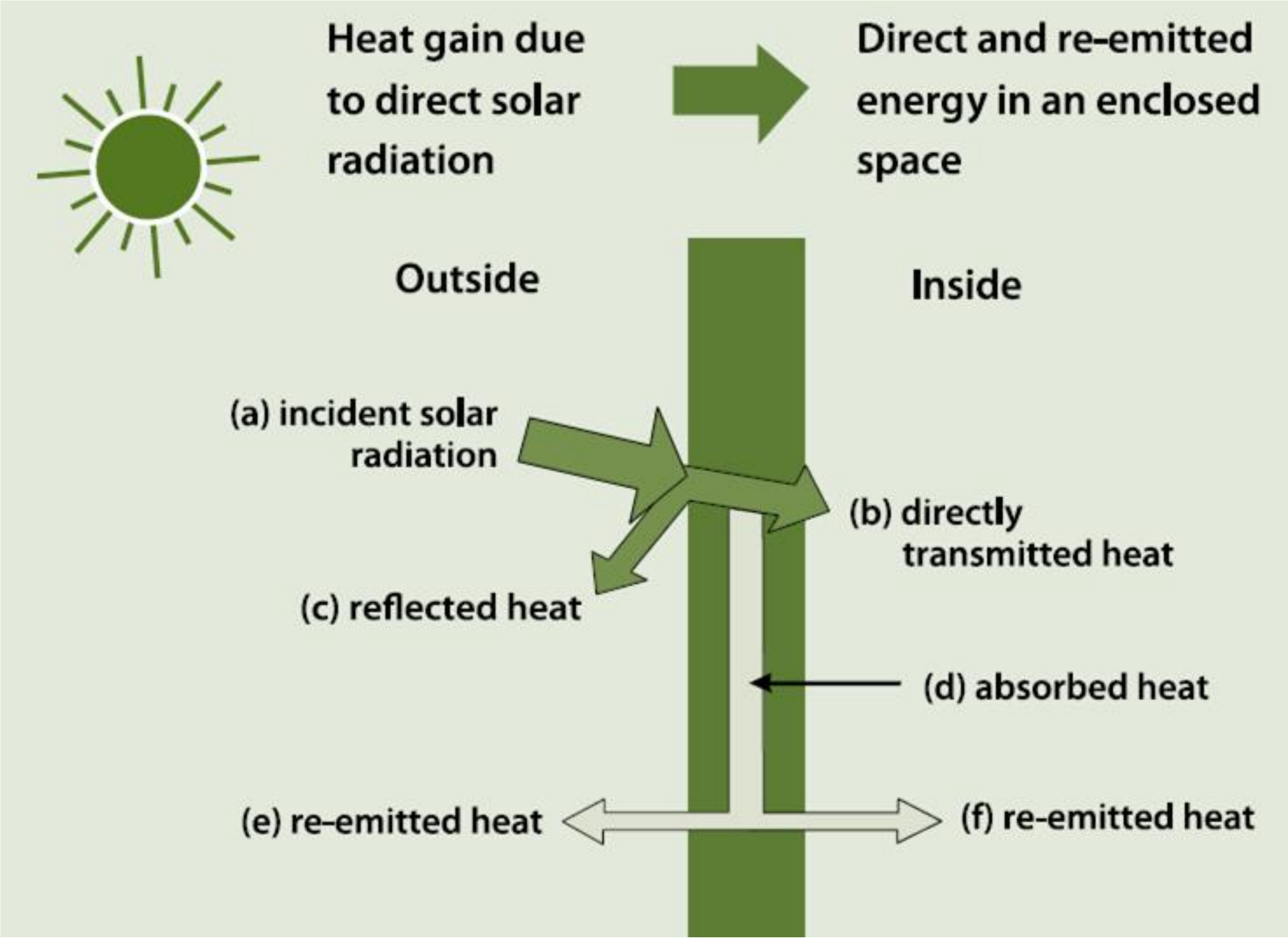
XPS Insulation

Glass Mineral Wool



Glazing Options

Thermal Comfort Improvement through Materials



Thermal Comfort Improvement through Materials

Glazing Selection

U-value / U-factor

- Conductive Heat Transfer
- Thermal conductivity (W/sqmK)
- Glass & Frame
- Lower the better??

SHGC – Solar Heat Gain Coefficient

- Radiation Transmission
- Amount of Heat passes through the glass
- Lower the better??

VLT – Visual Light Transmission

- Light passing through the glass
- Ratio
- Useful light vs Glare
- Higher the better??

Selectivity

- VLT / Solar Factor
- Ratio
- Higher the better??

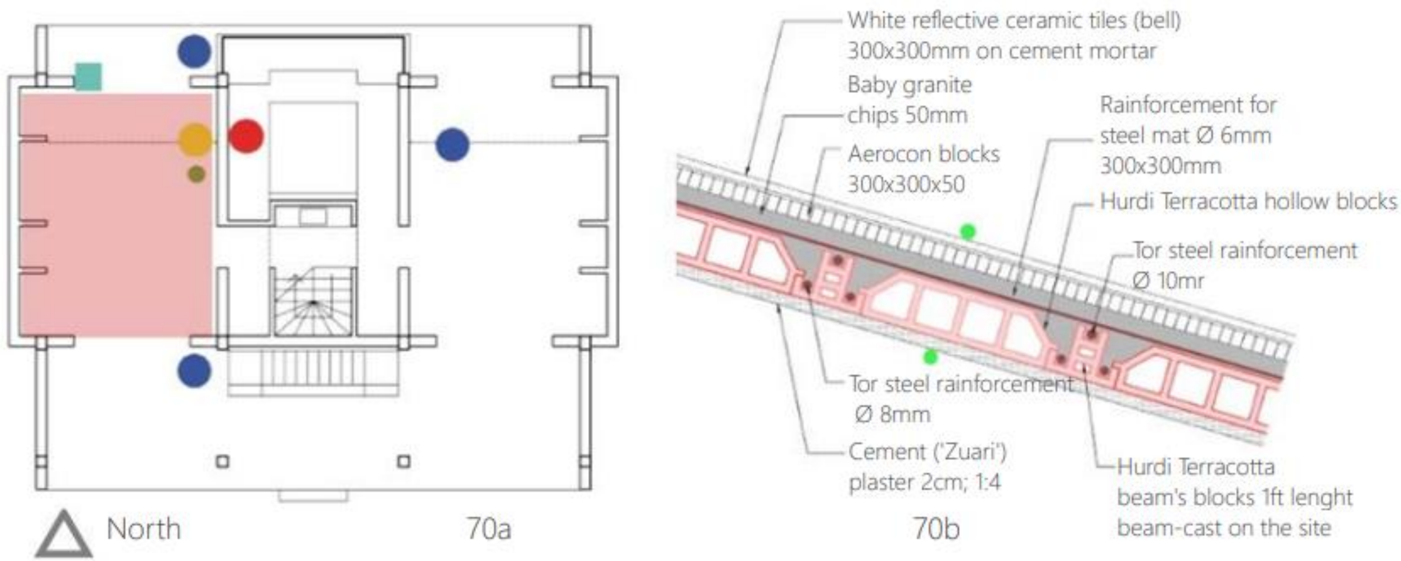
Case Study- The Blessing House, Auroville, India

This section presents a case study (Doctor-Pingel, Vardhan, Manu, Brager, & Rawal, 2019) of a residential building in warm-humid climate experienced in Auroville, India.

Building	Blessing House (AV)
Storeys and rooms	G+1 with 2 rooms and a mezzanine
Function	Private Residence and Workplace
Built-up Area (m^2)	107
Zone under study (m^2)	24
Hours Occupied/ Unoccupied	Always Occupied
No. of Occupants	2-3
Zones/Features Studied	Bedroom, Aerocon Insulated Roof Assembly, Balcony (Night Flushing)
Monitoring Period	SEP 2013-AUG 2014

The Blessing House is a two-story residential building with a home office. The design and construction of the house involves multiple passive design strategies.One of them is the roof assembly.

Case Study- The Blessing House, Auroville, India

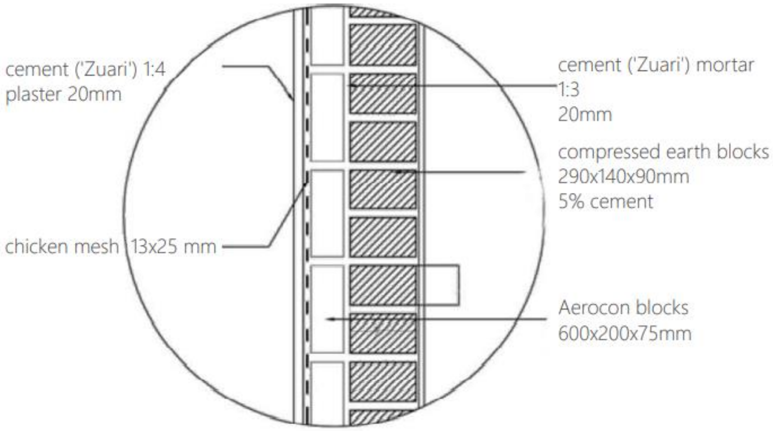


Blessing house architectural and monitoring details;70a- Position of HOBO loggers for monitoring the occupied zone; Yellow dot- HOBO Logger A(RH/Tair/lux), Red dot- HOBO Logger B 2ch(RH/ Tair),Blue dot- HOBO Logger D(RH, T), Green dot- Surface temperature sensor; Green square- logger to record open/close state of balcony window; 70b- Roof construction detail;
Source: (Doctor-Pingel & Vardhan, Blessing House: Post Occupancy Analysis, 2017);

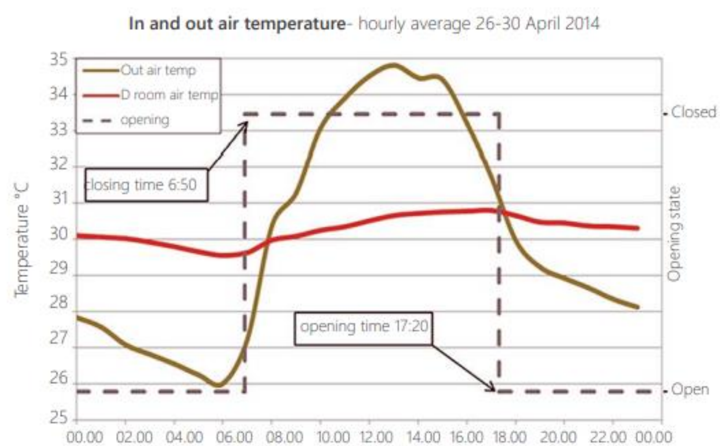
Moving from indoors to outdoors, the roof assembly consists of hurdi terracotta hollow blocks with reinforcement, a layer of cement concrete followed by AAC blocks and finished with white reflective ceramic tiles on top. The inside surface is finished with cement plaster.

Case Study- The Blessing House, Auroville, India

- Another prominent construction material-based passive design feature of the house is the walling assembly consisting of compressed earth blocks shown.
- Moving towards outdoors, the compressed earth block layer is followed by a layer of Aerocon blocks, also known as AAC (Aerated Autoclaved Concrete) blocks.
- Both inside and outside surfaces of the assembly are finished with cement plaster.
- The compressed stabilized earth blocks layer (CSEB) renders high thermal mass to the assembly preventing the loss of indoor coolth through walls.
- Additionally, AAC blocks offer better insulation; thus, preventing heat from outdoors to enter the house.



Walling assembly in Blessing House located in Auroville, India



Daytime closing and nighttime opening of windows prevents excessive temperature rise indoors in the Blessing House.
Source: (Doctor-Pingel, Vardhan, Manu, Brager, & Rawal, 2019)

Case Study- The Blessing House, Auroville, India

Key takeaways from the case study:

- Identifying the most efficient design-based and construction material based passive design measures for given building and climate is crucial to achieve maximum performance.
- Ensuring design details such as effective area of window openings and ventilation flow rates provides opportunity for the strategies to perform with efficiency
- In addition to designing and building with passive design strategies, it is equally relevant to operate buildings, specifically for ventilation-based strategies in accordance with the design measures.

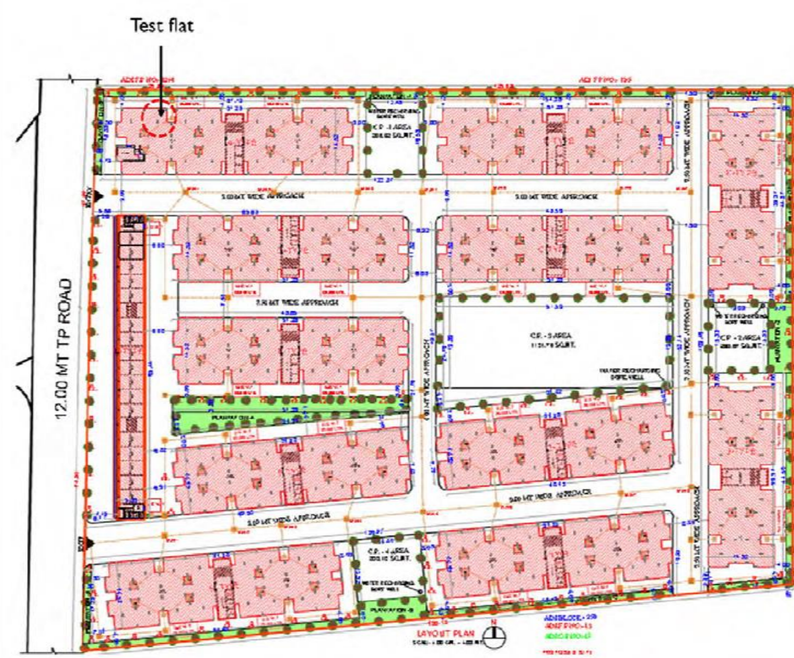
Case Study : Smart Ghar, Rajkot

A CASE STUDY ON DESIGN OF THERMALLY COMFORTABLE AFFORDABLE HOUSING IN COMPOSITE CLIMATE: SIMULATION RESULTS & MONITORED PERFORMANCE

by

Saswati Chetia, Sameer Maithel, Pierre Jaboyedoff, Ashok Lall, Prashant Bhanware, Akshat Gupta

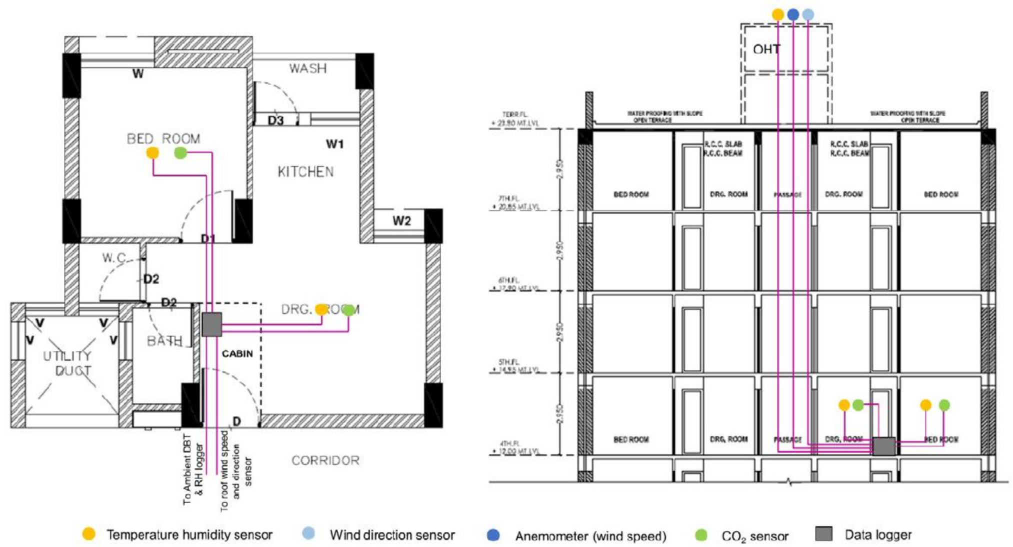
- Project Type - *PMAY Housing*
- Location - *Rajkot*
- Dwelling Units - *1176*
- DU Area - *33.6 m²*
- Ext Wall – *200mm AAC (E&N) & Cavity Wall (200mm AAC + 40mm air gap + 200mm AAC) (W&S Side)*
- Casement windows – for ventilation improvement
- Window shading – *Overhang & Side fins*
- *Glazed window*



Case Study : Smart Ghar, Rajkot

Validation by Software

- Simulated period - May 12, 2019 to May 22, 2019
- Software used - DesignBuilder 4.7 (EnergyPlus 8.3 simulation engine)

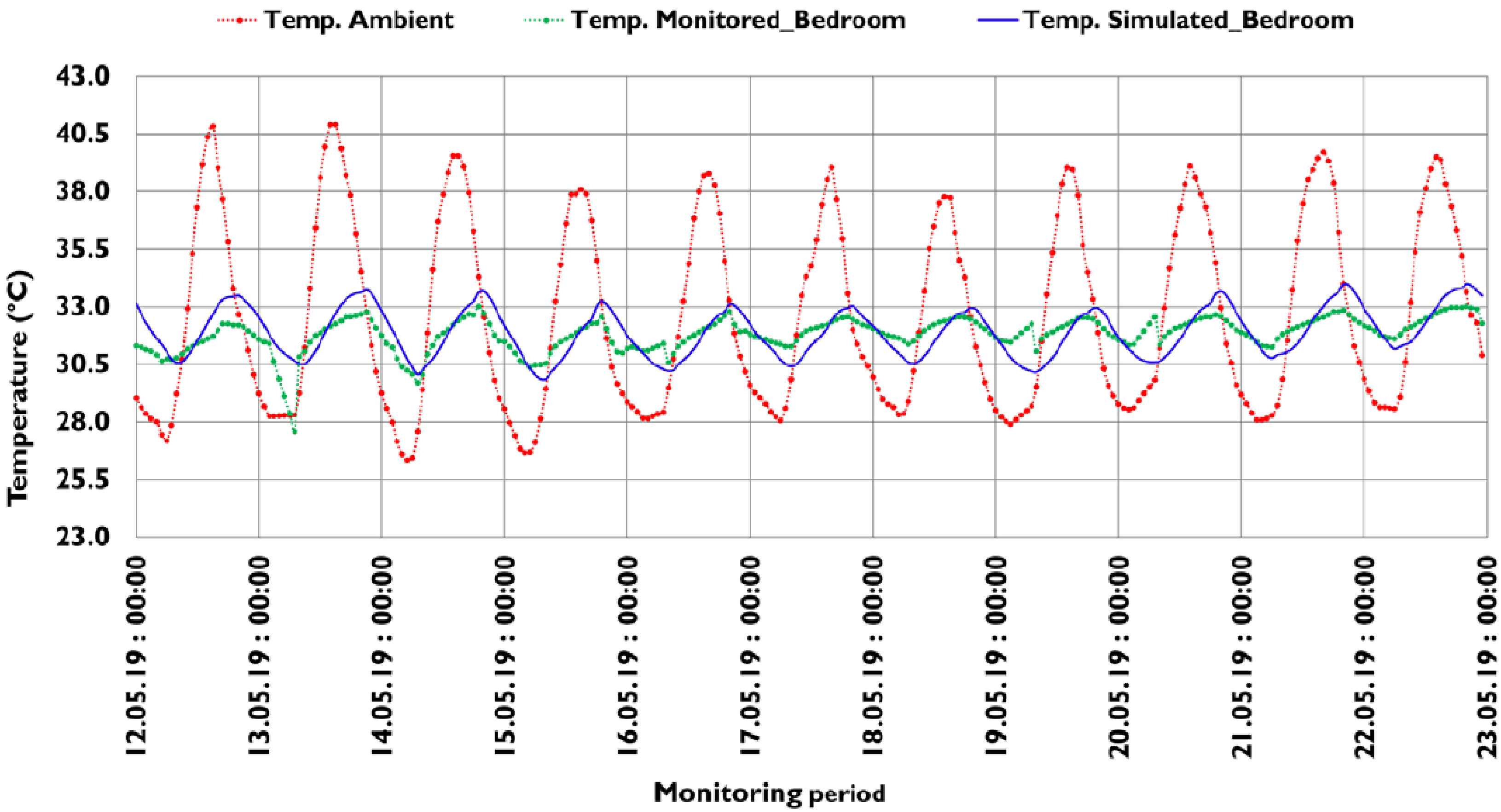


Results

- Indoor temperature for the bedroom goes up to a **maximum average of 32.7°C during the day** and minimum average of 30.6°C early morning. The maximum average ambient temperature was 39.3°C, while the average minimum ambient temperature was 27.8 °C.
- Thus compared to the diurnal variation of 11.5 °C in the ambient temperatures, the diurnal variation in indoor temperature was only 2.1 °C.

Case Study : Smart Ghar, Rajkot

Observations



Case Study : Smart Ghar, Rajkot

Results

- For the present study, the Indian Model for Adaptive Comfort (IMAC) is chosen as the thermal comfort model. It is observed that all hours of the monitored period falls within the 80% acceptability limits whereas 87% of the monitored period falls within the 90% acceptability limits.

Conclusion

- *The results of the monitoring show a* ***quantifiable impact of building envelope*** *(both construction material and openings for ventilation) on internal temperatures.*
- *It shows that with building envelope interventions it is possible to get maximum average temperature of 32°C in summer when the average maximum ambient temperature is 39°C, thus, increasing comfortable hours and reducing the need for air-conditioning.*

CASE STUDIES

Case Studies for Application of Thermal Comfort in Affordable Housing

The study established a time duration of one year to observe thermal performance of the spaces in all seasons. The study also sought to understand the various behavioural adaptations of the occupants during different seasons and their impact on their thermal comfort perception in the given indoor environment. Objective and subjective measurements were recorded to account for occupant adaptations, thermal perceptions, and expectations in defining the range of comfort temperatures. The field tests included half-hourly measurements of both outdoor and indoor conditions for the metrics- air temperature, relative humidity, and illumination levels for 25 days in each season (January: winter, April: pre summer, July: summer/rainy and October: pre winter).

CASE STUDIES

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

Warm and Humid




Cool and Humid (Urban)

Cold and cloudy




Results

Indoor temperature swings are within 10oC for all months in the case of representative houses located in warm-humid and cool-humid climates which is permissible limit for naturally ventilated buildings.

For the representative house in the cold and cloudy climate, the temperature swings are higher. This can be attributed to lower insulation and thermal inertia of walls than required.

Larger adaptability in Tezpur and Imphal as observed indicates higher adaptability of occupants in naturally ventilated buildings.

None of the houses exhibit significantly thermally comfortable environments in the winter months

Occupants have enhanced control over indoor environments in the vernacular houses because they have the flexibility to control their personal and environmental conditions in the form of different adaptations.

For all the cases studied, range of comfort temperatures lies between 6°C and 7.3°C.

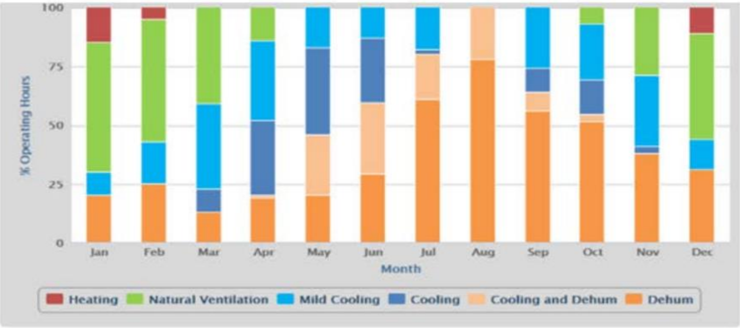
Conventional Houses in Ahmedabad

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

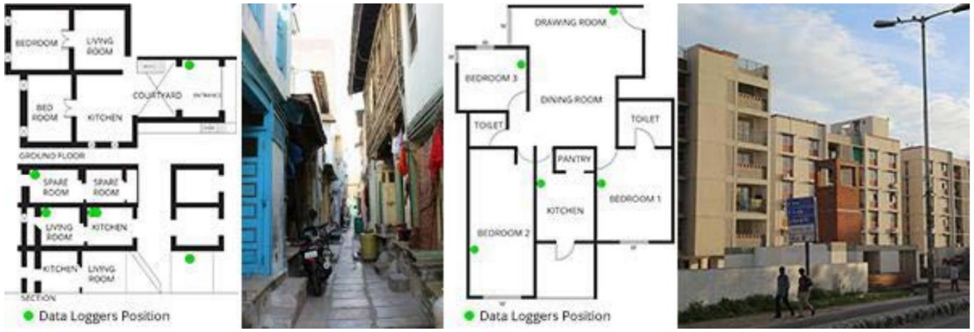
The study estimates the percentage of different operation modes for the building using the adaptive thermal comfort model described in ASHRAE Standard-55 (ASHRAE, 2013).

Additionally, the outdoor conditions were measured using an outdoor weather station installed centrally in the city. It provided the readings for outdoor air temperature, relative humidity, solar radiation, wind speed, wind direction and precipitation.

CASE STUDIES



Estimated operation modes for a typical building in Ahmedabad



Plans of Pol House (PH) and Conventional House (CH) with data logger positions (green dots) and photographs

<u>Conclusions</u>

- Mutual shading in case of pol houses ensures that the roof is the only surface exposed to direct solar irradiance. Additionally, vertical distribution of the total area further reduces the roof area. Hence closer look at the air temperature and relative humidity components may suggest the source of discomfort in pol houses as higher humidity levels.
- The contemporary houses are designed with lighter construction materials and have larger floor plates as compared to pol houses. However, their thermal performance does not differ significantly than the pol houses.

CASE STUDIES

Rajkot Smart GHAR III

The Smart GHAR III in Rajkot is an affordable housing project under PMAY Untenable Slum Redevelopment. Some of the project details are listed below (Indo-Swiss Building Energy Efficiency Project (BEEP), 2021):

Site Area: 17,593 m2

Built-up Area: 57,408 m2

No. of dwelling units (DU): 1176

Type of dwelling units: 1bhk

Built-up area per DU: 33.6 m2

Carpet area per DU: 29 m2

No. of residential towers: 11

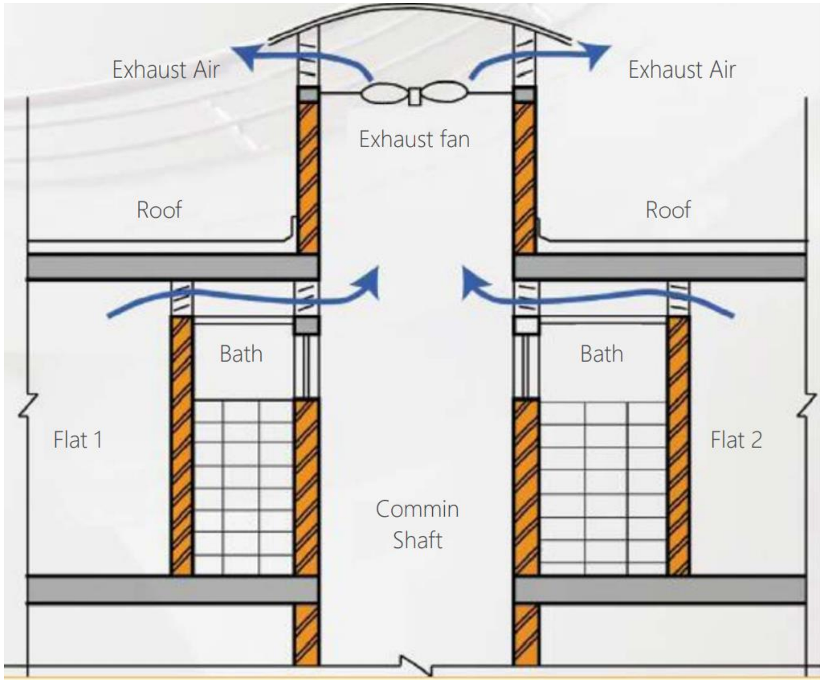
No. of floors: Stilt + 7

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

CASE STUDIES

The energy efficiency measures proposed and implemented in Smart GHAR III are described below:

- Reducing heat gains through walls and roof
- Improving Ventilation through shaft design
- Reducing heat gains through window design and ventilation



Improving ventilation through common service shaft.
Source: (Rawal, Shukla, Patel , Desai, & Asrani, 2021)

Session 5: Thermal Comfort Study Methods

Study Environments

Depending on the research aim, thermal comfort studies can be undertaken in one or combination of following ways:

Field Studies

- Occupant Behaviour
- User Behaviour
- Productivity

Laboratory Studies

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

Digital Simulations

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

Methods of studying thermal comfort

Study Environments

Climate Zones
Selection of cities

Selection of building based on typology, and income

Determination of Environmental parameters, personal parameters, and occupant behaviour related questionnaire

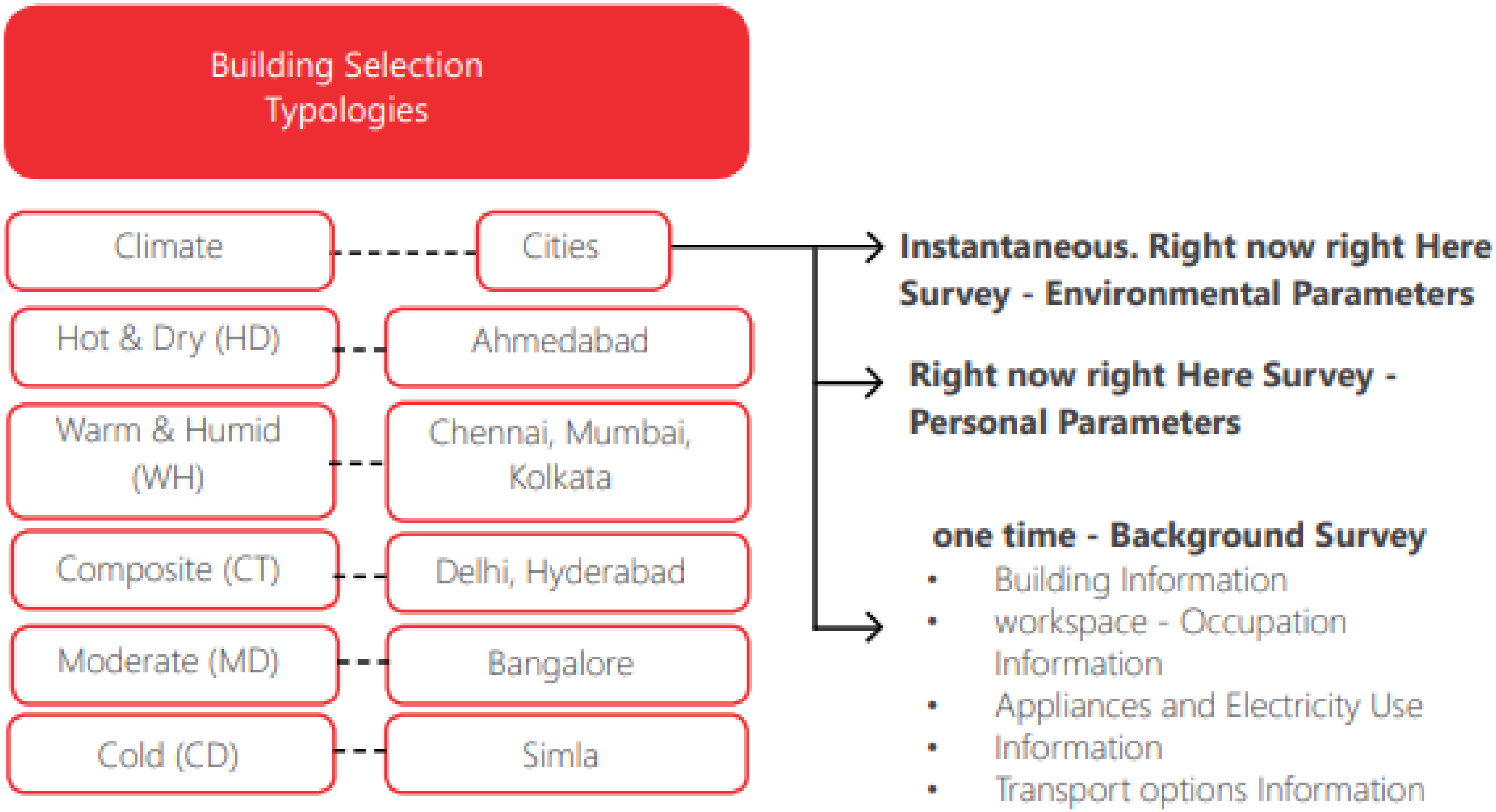
Detailed Methodology Protocol
Detail Instrumentation Plan

Determination of timeline for each city, identification of on-site researchers and deployment of equipment

Sensitization of occupants, Training workshop for Surveyors

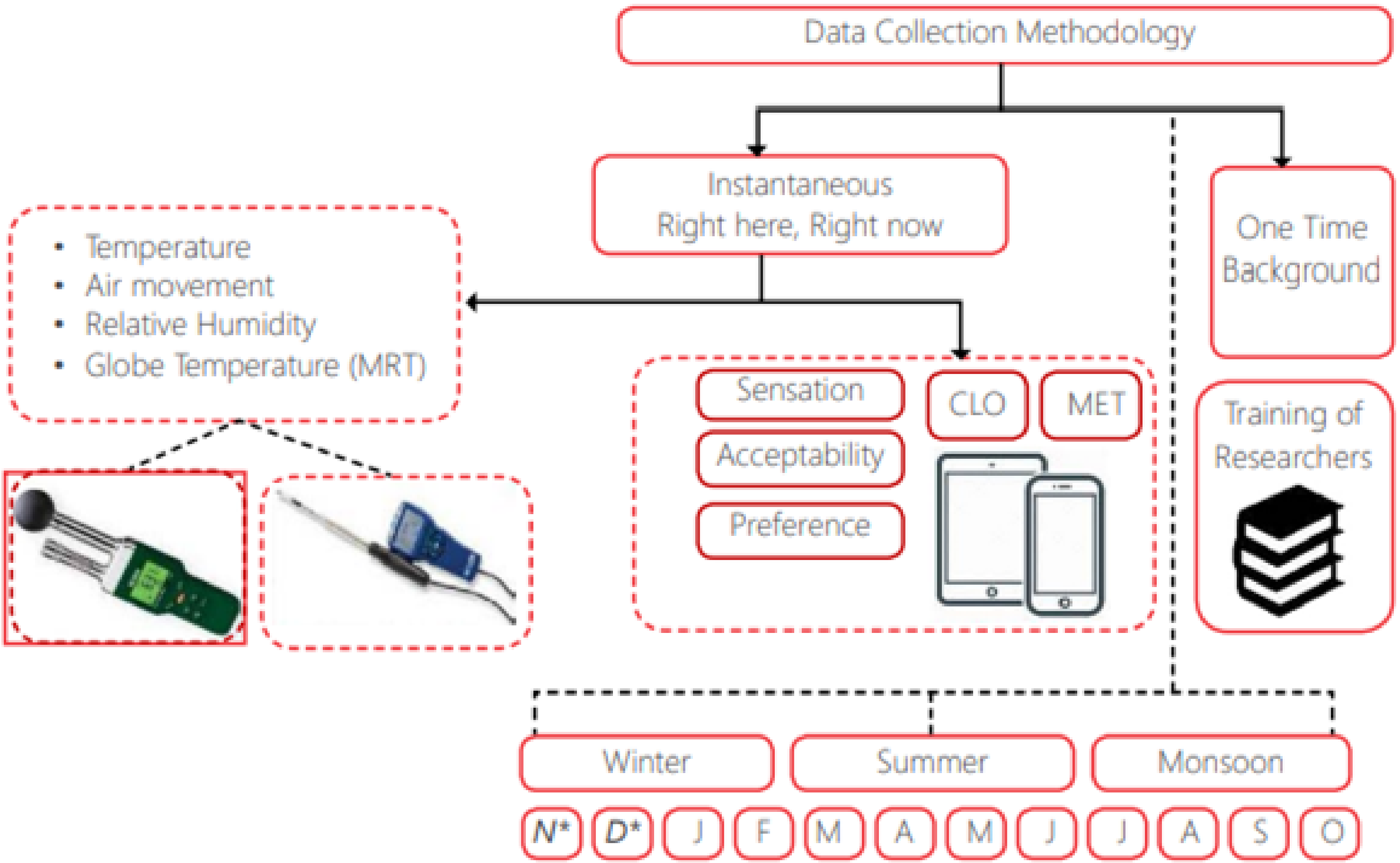
Forethought for thermal comfort studies

Study Environments



Thermal comfort survey execution aspects

Study Environments



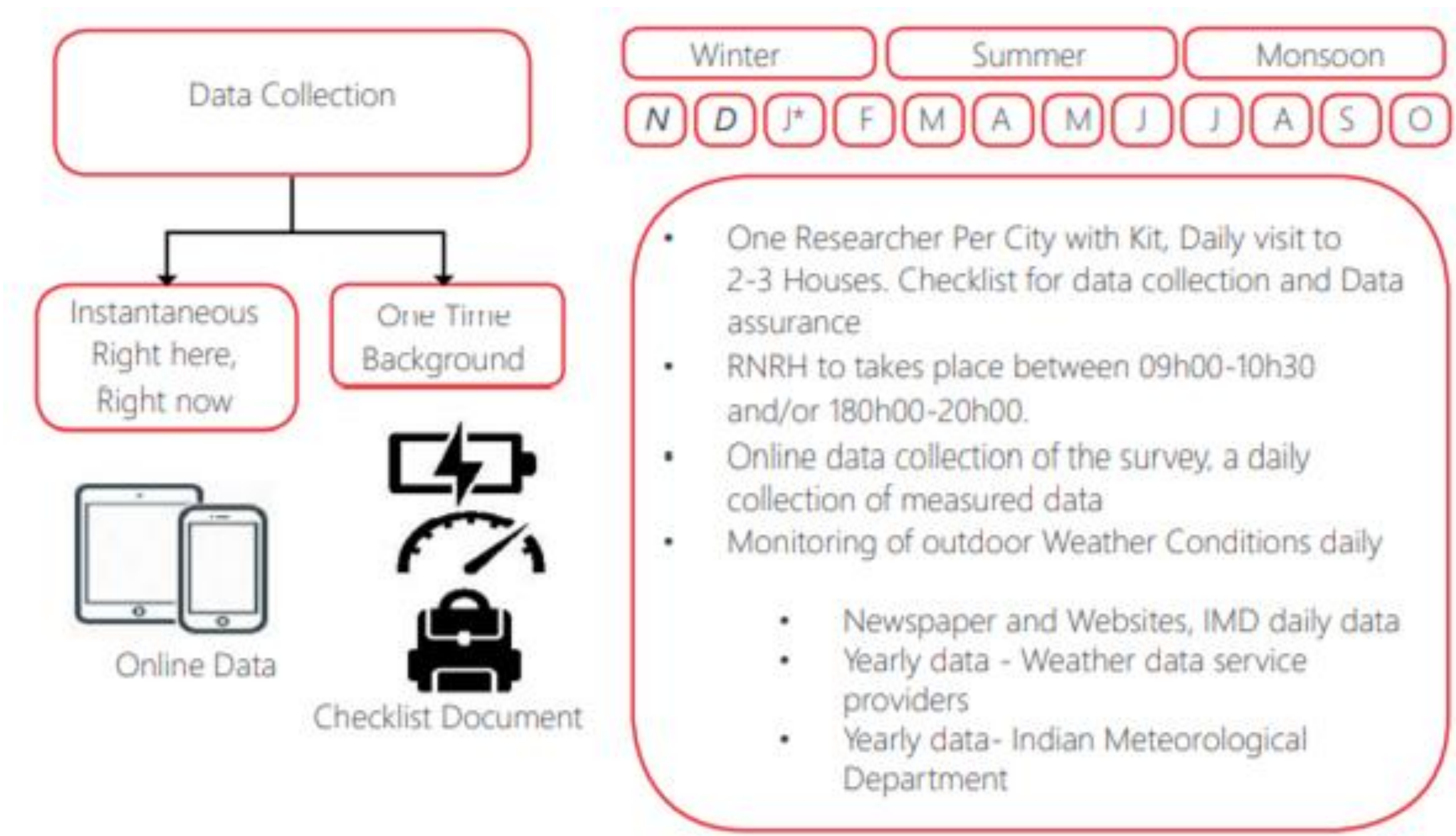
Data collection method for field studies

Study Environments

Scales of thermal sensations, preferences and acceptability

Vote scale	Thermal Sensation	Thermal Acceptability	Thermal Preference	Humidity Sensation	Air movement preference
-3	Very cold			Very humid	
-2	Cold	Completely unacceptable		Humid	
-1	Slightly cold	Just unacceptable	Cooler	Slightly humid	Want less
0	Neutral	Acceptable	No change	Neutral	No change
1	Slightly warm	Just acceptable	Warmer	Slightly dry	Want more
2	Warm	Completely acceptable		Dry	
3	Hot			Very dry	

Study Environments



Indoor and Outdoor data collection sources during thermal comfort survey

Study Environments

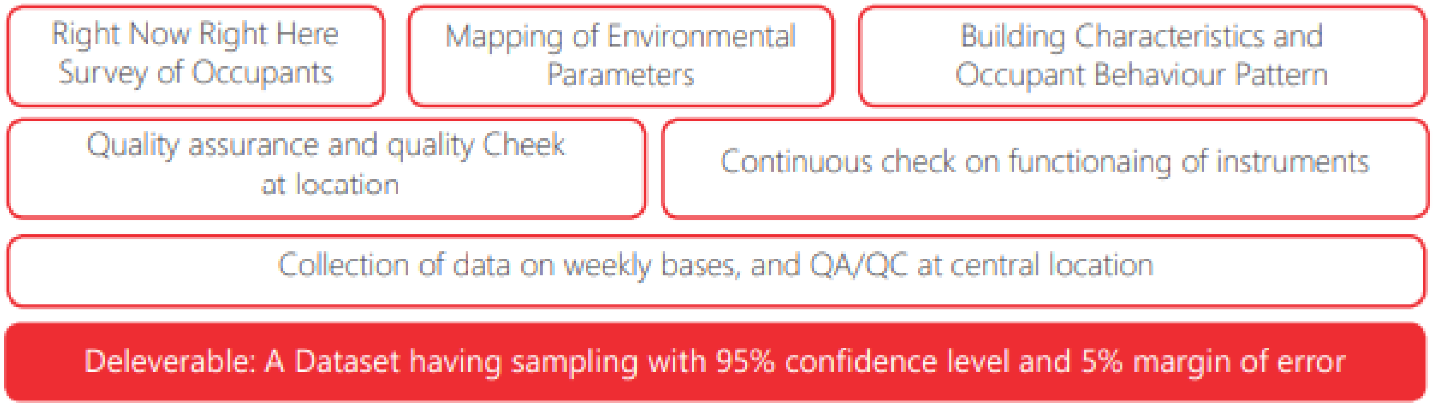
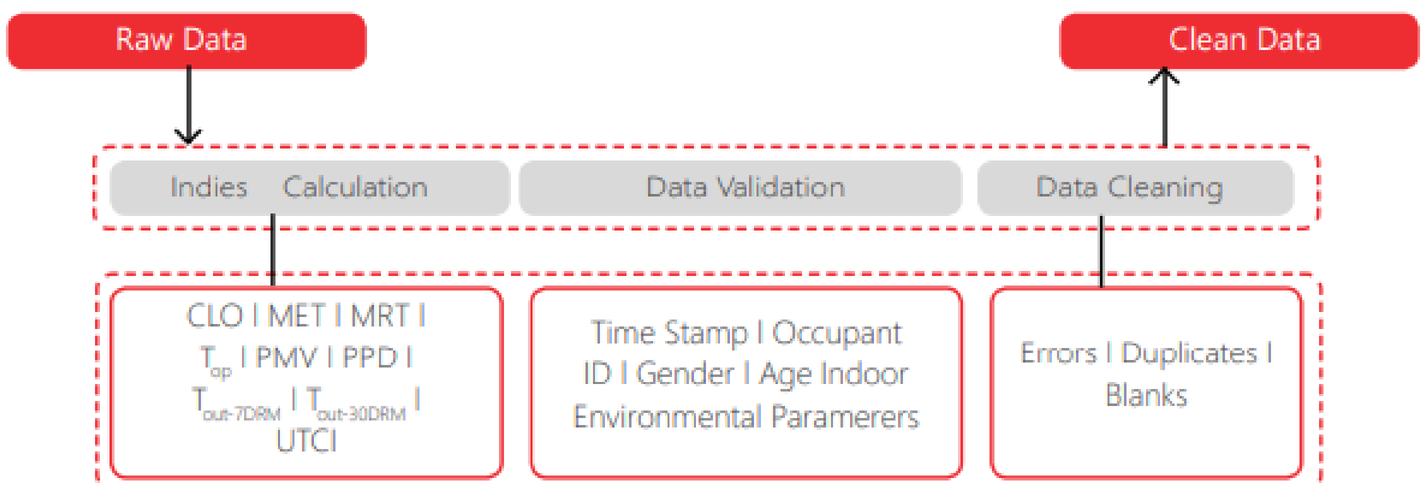


Figure 159: Post processing (QA/QC) of raw data



Quality assurance framework for IMAC-R

Study Environments

- **Measurements:**
  In this category, the component of human is removed from experiments allowing measurements of environmental parameters and their inter-dependencies at desirable granularity.

- **Occupants:** This category refers to involvement of humans in studies that require monitoring of thermal preferences and acceptability or productivity related response to indoor environment. It is different than field studies as a greater degree of control is available over the environment. Additionally, the intervals of measurement are smaller i.e., in minutes as compared to weekly intervals in field studies.

- **Thermal mannequins:** Thermal mannequins are manufactured to house thermal sensors in a composition and intensity that mimics human thermal sensations. Essentially, they represent the physiology of a human body, but without the involvement of psychological influence on thermal perception.

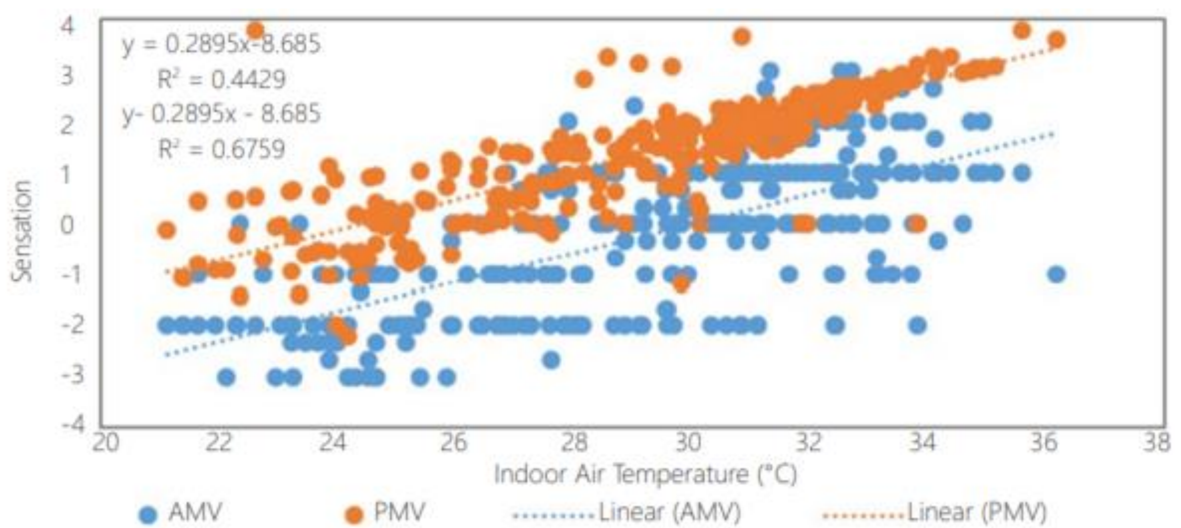
- **Digital Simulations:** Often digital simulations are used to understand the environmental parameters of a space. However, using physiological models with building physics models is an avenue offered by digital simulations.

Study Environments

Thermal comfort studies in controlled environments with (a) measurements, (b) Occupants, (c) thermal mannequins, and (d) digital simulations

Statistical Analysis

- Thermal comfort studies involve analysis of large databases containing multiple data points attributed to various indices and metrics. Incorrect handling of data can lead to wrong inferences. Performing statistical analysis before cleaning the data may result in null hypothesis (H0) or alternate hypothesis (H1).
- Hence, the method of data analysis should be appropriate to the objective and robust to result in reliable observations and relevant conclusions.
- The Figure below shows the difference in fitting models obtained when different approaches were applied to the same dataset.



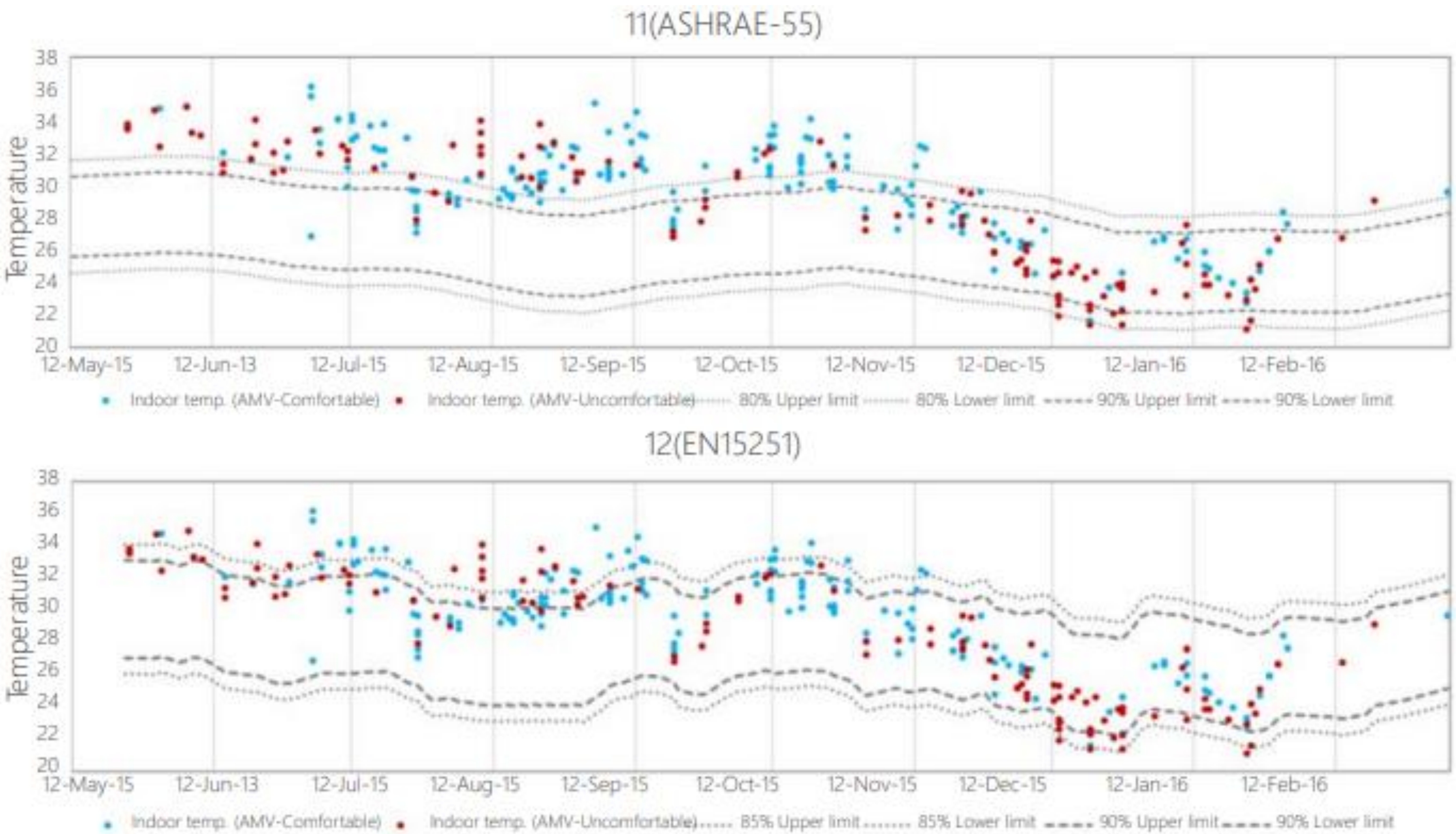
Linear fir for Actual Mean Votes and Predictive Mean Votes

Statistical Analysis

- The databases involved in research should be checked and filtered for bogus and/or contradictory data points. This can be achieved in multiple ways.
- Comparison with corresponding databases (if available) for consistency is one approach.
- For example Measurements of outdoor air temperature recorded at a site can be validated by comparison against temperature recorded by IMD or reported in newspapers for the given day and city.
- Another method to filter inaccurate data is correlating it with subjective data or physical reasoning.
- Moreover, databases should also be scanned for duplication of data to avoid undesirable bias in analysis.

- After filtering and cleaning the data, possible models of correlation should be identified and weighed for suitability. Linear regression, Kendall correlation, and spearhead correlation are common statistical methods used to establish the direction and strength of correlation between the variables. Various tools such as Shapiro – Wilk test, ANOVA (Analysis of Variance), Kruskal-Wallist Test, T test and Wilcoxon Rank test are available to determine the nature of data distribution.

Statistical Analysis

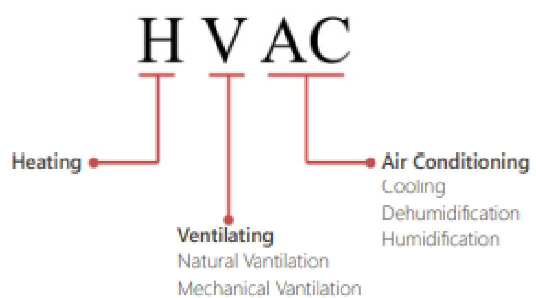


Different results of the fitting model for the same dataset due to different approaches

Session 6: Low Energy cooling technologies and comfort

Low Energy cooling technologies

- Low energy cooling technologies is a relatively new term which can be loosely defined to include technologies that do not use vapor compression cycles which is traditionally the most used refrigeration cycle in current mechanical devices for cooling.
- These include split air conditioner, chillers, variant refrigerant flows systems etc.
- As the name suggests, a characteristic of majority of low energy cooling technologies is reduced energy consumption for operation when compared to conventional vapor compression-based systems.
- The involvement of chemicals deemed to have high global warming potential is limited or completely absent from these technologies.
- Some of these technologies are designed to eliminate refrigerate heating or cooling.
- Few low energy technologies that use the concept of refrigerant-based cooling replace coolant fluids with water. It is one of the measures implemented in these technologies to reduce the undesirable environmental impacts.

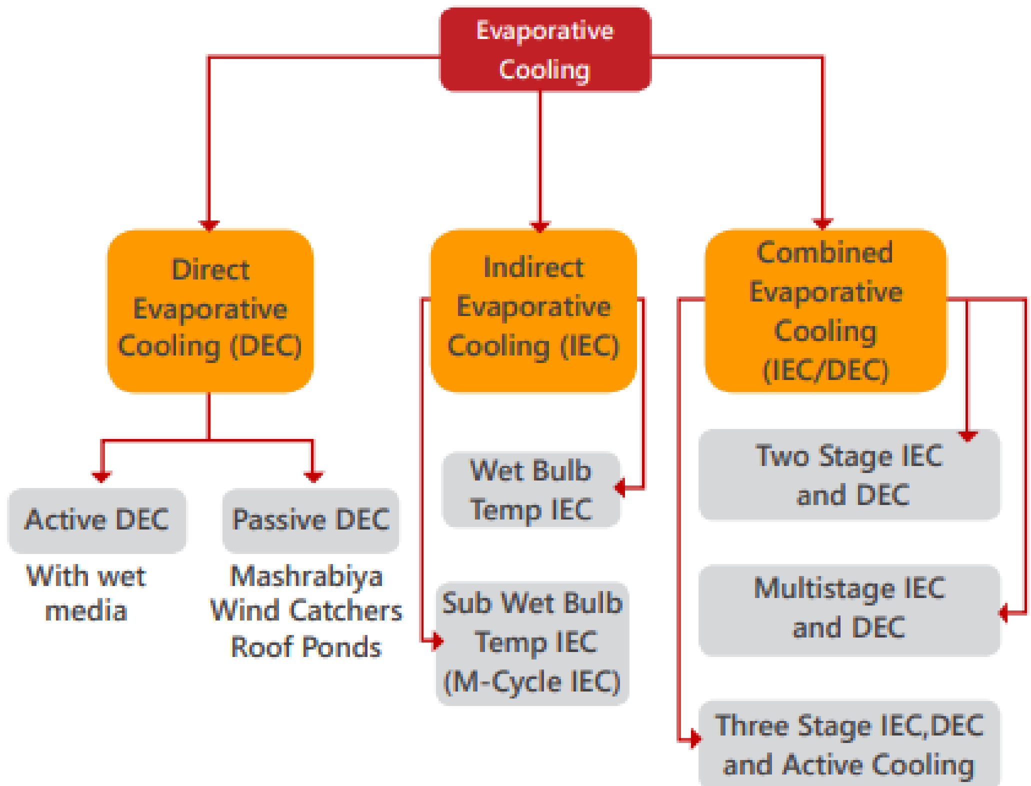


Scope of HVAC systems

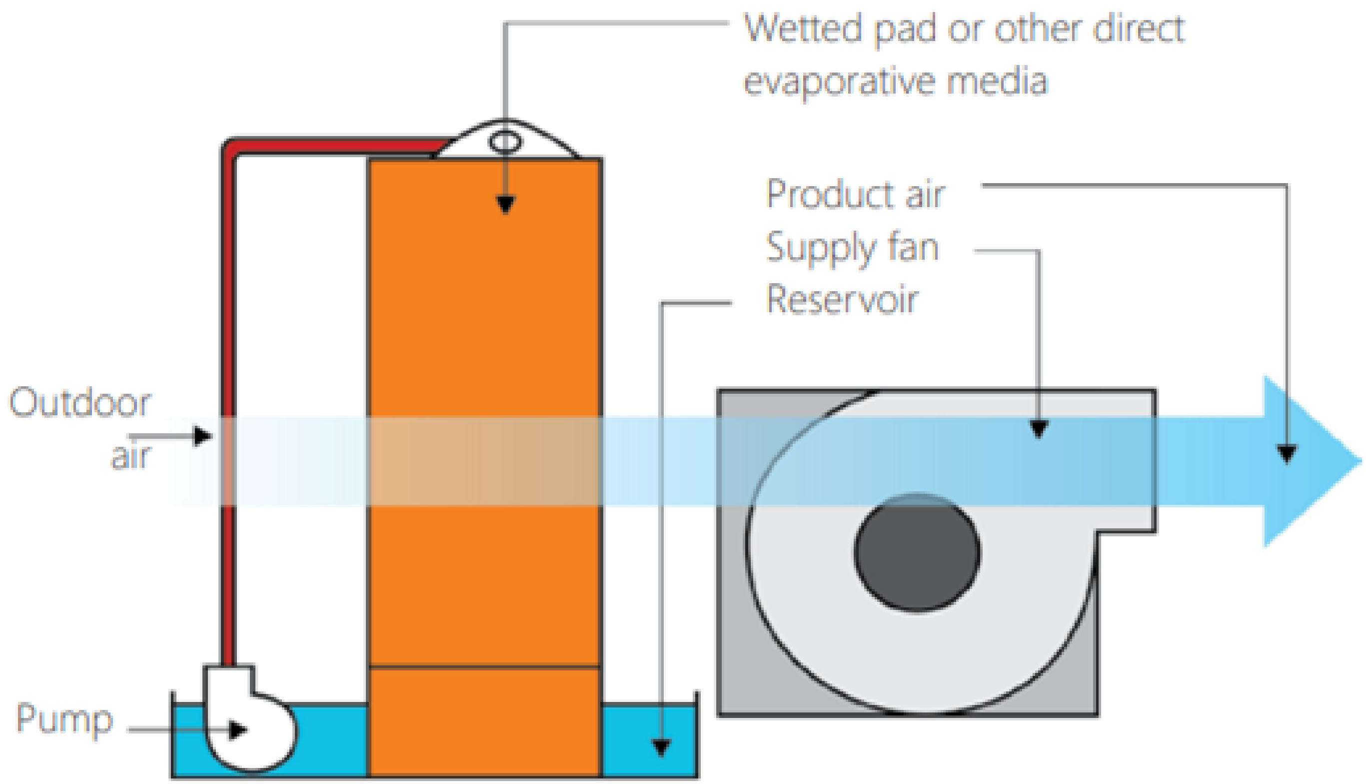
Categories of Low energy cooling systems

Evaporative Cooling

- The categorization for the variations of evaporative cooling systems is presented beside.
- Primarily they can be bifurcated into direct, indirect and combination of the two.
- Active and passive direct evaporative cooling condition the air by bringing it in contact with wet media or surfaces to lower its heat energy.
- Direct contact between air and water also raises the relative humidity of the air slightly.

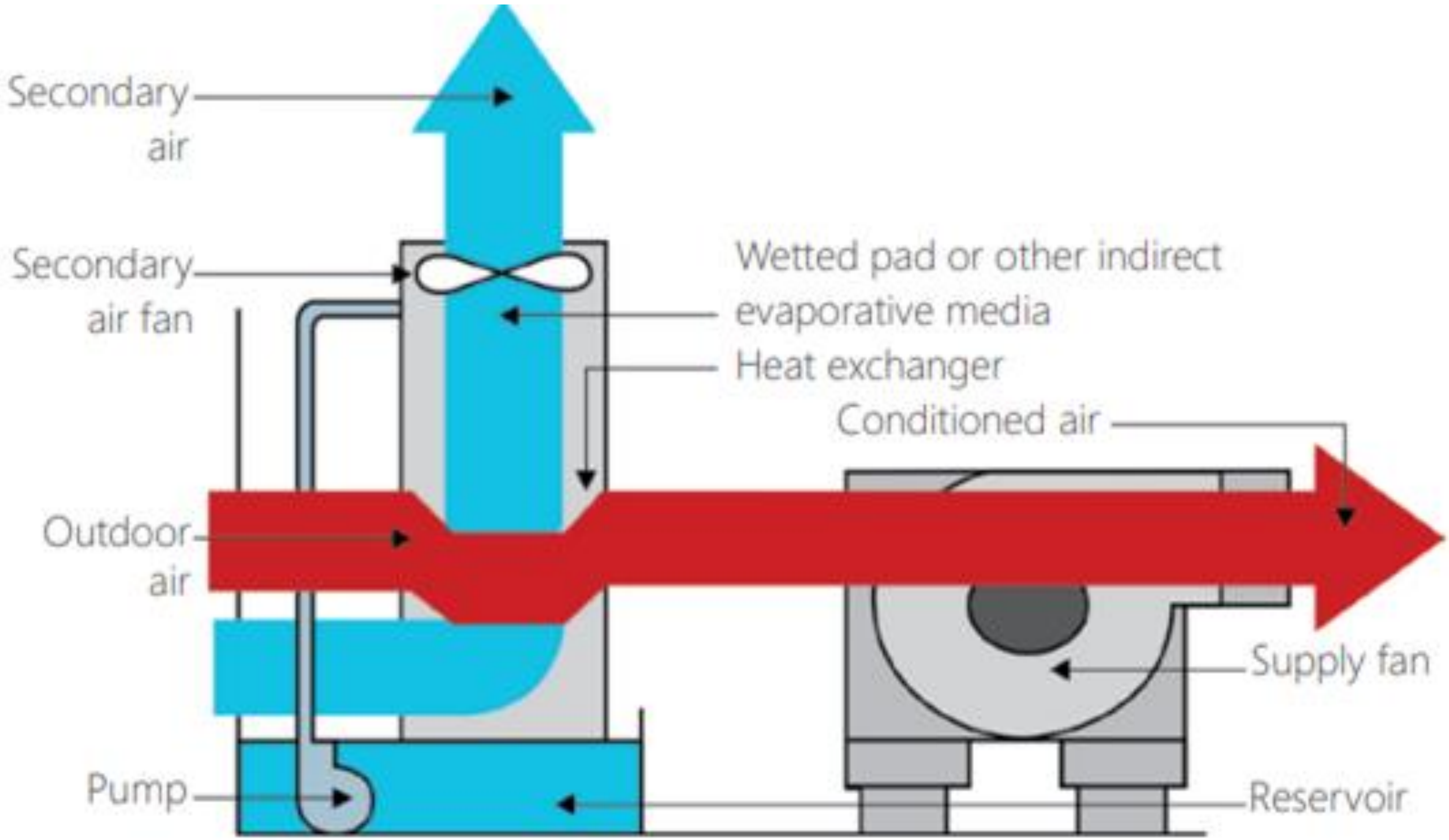


Categories of Low energy cooling systems



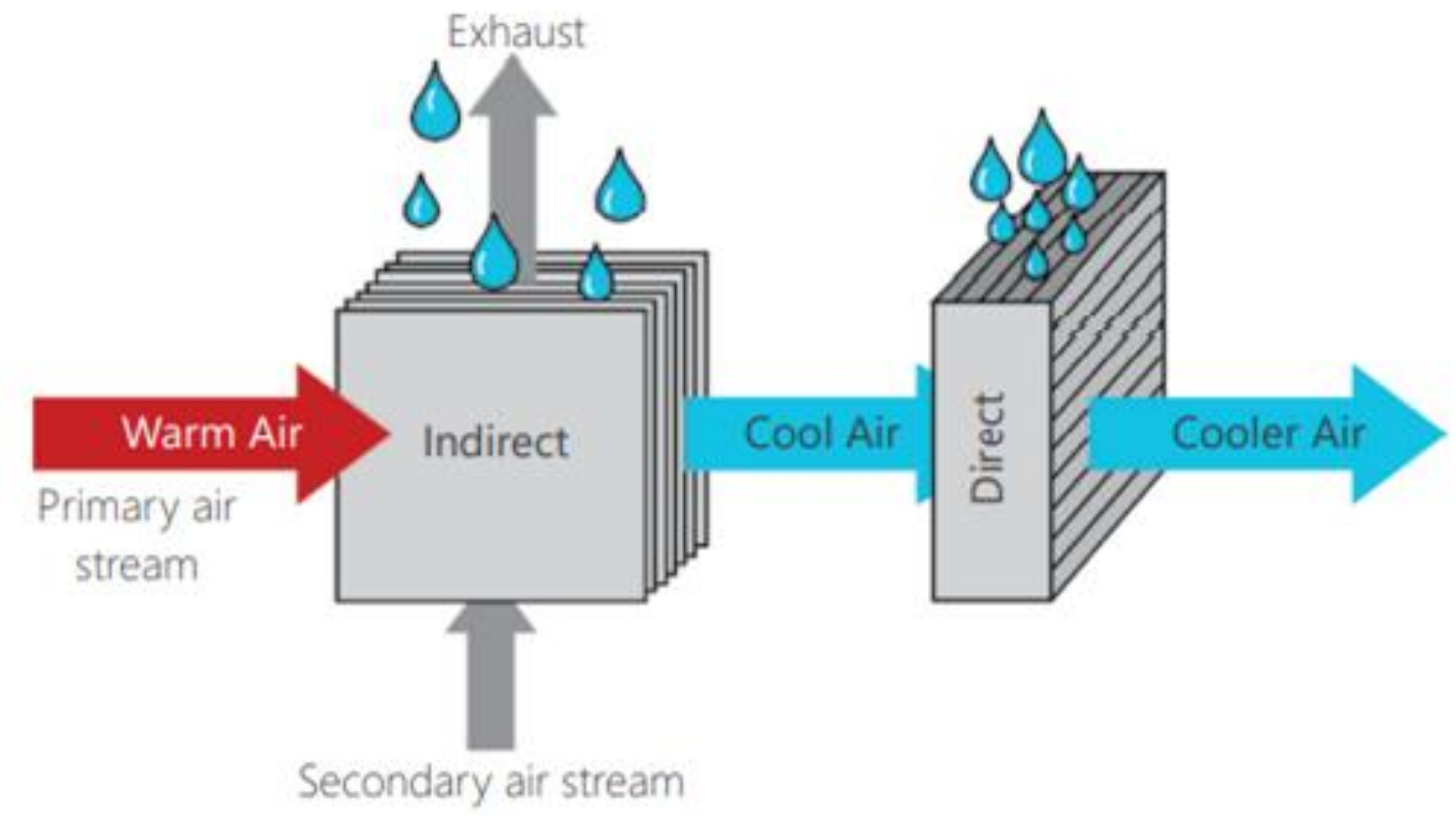
Schematic showing typical Direct Evaporative Cooling System

Categories of Low energy cooling systems



Schematic showing typical Indirect Evaporative Cooling System

Categories of Low energy cooling systems

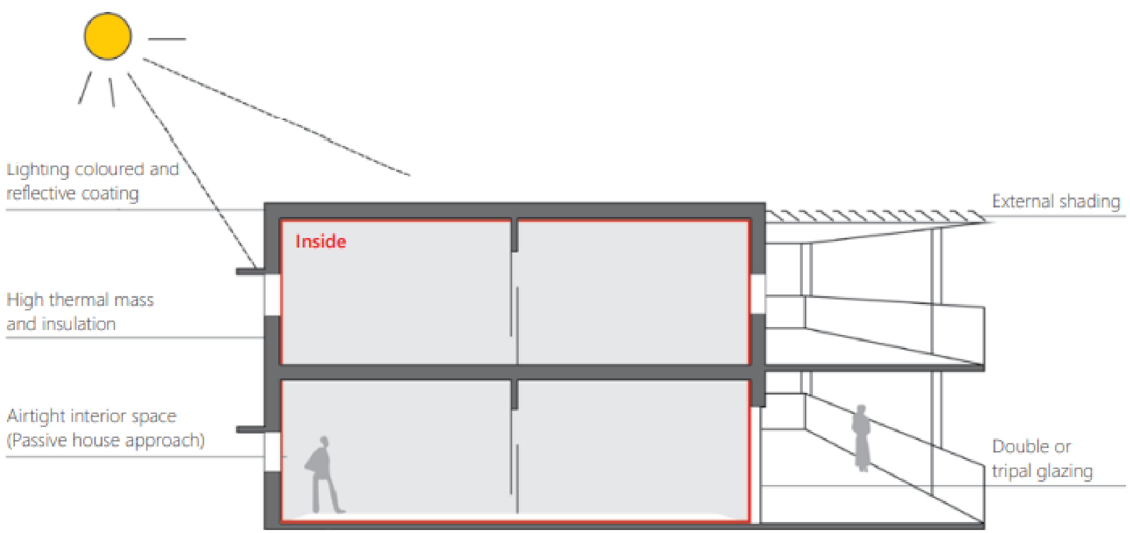


Schematic showing typical two-stage Indirect/Direct Evaporative Cooling System

Categories of Low energy cooling systems

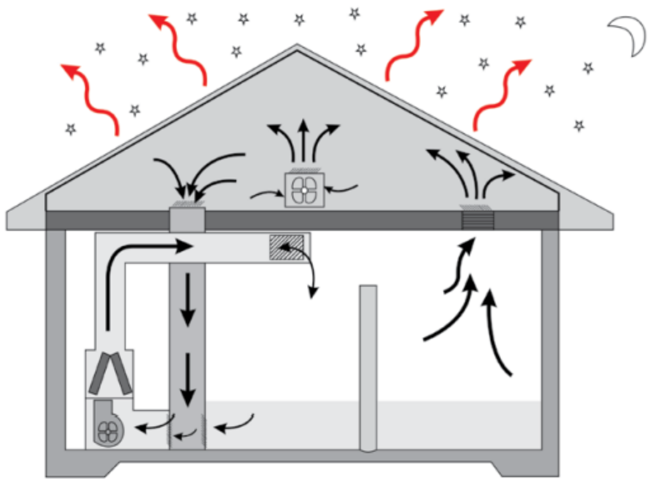
Night Cooling through Natural Ventilation

- Night cooling through natural ventilation is an effective no-cost strategy for ventilative cooling. In terms of building components, it only requires intentional positioning of operable windows or openings in the building design to facilitate movement of outdoor air inside the building.
- This strategy is also effective in lowering internal loads and maintain them in a periodic cycle. Since natural ventilation will regulate the indoor air at nighttime, use of air-conditioners can get restricted to few hours during the middle of the day.



Categories of Low energy cooling systems

Night Cooling through Mechanical Ventilation



- Mechanical ventilation-based cooling at night refers to use of air motion devices such as fan to force outside air to enter indoors and generate cooling effect within the building or space.

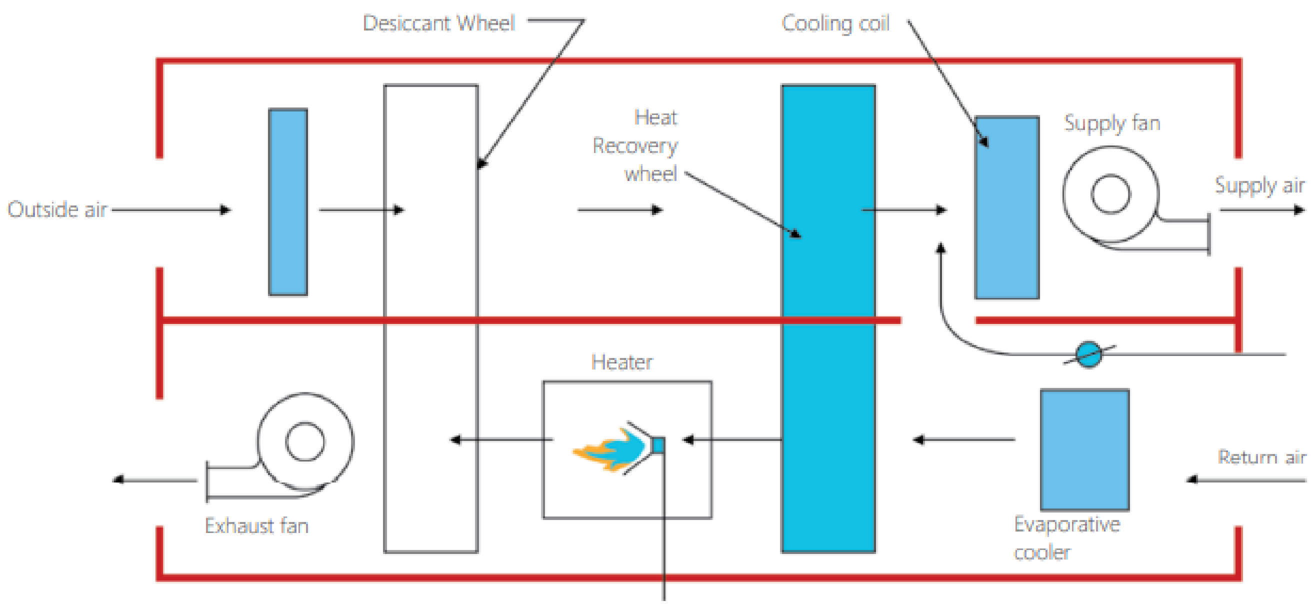
Certain factors that may hamper the effectiveness of night-time cooling by mechanical ventilation are:

- No possibility of fresh air intake
- The forced motion of air through mechanical ventilation requires a certain volume of the space to be effective. If the building has low floor to ceiling height, adequate air movements or drafts, pressure differences may not be created, thereby reducing the cooling effect.
- Additionally, the poor insulation or low thermal mass of walling materials can also reduce the effectiveness of cooling effect of mechanical ventilation at night.

Categories of Low energy cooling systems

Desiccant Cooling Systems

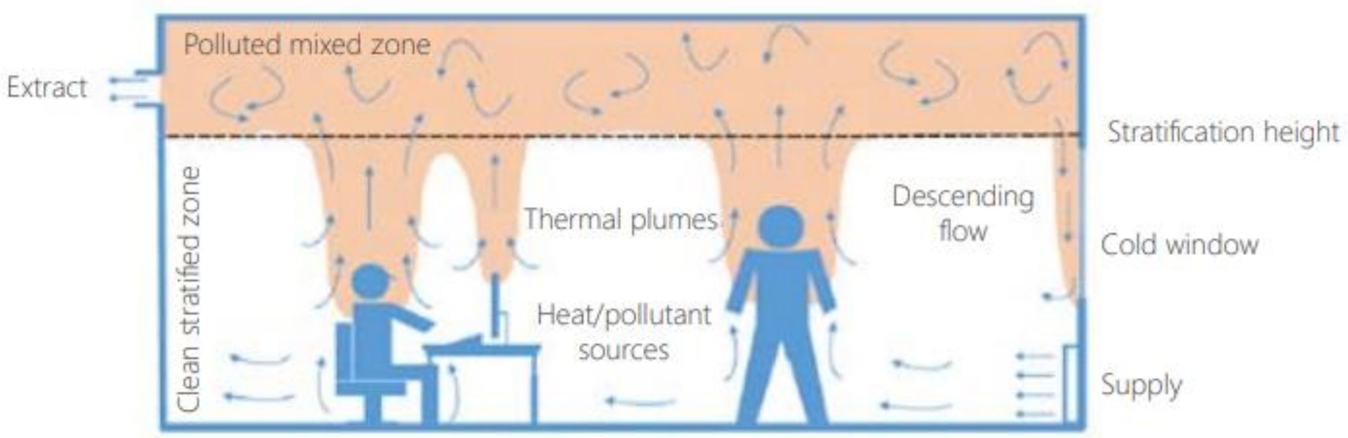
- Desiccant cooling system rely on materials capable of absorbing moisture from the air. It is noteworthy that all materials have a limit to their moisture absorption capacity. Once saturated, the desiccant materials must be refreshed i.e., they require periodic charging to ensure maximum efficiency in moisture absorption. They are highly useful in warm and humid climate where relative humidity of indoor air needs to be regulated for ef



Categories of Low energy cooling systems

Displacement Ventilation

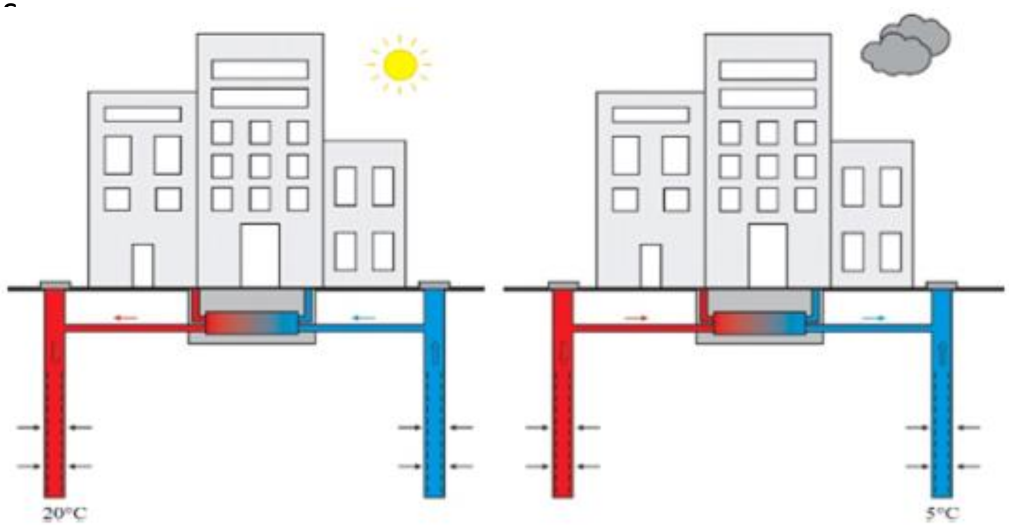
- Displacement ventilation strategy uses natural gravitational movement of air having variable heat energy levels.
- In this system, the cool air is supplied from vents in the floor or from areas of wall closer to the floor.
- As this cool air absorbs heat from the space, its density reduces, allowing it to naturally rises and reach the ceiling in convective air flow. This exhaust air is later removed from vents in the ceiling.



Categories of Low energy cooling systems

Ground and Aquifer cooling

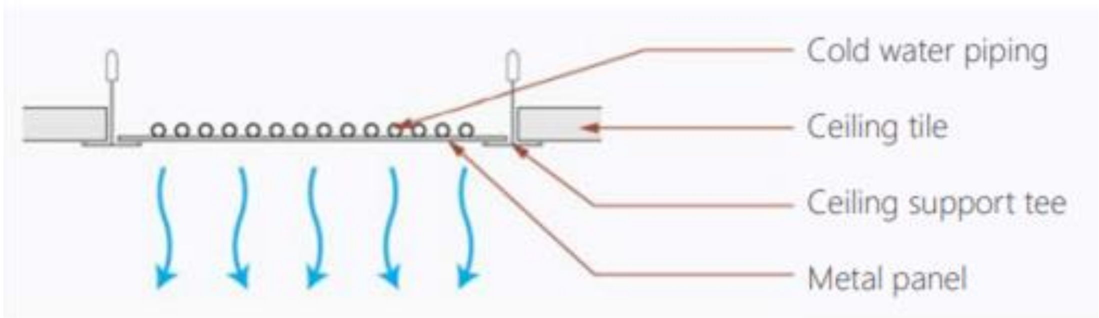
- The temperature of earth beyond a certain depth (3 m in most cases) remains constant in comparison to the air just above or near ground. This is because of the high thermal mass of the soil or earth which heavily inhibits heat transfer.
- This constant temperature can be used to regulate indoor air all throughout the year to maintain thermal comfort inside the buildings.
- With the use of fans, untreated air is blown in the earth tunnels for conditioning.
- Once regulated, it is distributed indoors to achieve thermally comfortable indoor temperatu

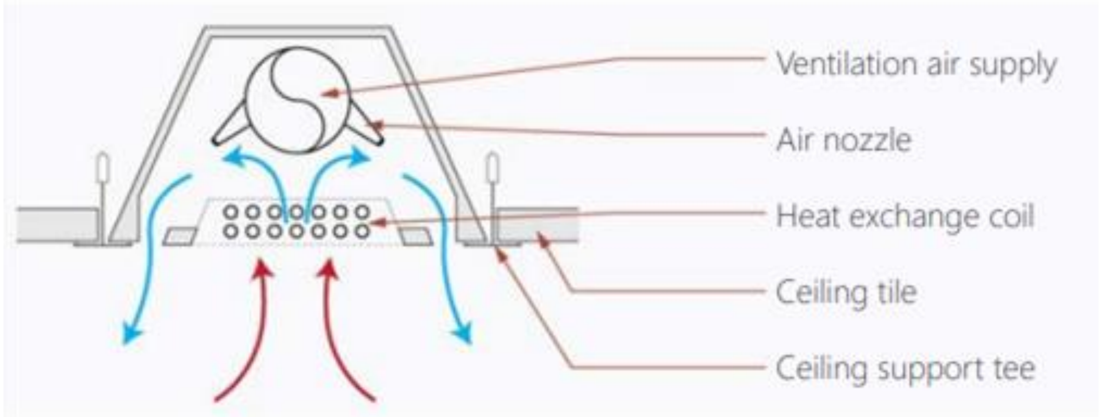


Categories of Low energy cooling systems

Chilled Ceiling and Beams

- This technology utilizes radiative and convective heat transfer mechanisms to effectively manage sensible loads of an indoor space.
- Active and Passive chilled beams are two categories that differ in terms of presence of nozzle blowers to aid the convective motion of air for greater efficiency in cooling.

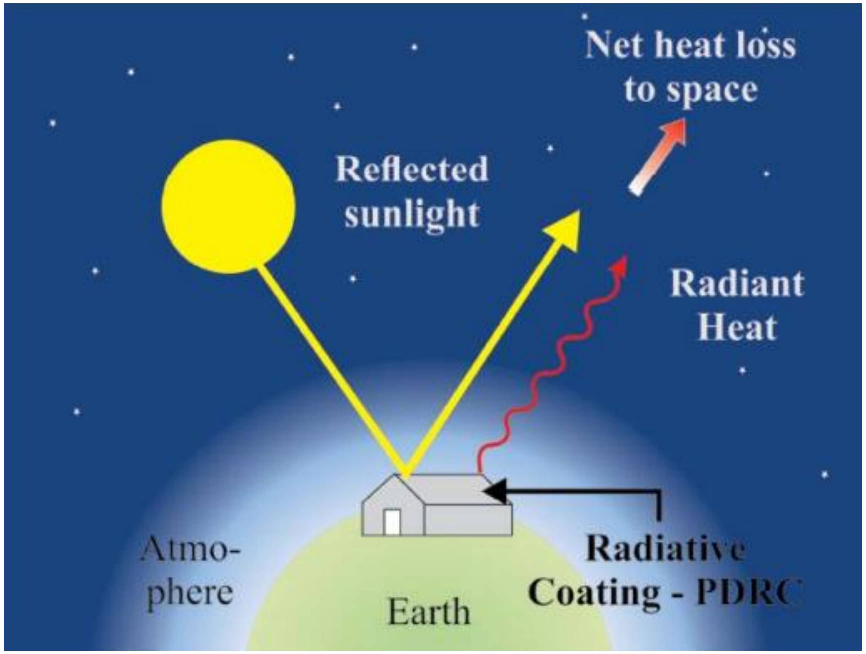




Categories of Low energy cooling systems

Radiative Cooling

- The building envelope component receiving the highest amount of direct solar radiation is roof. Hence, cutting down radiative heat transfer in the indoors through roof is a highly effective strategy to lower cooling loads.
- Termed as radiative cooling, this concept includes covering or coating roof surfaces with tiles, paints or materials having SRI values to increase the amount of radiation reflected by the surfaces.
- Since this radiation is directly reflected in the same wavelength as incident radiation, deep sky becomes the heat sink in this system. Radiative heat transfer surrounding environment is therefore minimized. Hence, radiative cooling is highly effective in managing sensible loads.



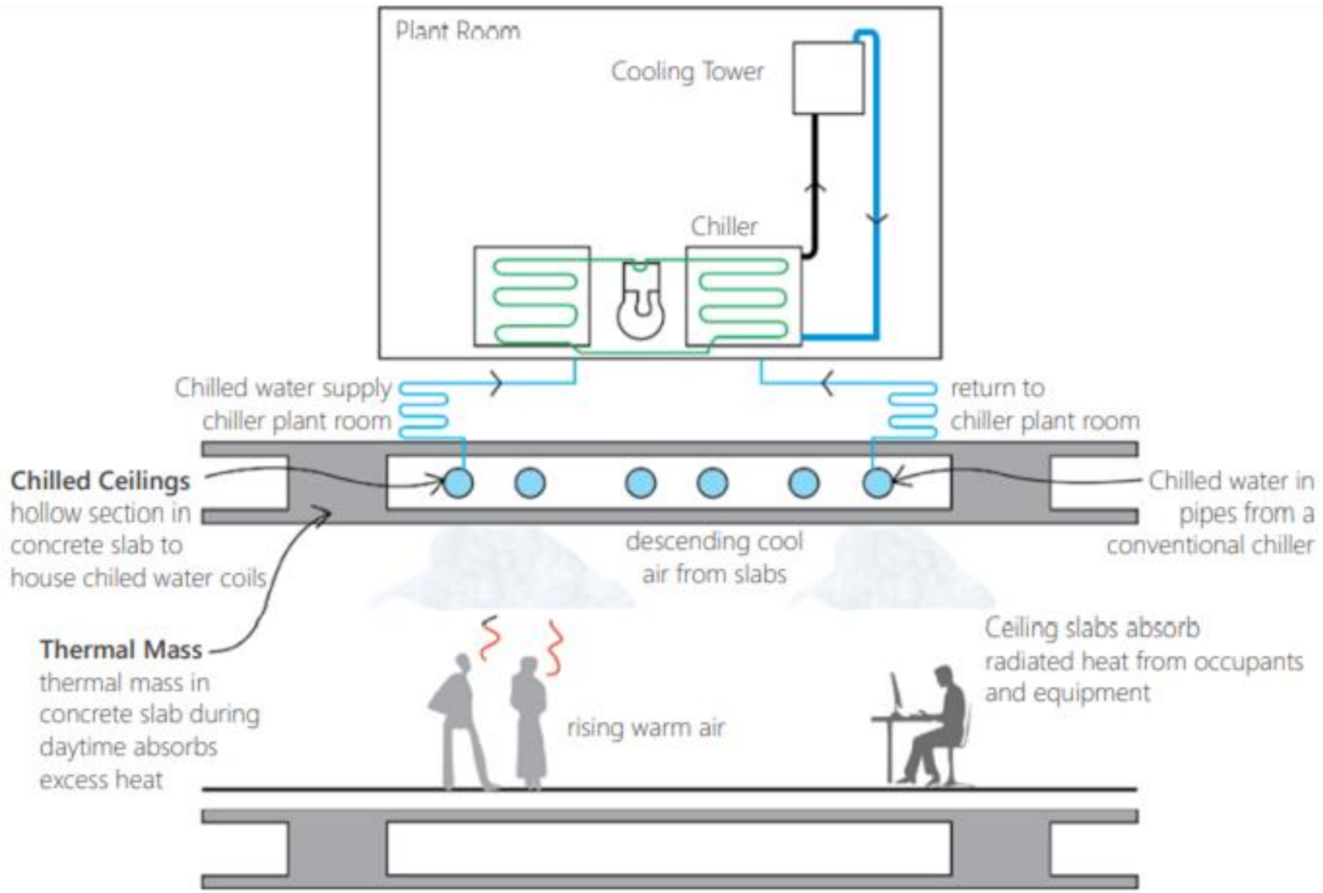
Categories of Low energy cooling systems

Radiant Structural Cooling

- In this technology, chilled water pipes are embedded in the structural system of the building i.e., either roof or walls.
- Heat transfer predominantly occurs through surfaces like floors, ceiling, or wall which in turn are heated or cooled by embedded coils.
- Radiant systems are installed in combination of large thermal mass to facilitate absorption and radiation.
- For optimizing performance of the systems, coils should be installed in floors for heating purposes, and in ceiling for all cooling purposes.

Categories of Low energy cooling systems

Radiant Structural Cooling



Rating Steps and Standards

Energy Efficiency Ratio calculation steps

- The DBT, WBT and pressure conditions at the inlet and outlet of the low energy cooling technologies should be measured to derive the enthalpy, specific volume and relative humidity values of the indoor air using a psychrometric chart or table.

- Measuring the flow rate of air determines the total cooling capacity of the technology. This amount of total cooling load delivered is bifurcated into sensible and latent cooling capacity by either measuring the latent cooling capacity directly or removing calculated sensible cooling capacity from the calculated total cooling capacity.

- This feeds into the calculation for dehumidification capacity, and subsequently the power consumption is measured to obtain Energy Efficiency Ratio (EER) of the test unit.

Rating Steps and Standards

Steps for rating as per standards

Measurements of DBT, WBT, Pressure

↓

Derivation of Enthalpy, Specific Volume, Relative Humidity (using Psychrometric tables)

↓

Calculation of flow rate of air

↓

Determining Total cooling capacity

↓

Calculating Sensible cooling capacity

↓

Latent cooling capacity = Total cooling capacity – Sensible cooling capacity

↓

Calculation of Dehumidification capacity

↓

Determination of EER for the test unit

Rating Steps and Standards

Reference Standards

Country specific standards for evaporative cooling systems (not included in the table) are available in various parts of the world

Standard	Scope
AHRI 340/360	Performance testing of commercial and industrial unitary air conditioning and heat pump equipment (up to 65,000 Btu/h)
ASHRAE 37	Performance testing of electrically driven unitary air conditioning equipment (less than 65,000 Btu/h)
ASHRAE 116	Determining seasonal efficiency of unitary air conditioning equipment
ASHRAE 16	Performance testing of room air conditioners and packaged terminal units
IS 1391 – 1	Performance testing of room air conditioners – unitary air conditioners (from 6000 Btu/h to 35,000 Btu/h)
IS 1391 – 2	Performance testing of room air conditioners- split air conditioners (12,000 Btu/h to 65,000 Btu/h)
AHRI 1230	Performance testing of variable refrigerant systems (VRF) and heat pump equipment (12,000 Btu/h to 65,000 Btu/h)
AHRI 210/240	Performance testing of unitary air conditioning and heating pump equipment (capacities less than 65,000 Btu/h)

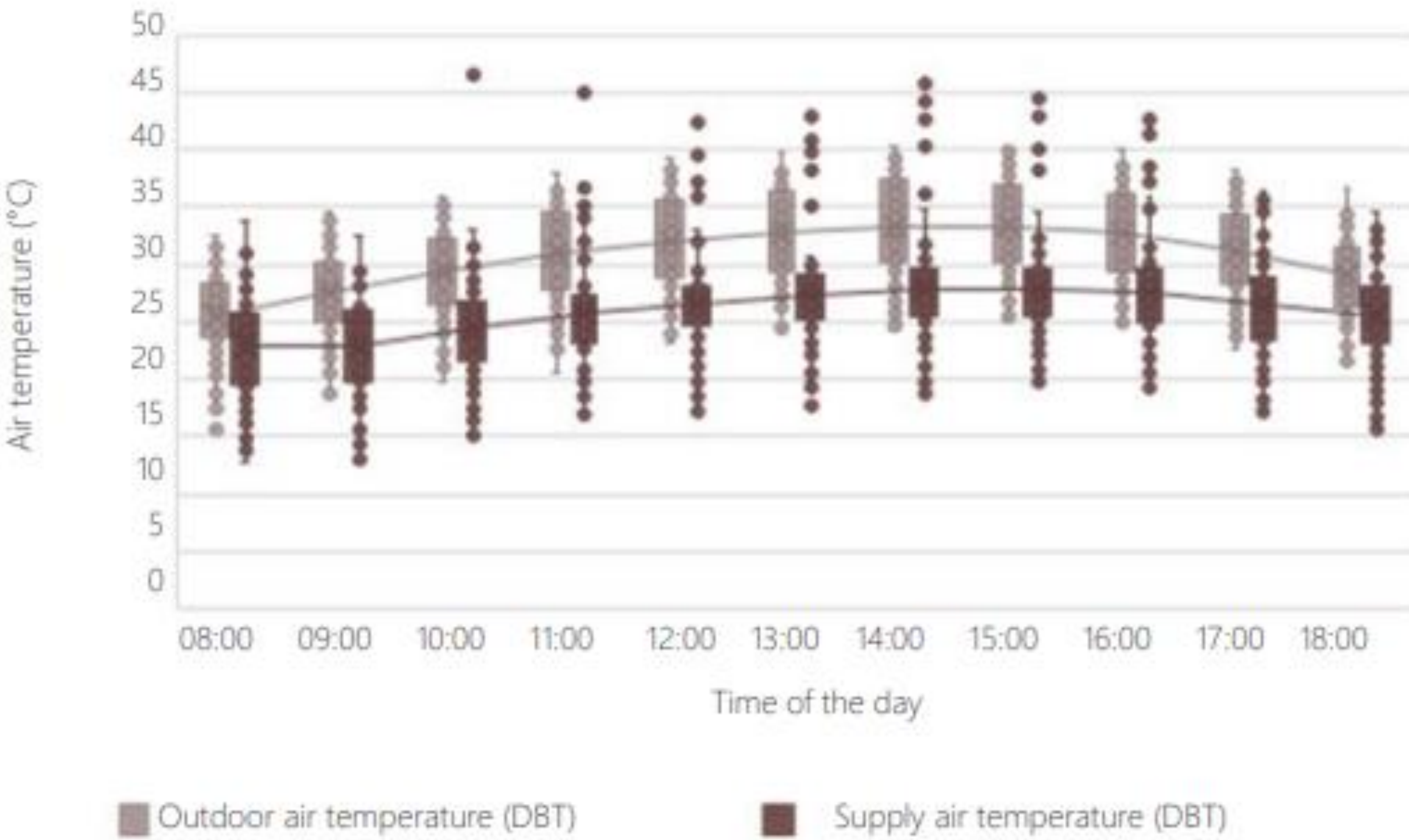
Case Study

Food manufacturing facility in Nadiad, Gujarat; Total system capacity- 30,000 CFM

Shown next is the supply air temperature variation is nearly 5-6 °C and the RH level fluctuates within 30-35% range from 12h00 to 18h00 hours. Considering wet bulb effectiveness, the variation is quite high (25%-100%) and the system takes nearly one hour to stabilize. On the other hand, the energy consumption throughout the day is constant.

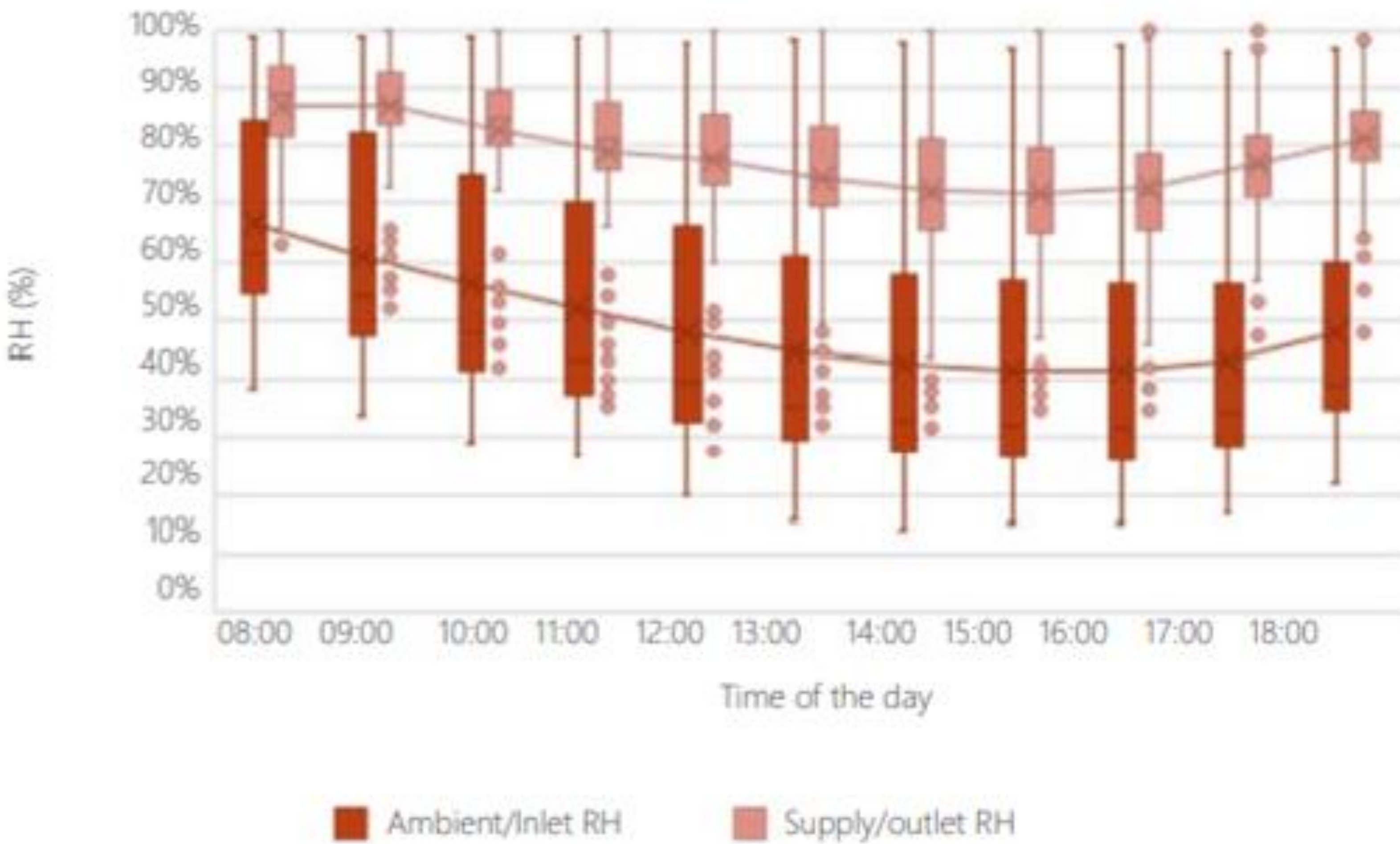
Graphs show that at 35°C, base case system consumes high amount of energy to provide maximum comfort indicated by 0.2 on the PMV scale. Standalone DEC systems indicate the opposite scenario of low energy consumption and less comfort.
However, hybrid systems comprising of base case and DEC combination are capable of providing slightly higher thermal comfort with relatively lower energy consumption.
As the humidity levels change, energy consumption of compared cases increase significantly to maintain thermal comfort of same level.

Case Study



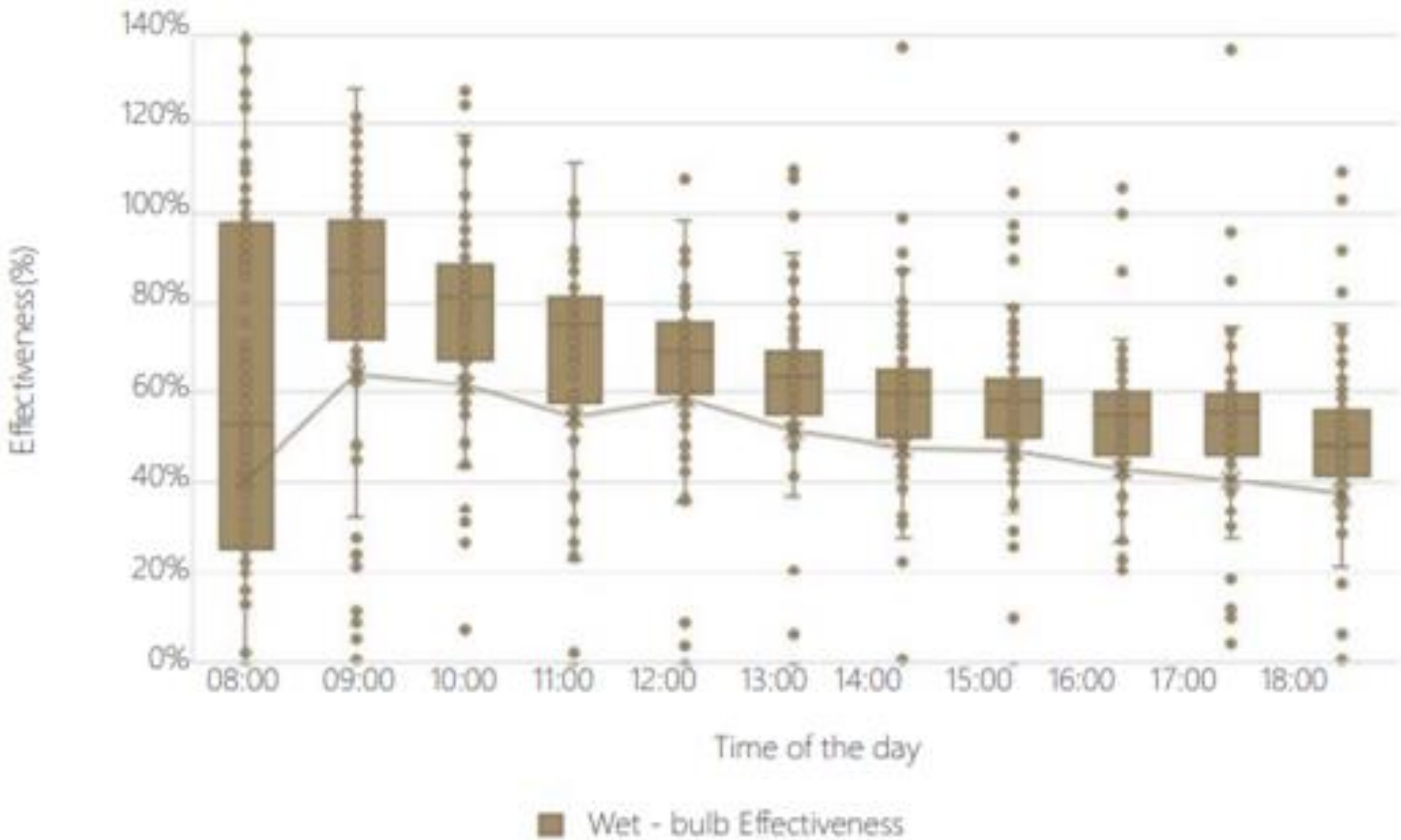
Graph showing outside and inside DBT range from July to Dec for operating hours

Case Study



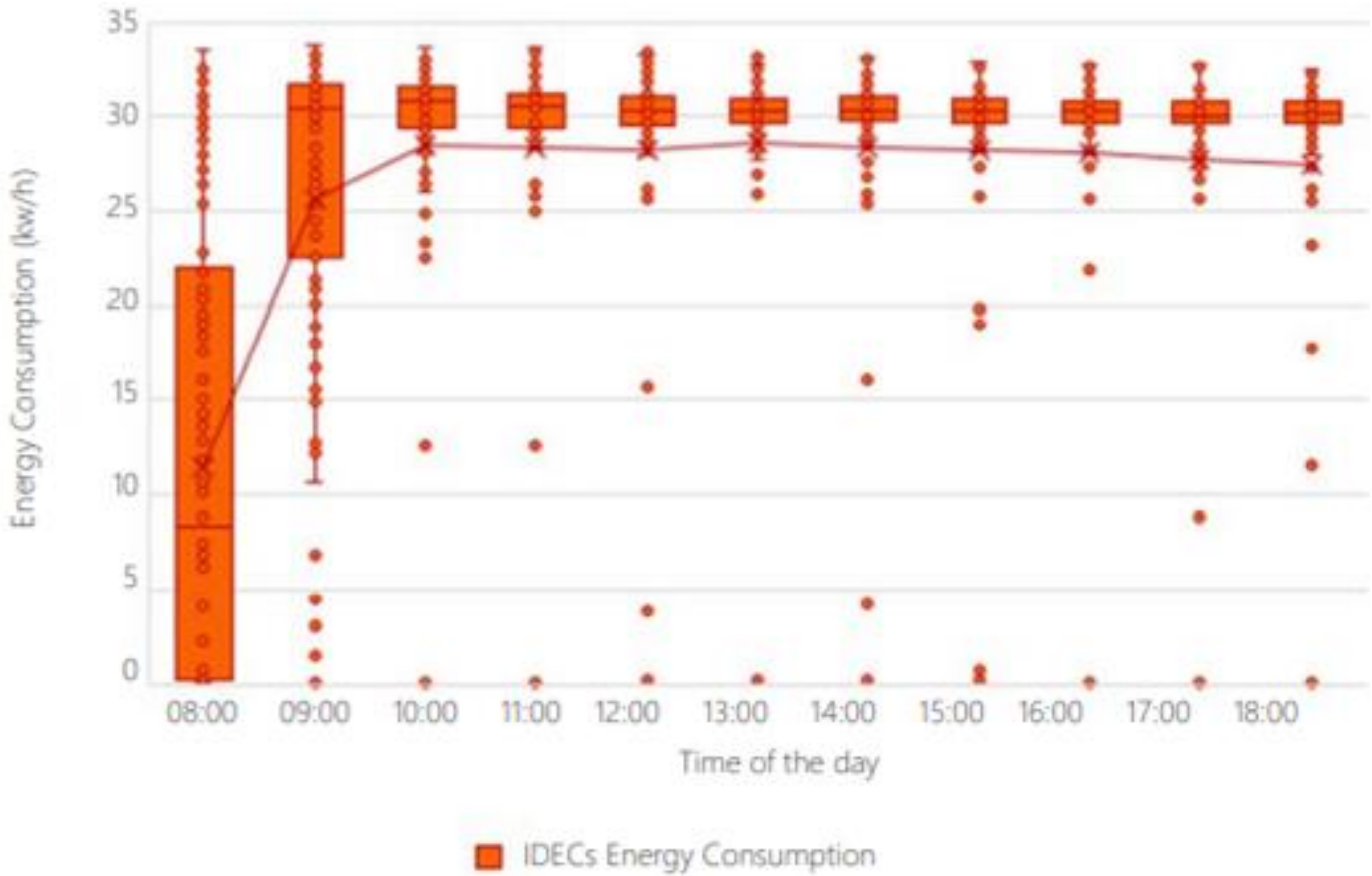
Graph showing outside and inside RH range from July to Dec for operating hours

Case Study



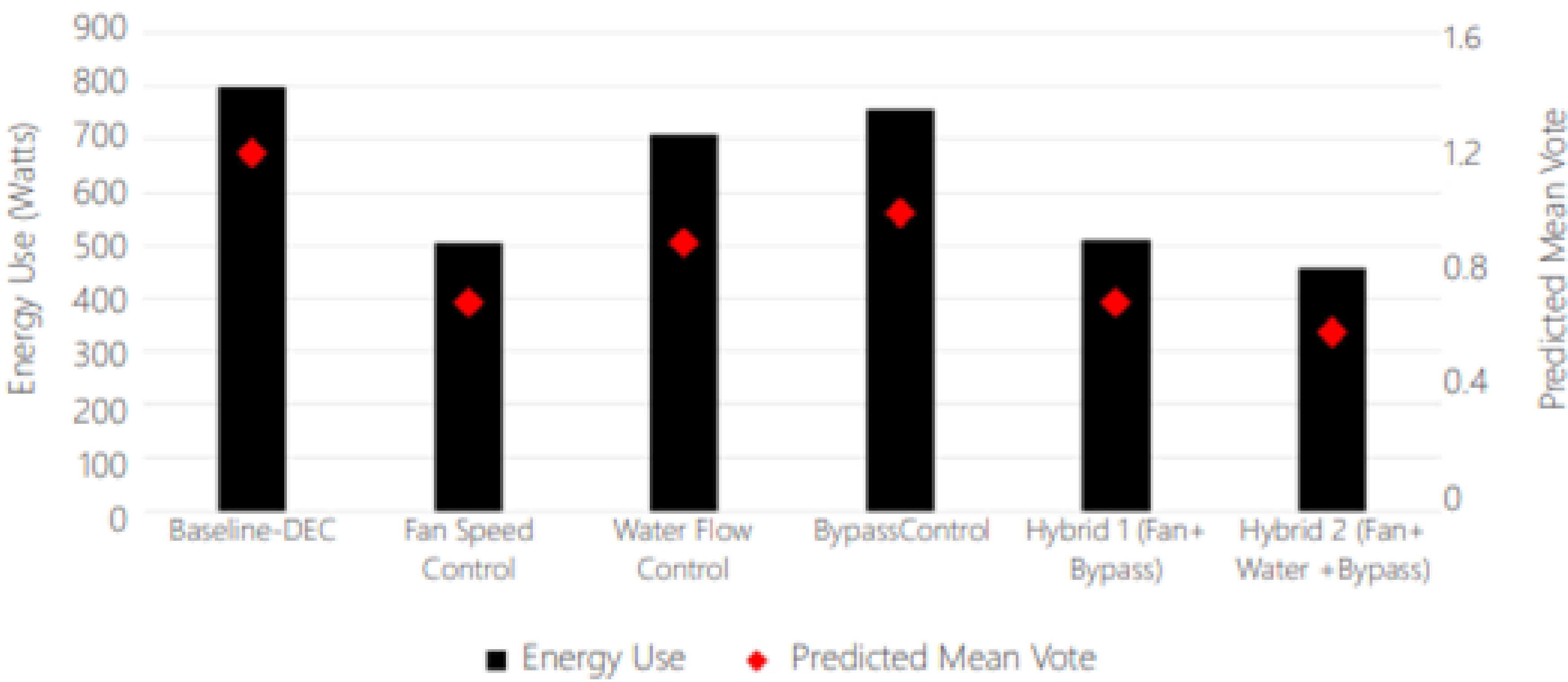
Graph showing Wet Bulb Effectiveness range from July to Dec for operating hours

Case Study



Graph showing energy consumption range from July to Dec for operating hours

Case Study



Energy use and comfort for control algorithms

Case Study

Food manufacturing facility in Nadiad, Gujarat; Total system capacity- 30,000 CFM

In conclusion the following observations and conclusions can be made:

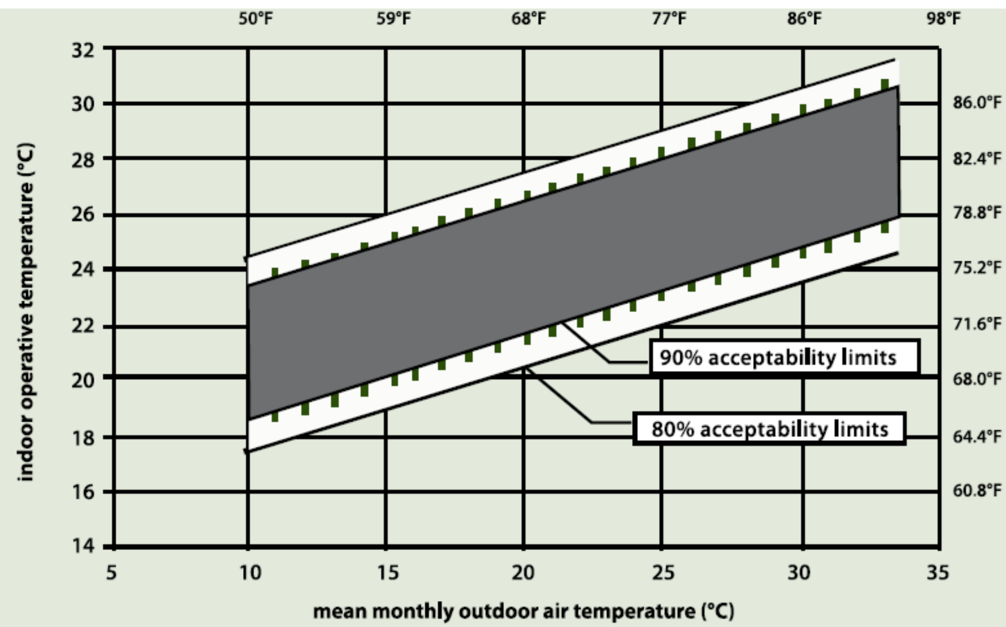
- Smart control algorithms reduce energy use by 10-25% compared to current operational practices
    - Comparison is performed with on/off low energy cooling systems
    - Fan speed modulation significantly reduces power consumption especially when cooling needs in the space are low y Smart control increases comfort by 0.5 to 1.0 PMV
    - Increased air velocity in the space further improves heat loss
    - Maintains sensible heat dissipation of Manikin but needs to avoid the draft
    - Humidity control of low energy cooling system is effective
- Hybrid systems reduce energy consumption by 30-40% due to capacity reduction of the baseline system and maintain comfort throughout the year
- Smart control algorithms vary suitable for control of hybrid systems

Disclaimer *The content of this chapter is based on the work originally supported by Shakti Sustainable Energy Foundation Grant No. 1503 – 50681, during 2014 – 2015 and its deliverable report (Rawal & Shukla, 2015)*

Session 7: Building Codes

Thermal Comfort Standard – IMAC R

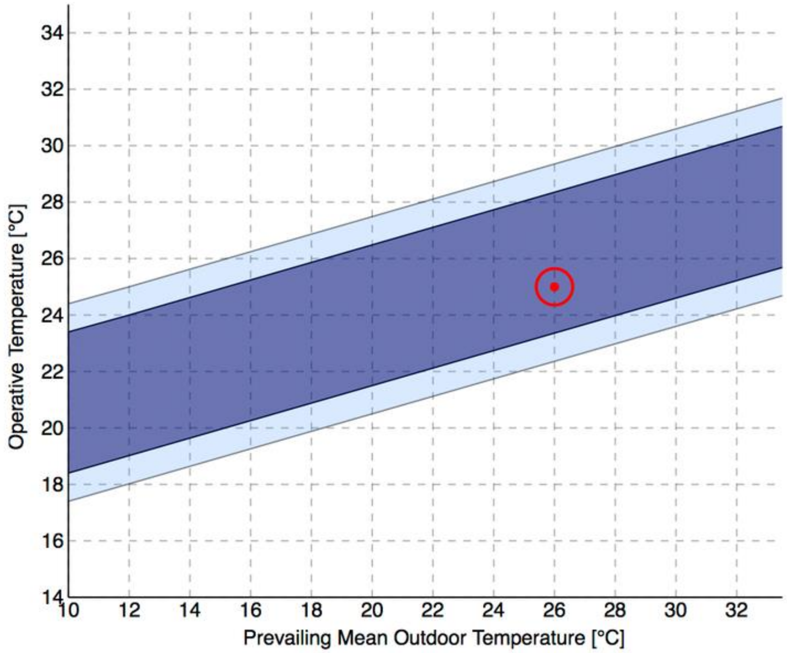
Indian Model for Adaptive Thermal Comfort (IMAC) models for neutral temperature and acceptability limits for naturally ventilated residential buildings through an empirical field study specific to the Indian context. It offers an energy-efficient pathway for the building sector without compromising occupant comfort.



Composite Location: Rajkot			
Months	**Description**	**90% Acceptability Temperature (degC.)**	**80% Acceptability Temperature (degC.)**
Jan	Minimum	24.13	22.68
	T nuet	26.28	26.28
	Maximum	28.43	29.88
Feb	Minimum	25.52	24.07
	T nuet	27.67	27.67
	Maximum	29.82	31.27
Mar	Minimum	26.87	25.42
	T nuet	29.02	29.02
	Maximum	31.17	32.62
Apr	Minimum	28.48	27.03
	T nuet	30.63	30.63
	Maximum	32.78	34.23
May	Minimum	28.78	27.33
	T nuet	30.93	30.93
	Maximum	33.08	34.53
Jun	Minimum	28.58	27.13
	T nuet	30.73	30.73
	Maximum	32.88	34.33
Jul	Minimum	27.38	25.93
	T nuet	29.53	29.53
	Maximum	31.68	33.13
Aug	Minimum	27.04	25.59
	T nuet	29.19	29.19
	Maximum	31.34	32.79
Sep	Minimum	27.09	25.64
	T nuet	29.24	29.24
	Maximum	31.39	32.84
Oct	Minimum	27.83	26.38
	T nuet	29.98	29.98
	Maximum	32.13	33.58
Nov	Minimum	26.56	25.11
	T nuet	28.71	28.71
	Maximum	30.86	32.31
Dec	Minimum	25.11	23.66
	T nuet	27.26	27.26
	Maximum	29.41	30.86

Thermal Comfort Standard – ASHRAE 55

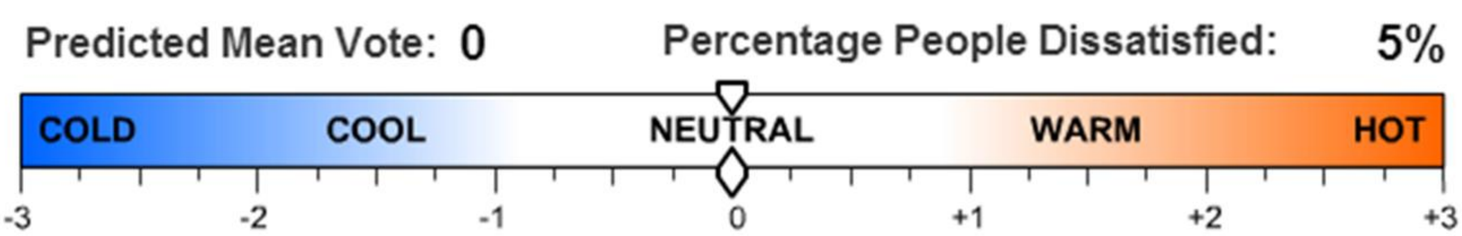
- The adaptive model is based on the idea that outdoor climate influences indoor comfort because humans can adapt to different temperatures during different times of the year.
- These results were incorporated in the ASHRAE 55-2004 standard as the adaptive comfort model. The adaptive chart relates indoor comfort temperature to prevailing outdoor temperature and defines zones of 80% and 90% satisfaction.
- This model applies especially to occupant-controlled, natural-conditioned spaces, where the outdoor climate can actually affect the indoor conditions and so the comfort zone.
- Adaptive models of thermal comfort are implemented in other standards, such as European EN 15251 and ISO 7730 standard.
- There are basically three categories of thermal adaptation, namely: behavioral, physiological, and psychological.



Thermal Comfort

•Predicted Mean Vote', PMV, is an index that predicts the mean value of the votes of a large group of persons on a seven point thermal sensation scale (Franger, 1973). The

•'Predicted Percentage of Dissatisfied', PPD, is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied subjects determined from the PMV (Franger, 1973)



Eco Niwas Samhita

Eco Niwas Samhita (ENS)

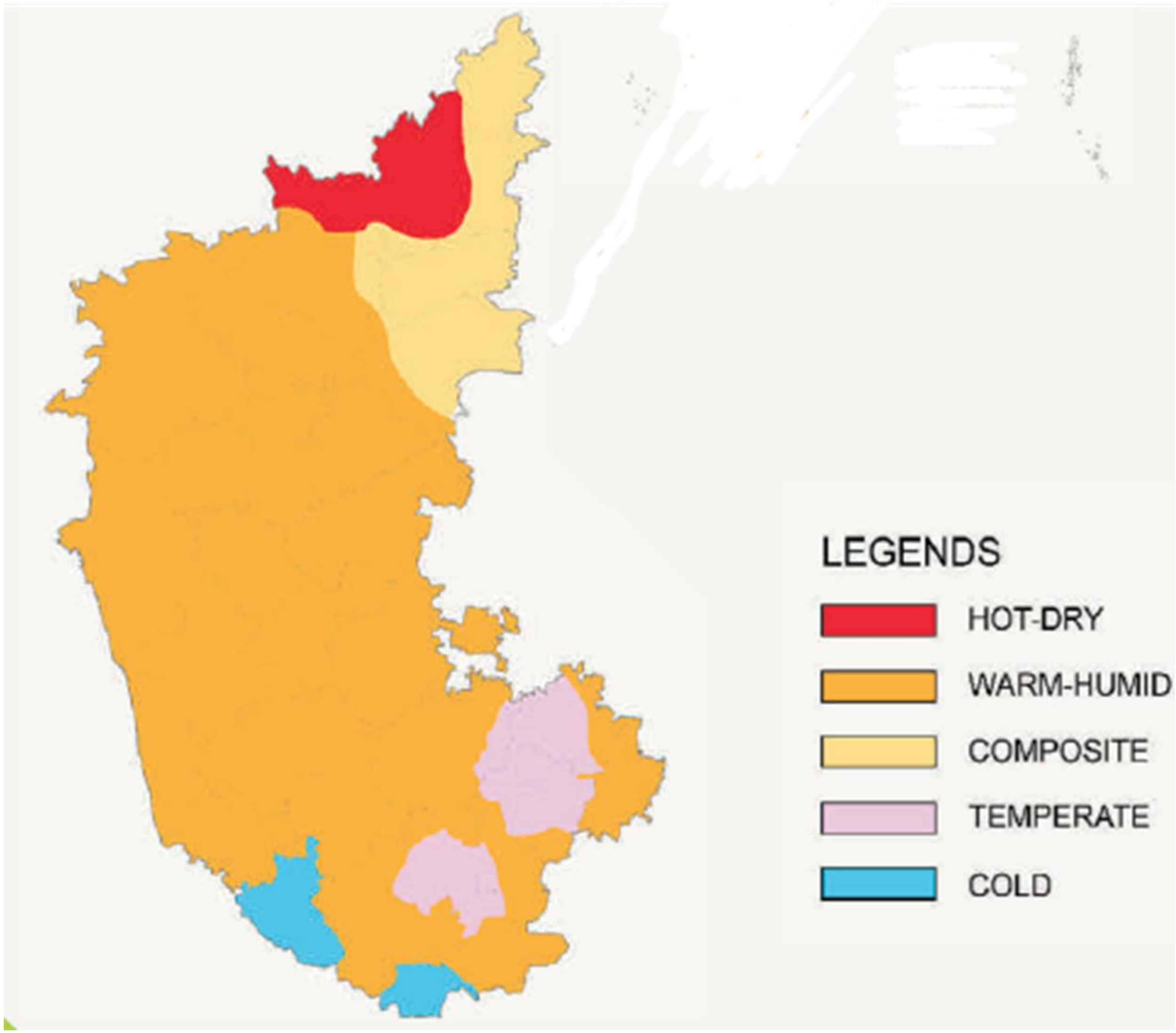
BEE (BUREAU OF ENERGY EFFICIENCY)	+	**GIZ** (Deutsche Gesellschaft für Internationale Zusammenarbeit)
Government of India		**Government of Germany**

Eco Niwas Samhita Part 1

Launch of Eco Niwas Samhita in December 2018

Eco Niwas Samhita (ENS)

Climatic Details and Regions for Karnataka



Climatic Details for Districts of Karnataka

Climatic Zones	Districts				
Cold	Central Kodagu	South Chamrajanagar			
Hot-Dry	North-Bijapur/ Vijayapur	North-West Gulbarga/ Kalburgi			
Composite	East-Bijapur/ Vijayapur	Gulbarga/ Kalburgi	Yadgir	Raichur	Bidar
Temperate	Mandya	Bangalore Urban	Bangalore Rural	North-West & South- West Chikballapur	
Warm & Humid	South-West Bijapur/ Vijayapur	Bagalkot	Belgaum	Uttar kannada	Dharwad
	Koppal	Haveri	Bellary	Shimoga	Davanagere
	Udupi	Chikmangalur	Chitradurga	Kodagu	Hassan
	Tumkur	North-East & South- East Chikballapur	Mysore	Chamrajanagar	Kolar
	Gadag	Ramanagara	Shimoga	Dakshina Kannada	

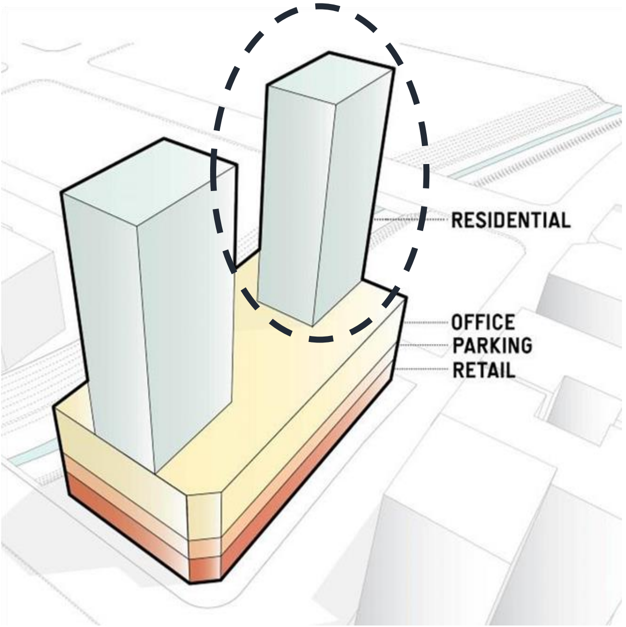
Scope of ENS

New building	• Residential Buildings with (Plot area ≥ 500Sqm) built up area of 800 sqm/ Connected load ≥ 35kW
Mixed Land Use	• Residential part of “Mixed Land-use building projects” with (Plot area ≥ 500Sqm) built up area of 800 sqm/ Connected load ≥ 35kW
Additions	• All additions made to existing residential buildings with (Plot area ≥ 500Sqm) built up area of 800 sqm/ Connected load ≥ 35kW
Alterations	• Alterations made to existing residential buildings with (Plot area ≥ 500Sqm) built up area of 800 sqm/ Connected load ≥ 35kW

Eco Niwas Samhita (ENS)

The code is applicable to

(a)Residential Buildings with **plot area ≥ 500m²**



(b) Residential part of **"Mixed Land-use building projects" built on plot area of ≥ 500m².**

Excluded from the code

Dormitories

Hotels

Lodging Rooms

Scope of ENS (Setting Minimum Requirement)

Building Envelope
- Opaque Construction Materials
- Fenestration U-factors
- Solar Heat Gain Coefficients (SHGC)
- Visible Light Transmittance (VLT)
- Overhangs +Fins
- Operable Window Area

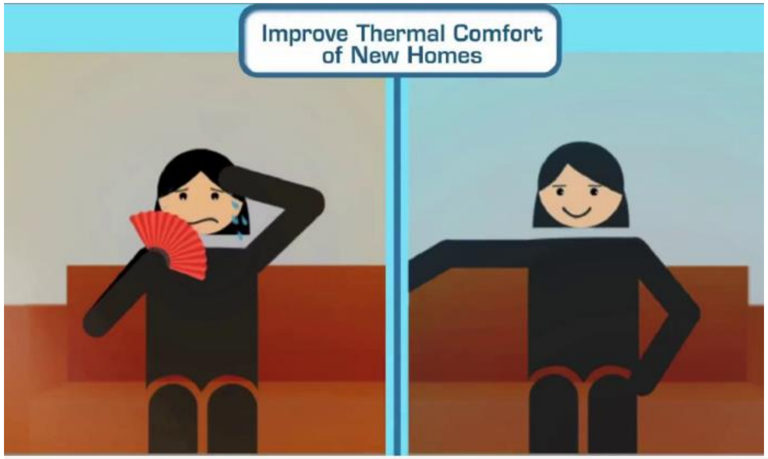
Building Services
- Common Area Lighting
- Pump Efficiencies
- Elevator Technologies
- Transformer Losses
- Power Factor Correction
- Basement Ventilation
- Charging Infrastructure
- Electrical Metering & Monitoring

Indoor Electrical End Use
- Indoor Lighting
- Automatic Lighting Shutoff
- Occupancy Sensors
- Ceiling Fan Star Labelling
- Service Hot Water
- Air Conditioner system, sizes, efficiencies and controls

Renewable Energy Systems
- System Peak Generation Capacity
- Solar Water Heating System
- Technical Specifications
- Renewable Energy Zone Area

Eco Niwas Samhita (ENS) Benefits

Improve Thermal Comforts



Reduce Electricity Bills

Estimated Impact Of Implementing Eco Niwas Samhita

- Minimum **20% energy saving** as compared to a typical Building
- **125 billion KWH** of electricity Saving
- **100 million tonnes of CO_2** equivalent abatement

ENS – Part 1 – Building Envelope

Performance Standards for Building Envelope

Standard	Purpose
3.1 Openable Window to Floor Area Ratio (WFR_{op})	For Natural Ventilation
3.2 Visible Light Transmittance (VLT)- Derived from WWR	For Day Light Potential
3.3 Thermal Transmittance of Roof (U_{roof})	For Thermal Transmission
3.4 Residential Envelope Transmittance Value (RETV)	For Thermal Transmission
3.5 Thermal Transmittance for Cold Climate ($U_{envelope,cold}$)	For Thermal Transmission

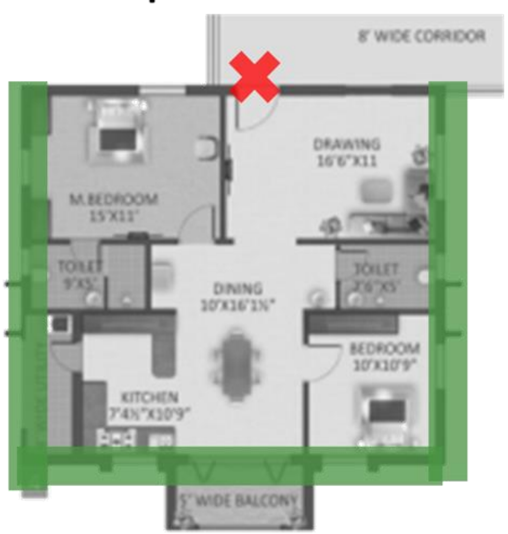
ENS – Part 1 – Building Envelope

3.1 Openable Window to Floor Area Ratio (WFR_{op})

$$WFR_{op} = \frac{A_{openable}}{A_{carpet}}$$

Window to floor area ratio is the ratio of Openable area to the carpet area of the dwelling Units.

Openable Area



Windows, Ventilators, opening directly to

- External air,
- Open balcony,
- Corridor,
- Shaft

Doors opening directly into

- Open balcony

Carpet Area

- Total Internal Area of the habitable space

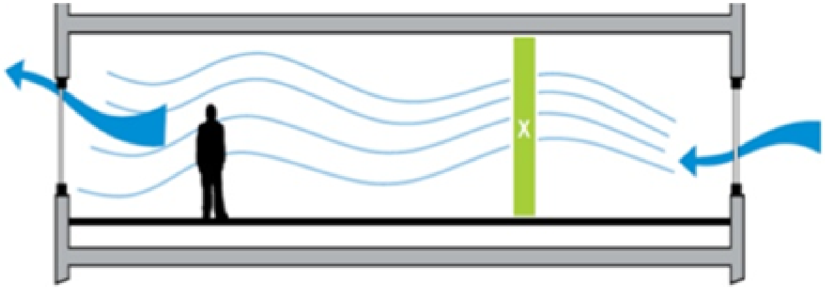
Balconies - Excluded

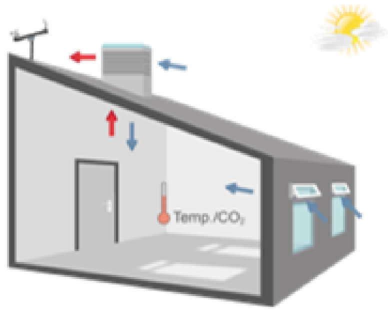
ENS – Part 1 – Building Envelope

3.1 Openable Window to Floor Area Ratio (WFR_{op})

Minimum WFRop helps in

Natural Ventilation | Improvement in Thermal Comfort | Reduction in Cooling Energy Loads





Minimum requirement of window-to-floor area Ratio	
Climate Zone	**Minimum WFRop**
Composite	12.50
Hot-Dry	10.00
Warm-Humid	16.66
Temperate	12.50
Cold	8.33

Openable Area Percentages (In case the exact Openable is not known)	
Type of Window/Door/ Ventilator	**Percentage Openable Area**
Casement	90%
Sliding (2 Panes)	50%
Sliding (3 Panes)	67%

ENS – Part 1 – Building Envelope

3.2 Window to Wall Area Ratio (WWR)

$$WWR = \frac{A_{non-opaque}}{A_{envelope}}$$

WWR – Window to wall area ratio
Area (non-opaque) –
Total glass area in the opening .
Excluded - Opaque part of the total opening size.
Area(Envelope) –
Total envelope area of all facades.
Included – opaque and non-opaque

*** Note for WWR ≤ 0.15 , VLT – 40%**

Relation between WWR and Visual Light Transmittance

Window to Wall Ratio (WWR)	Minimum VLT
0-0.30	0.27
0.31-0.40	0.20
0.41-0.50	0.16
0.51-0.60	0.13
0.61-0.70	0.11

ENS – Part 1 – Building Envelope

3.3 Thermal Transmittance (U_{roof})

Thermal Transmittance of roof U_{roof} - Is the rate of transfer of heat through the roof structure (which can be a single material or an assembly), divided by the difference in temperature across that structure.

Limiting U_{roof} by helps in reducing heat gains or losses from the roof. Ex : Insulation, Cool Roofs, Green Roofs

Thermal transmittance of roof shall comply with U_{roof} value – 1.2 W/m².k

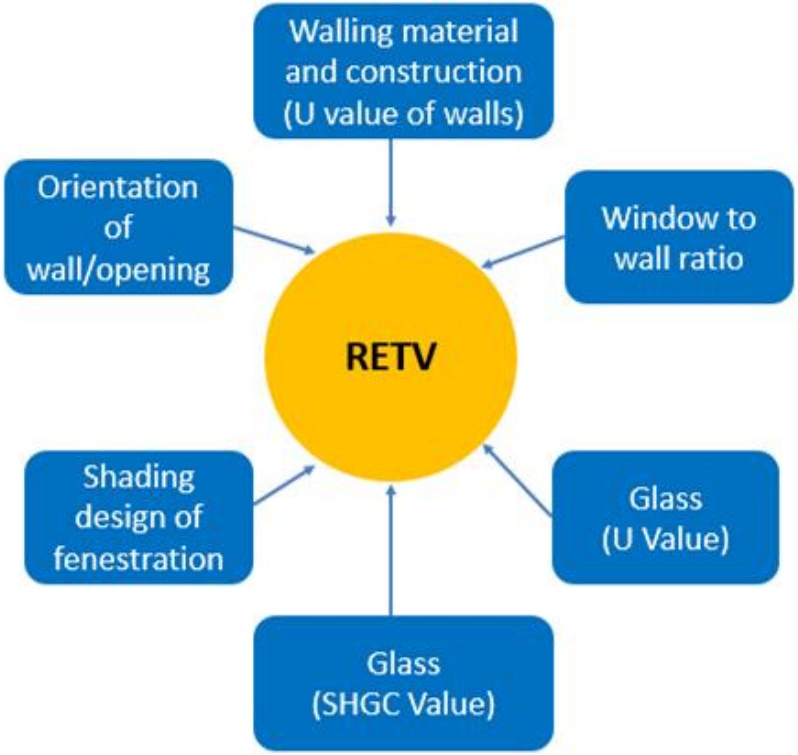
ENS – Part 1 – Building Envelope

3.4 Residential Envelope Transmittance (RETV)

Solar Radiation through non-opaque surfaces

Conduction through opaque surfaces

Conduction through non-opaque surfaces



ENS – Part 1 – Building Envelope

3.4 Residential Envelope Transmittance (RETV)

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

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

RETV for the building envelope (except roof) for four climate zones, namely, Composite Climate, Hot-Dry Climate, Warm-Humid Climate and Temperate Climate shall comply with the maximum RETV of **15 W/m²**

ENS – Part 1 – Building Envelope

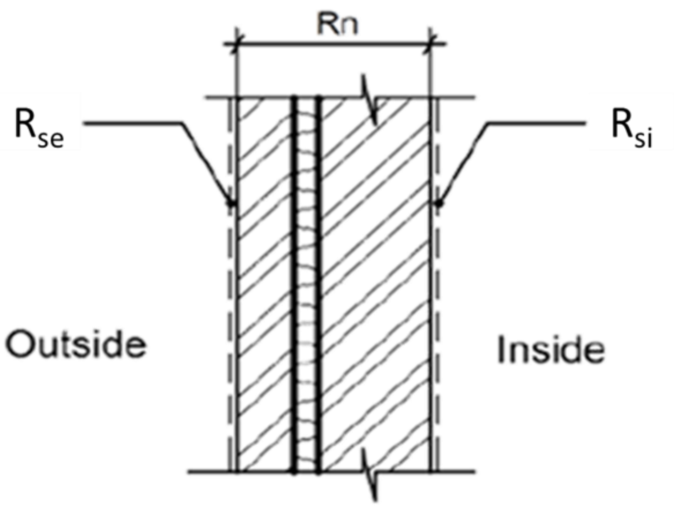
3.4 Thermal Transmittance Value (U-Value) Non Opaque

$$U = 1 / R_t$$

$$U = 1/ (R_{so} + \sum R_n + R_{si})$$

U-value is the reciprocal of Thermal Resistance (R)

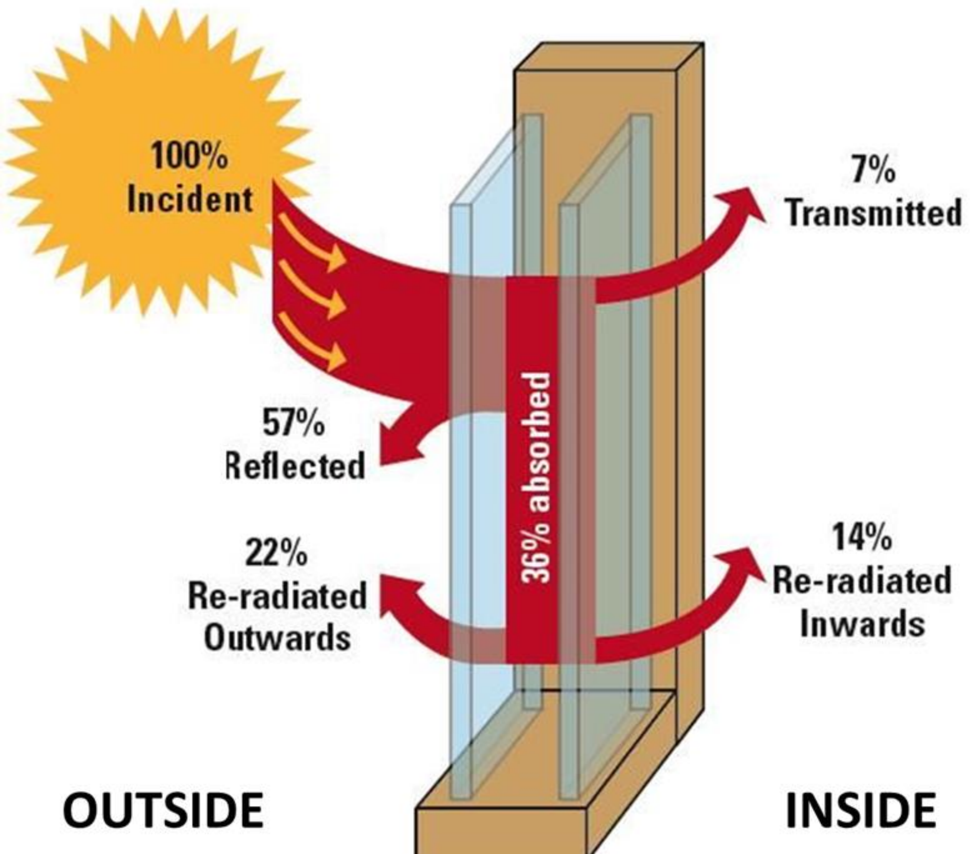
	Wall	Roof	
	All climatic Zones	Composite , Hot-Dry, Warm-humid, and Temperate climate	Cold climate
Rsi (m2.K/W)	0.13	0.17	0.10
Rse (m2.K/W)	0.04	0.04	0.04



Source: Eco Niwas Samhita -2018, Table 6, Annexure - 5

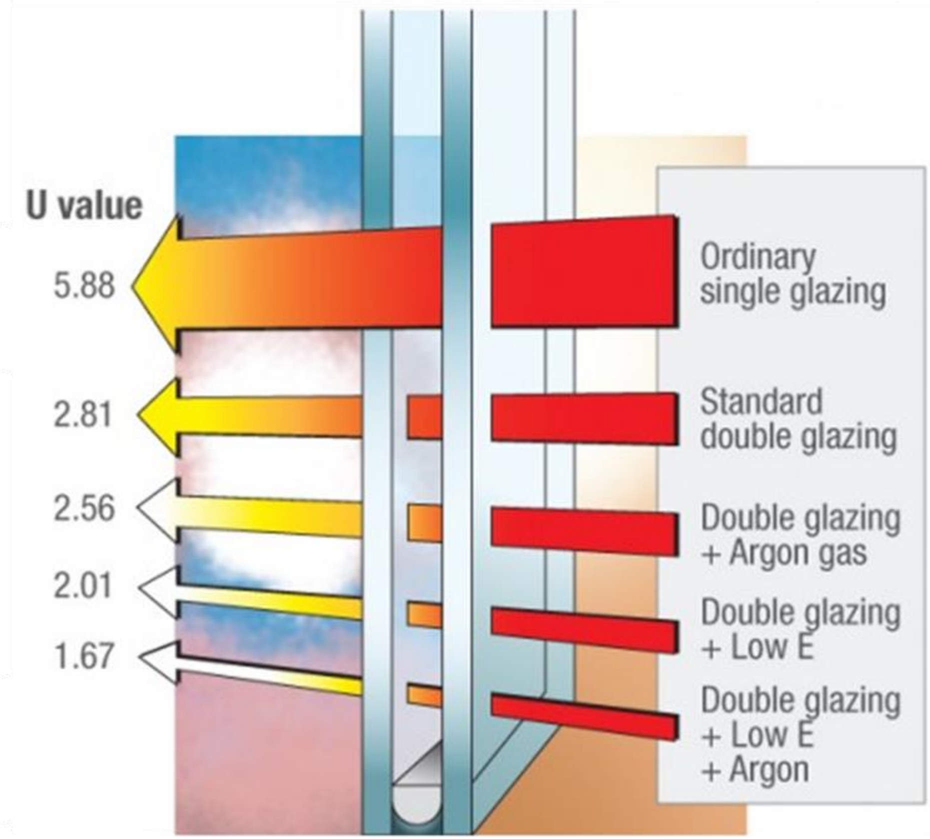
ENS – Part 1 – Building Envelope

3.4 Thermal Transmittance Value (U-Value) Non Opaque



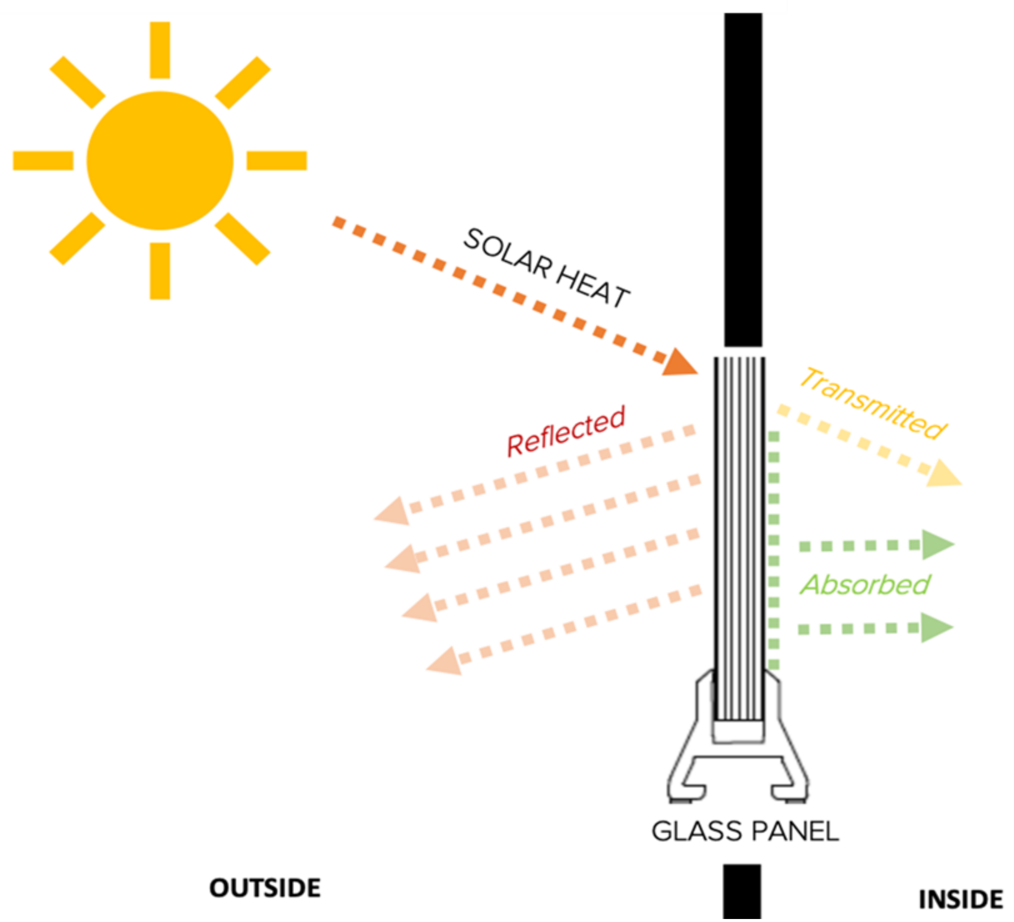
Total Solar Heat Elimination : 79%

Total Solar Heat Transmission : 21%



ENS – Part 1 – Building Envelope

3.4 Solar Heat Gain Coefficient (SHGC) Non Opaque



Solar heat gain coefficient is the measure of solar heat –

- Absorbed
- Transmitted

Lower SHGC ∝ lesser Heat Transfer

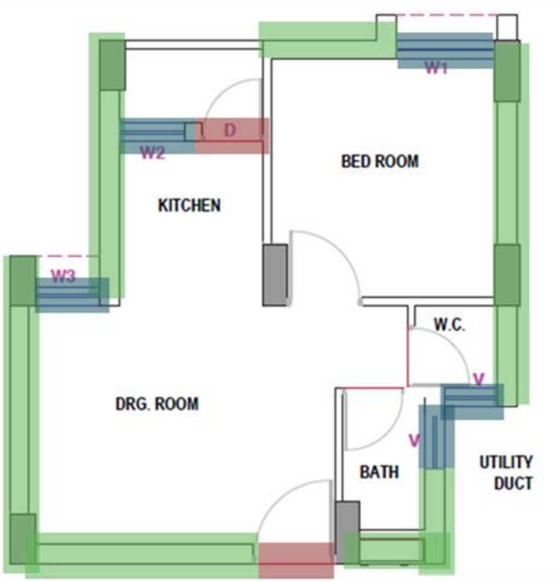
Solar Radiation is subsequently released inward through conduction, convection and radiation.

ENS – Part 1 – Building Envelope

3.5 Thermal Transmittance – Wall (Except roof) for Cold Climate (U envelope, cold)

$$U_{envelope,cold} = \frac{1}{A_{envelope}}\left[\sum_{i=1}^{n}(U_i \times A_i)\right]$$

➢The thermal transmittance of the building envelope (except roof) for cold climate shall comply with the maximum of **1.8 w/M²K**



	Area (sq mt)	U- value (w/m²k)
Wall (opaque)	2793.38	0.78
Door (opaque)	210	5.23
Window (non-opaque)	475.88	5.80

AAC Wall

Wooden Door

Glass Window

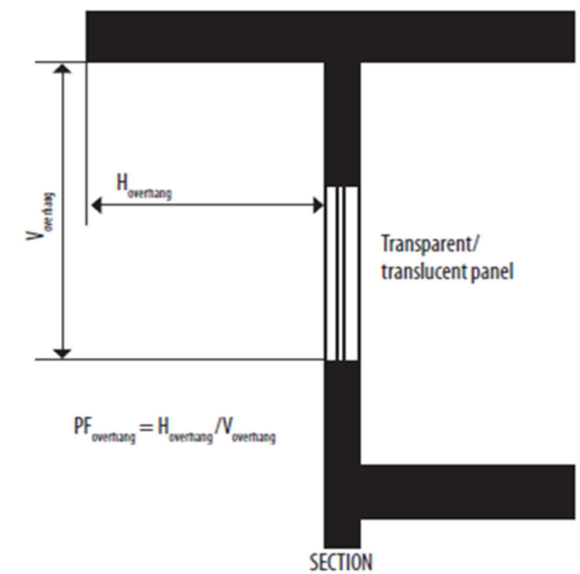
$$U_{envelope,cold} = \frac{(2793.38\times0.78)+(210.00\times5.23)+(474.88\times5.80)}{2793.38+210.00+474.88} = 1.73\ \ W/m^2.K$$

ENS – Part 1 – Building Envelope

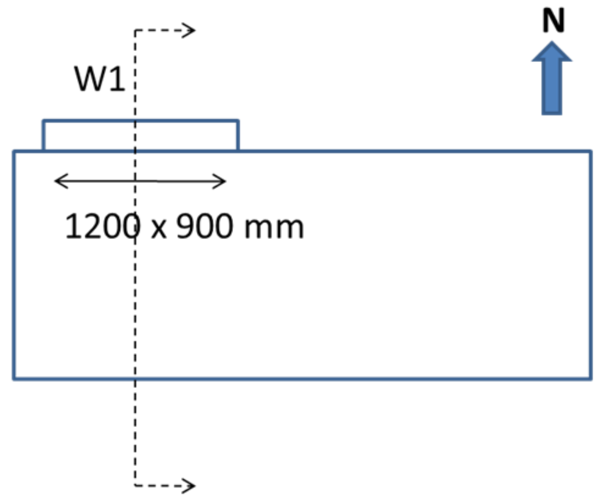
3.4 Projection Factor (PF)

Projection Factor (PF) is the ratio of the horizontal depth of the external shading projection ($H_{overhang}$) to the bottom of the farthest point of the external shading projection ($V_{overhang}$), in consistent units.

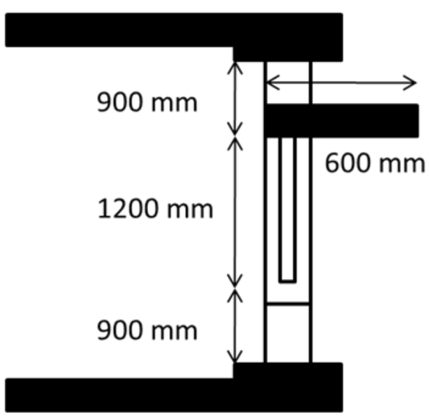
$$PF_{overhang} = \frac{H_{overhang}}{V_{overhang}}$$



Solved exercise: Considering a room size of 3m * 5m, with a window W1 shown in plan and section. The projection factor for the same is calculated, to arrive at the ESF (Effective Shading Factor). Glass parameters; Single Glazing Unit (SGU), U value = 5.6 W/m2 K, SHGC = 0.6, VLT = 0.7



Plan

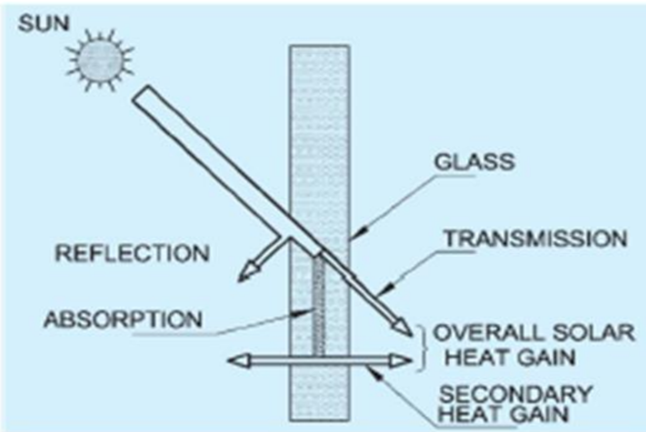


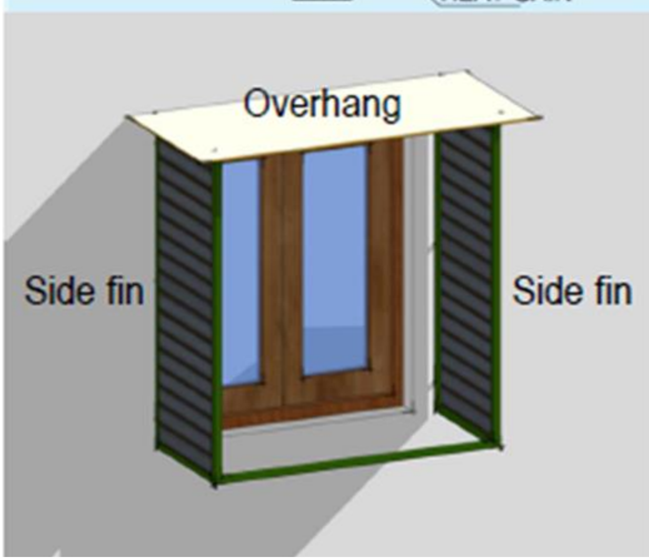
PF = 600/1200 = 0.5

Section

ENS – Part 1 – Building Envelope

3.4 Equivalent SHGC





$$SHGC_{unshaded} = \frac{\text{Transmission + Secondary heat gain}}{\text{Incident Solar radiation}}$$

External Shading (overhang,side fins)cut the solar radiation

External Shading Factor (ESF_{total} ≤ 1) accounts the impact of shading.

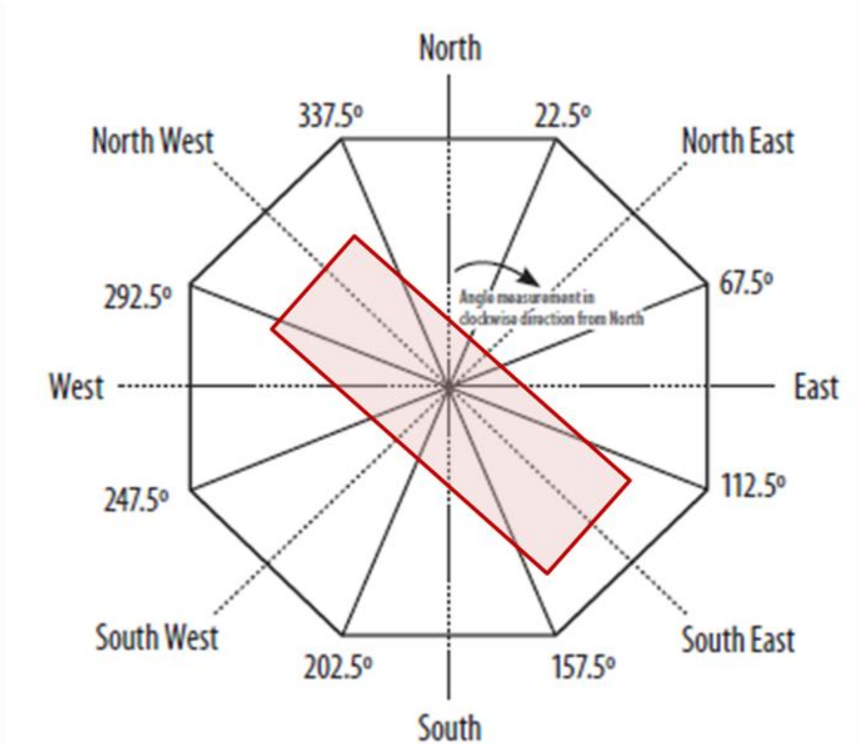
$$\mathbf{SHGC_{eq} = SHGC_{unshaded} \times ESF_{total}}$$

ENS – Part 1 – Building Envelope

3.4 Orientation Factor

The orientation factor (ω) is a measure of the amount of direct and diffused solar radiation that is received on the vertical surface in a specific orientation

Orientation	Orientation factor (ω) Latitudes <23.5°N
North (337.6°–22.5°)	0.659
North-east (22.6°–67.5°)	0.906
East (67.6°–112.5°)	1.155
South-east (112.6°–157.5°)	1.125
South (157.6°–202.5°)	0.966
South-west (202.6°–247.5°)	1.124
West (247.6°–292.5°)	1.156
North-west (292.6°–337.5°)	0.908



ENS – Part 1 – Building Envelope

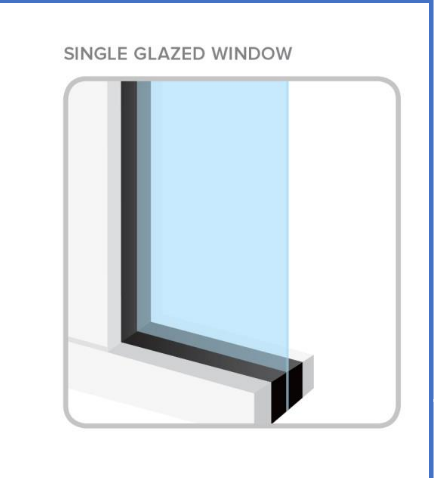
3.4 RETV – Case 1

Case 1

External wall	Roof Construction	Glazing	Window to wall Ratio
230mm thick Solid Burnt Clay Brick	150 mm thick RCC slab + 50mm thick EPS	50 mm Steel Frame; Single glazed Unit U Value = 5.7 W/m2k, SHGC = 0.56, VLT=0.51	22.55%
RETV – 14.92 W/m^2.K			

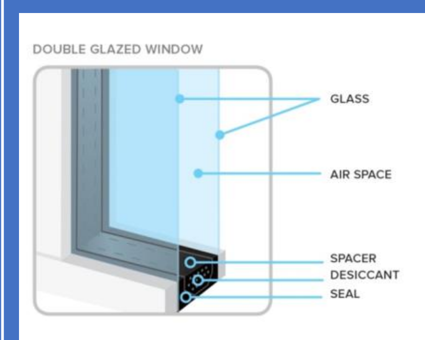
ENS – Part 1 – Building Envelope

3.4 RETV – Case 2

Case 2		External wall	Roof Construction	Glazing	Window to wall Ratio
	 	200mm thick AAC Block wall	150 mm thick RCC slab + 50mm thick EPS	50 mm Steel Frame; Single glazed Unit U Value = 5.7 W/m2k, SHGC = 0.56, VLT=0.51	22.55%
		RETV – 9.71 W/m^2.K			

ENS – Part 1 – Building Envelope

3.4 RETV – Case 3

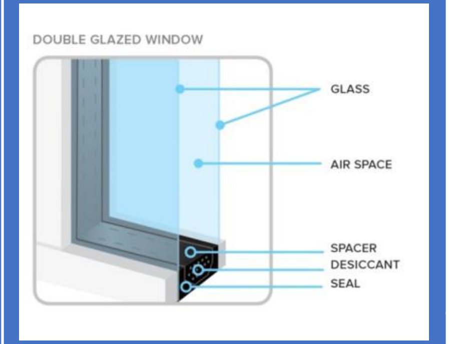


Case 3	External wall	Roof Construction	Glazing	Window to wall Ratio
	200mm thick AAC Block wall	150 mm thick RCC slab + 50mm thick EPS	Double glazed Unit - Asahi LC 54/37 U Value = 1.64 W/m2k, SHGC = 0.36, VLT=0.52	22.55%

RETV – 6.62 W/m².K

ENS – Part 1 – Building Envelope

3.4 RETV – Case 4



Case 4	External wall	Roof Construction	Glazing	Window to wall Ratio
	200mm thick AAC wall, 50 mm EPS, high SRI paint	150 mm thick RCC slab + 50mm thick EPS	Double glazed Unit - Asahi LC 54/37 U Value = 1.64 W/m2k, SHGC = 0.36, VLT=0.52	22.55%

RETV – 5.13 W/m².K

ENS – Part 1 – Building Envelope

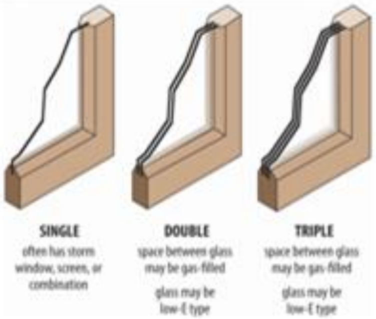
Building Design Flexibility by ENS

Material wall Assembly

Design of Window Panel

Shading of external Windows

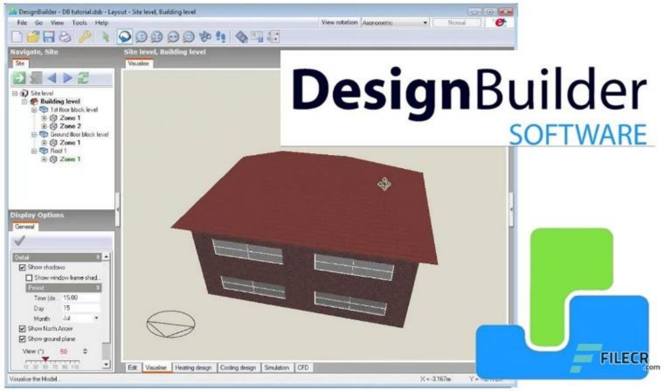
Type of glazing

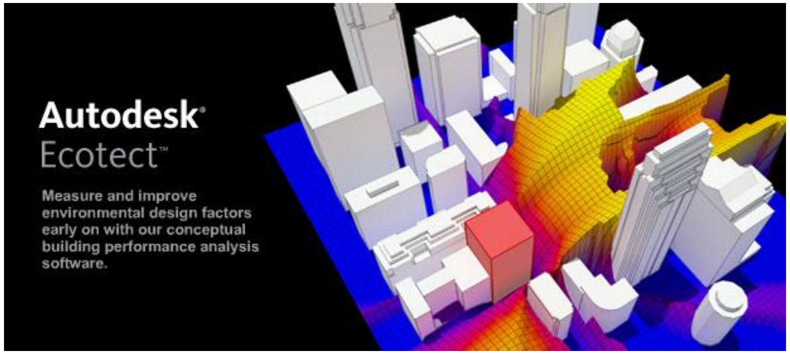


ENS Compliance Tool

Simulation Tools

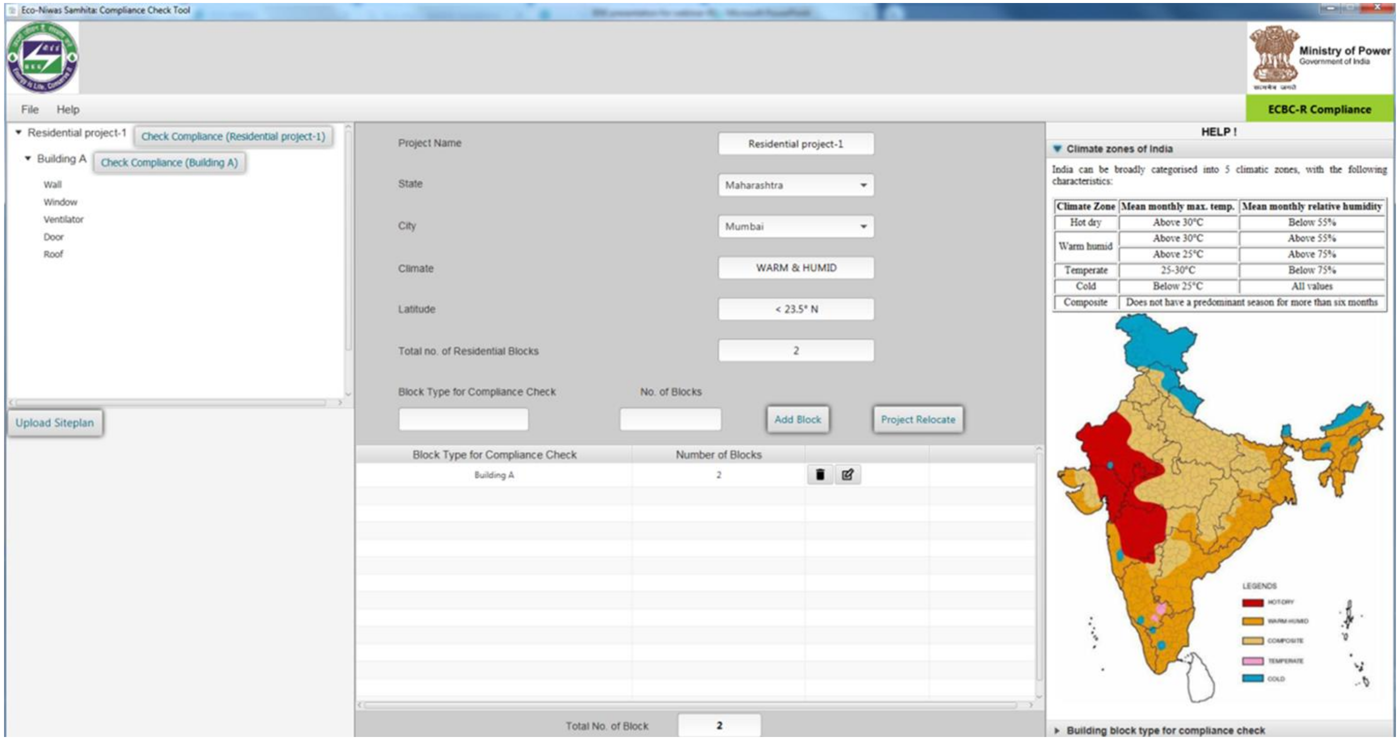
eQuest
Quick Energy Simulation Tool





Compliance Tool

Java based ENS compliance check tool has been developed to check compliance for residential project.

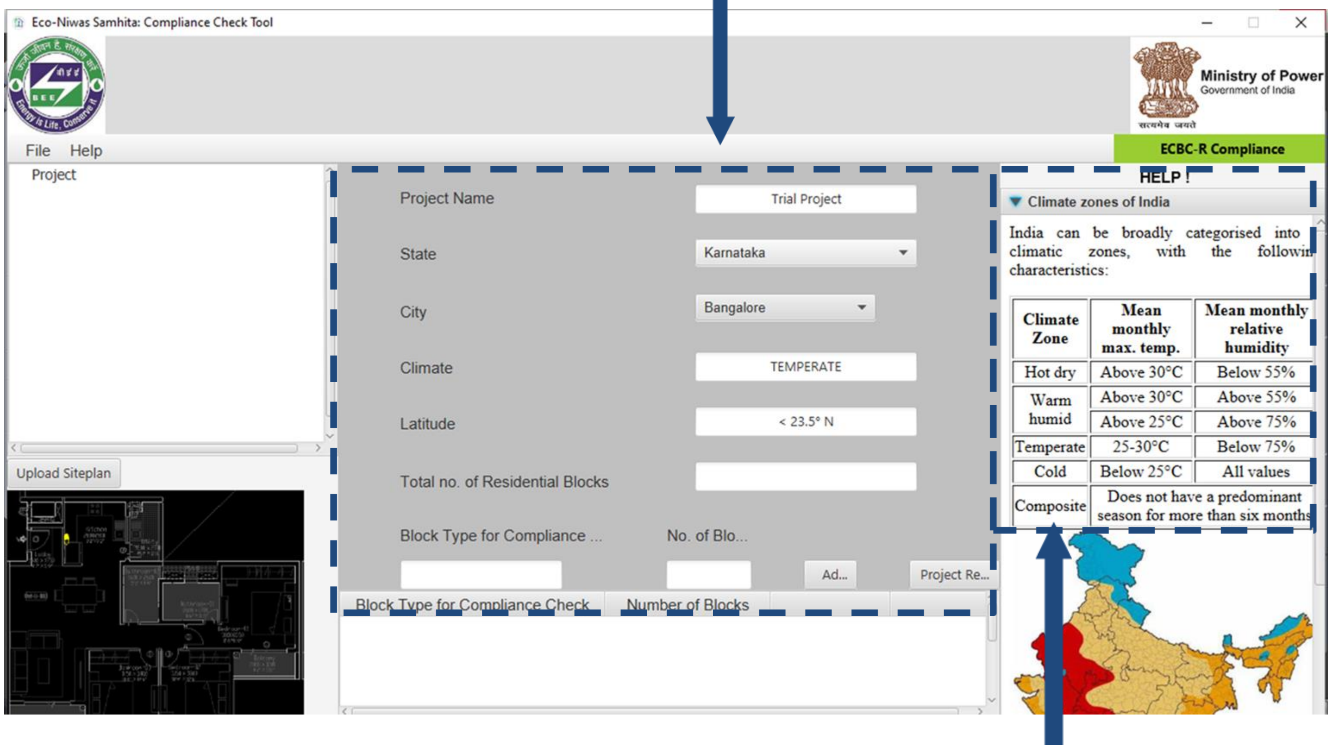


Available on Bureau of Energy Efficiency’s website for download.

Link - https://beeindia.gov.in/content/ecbc-residential

Compliance Tool

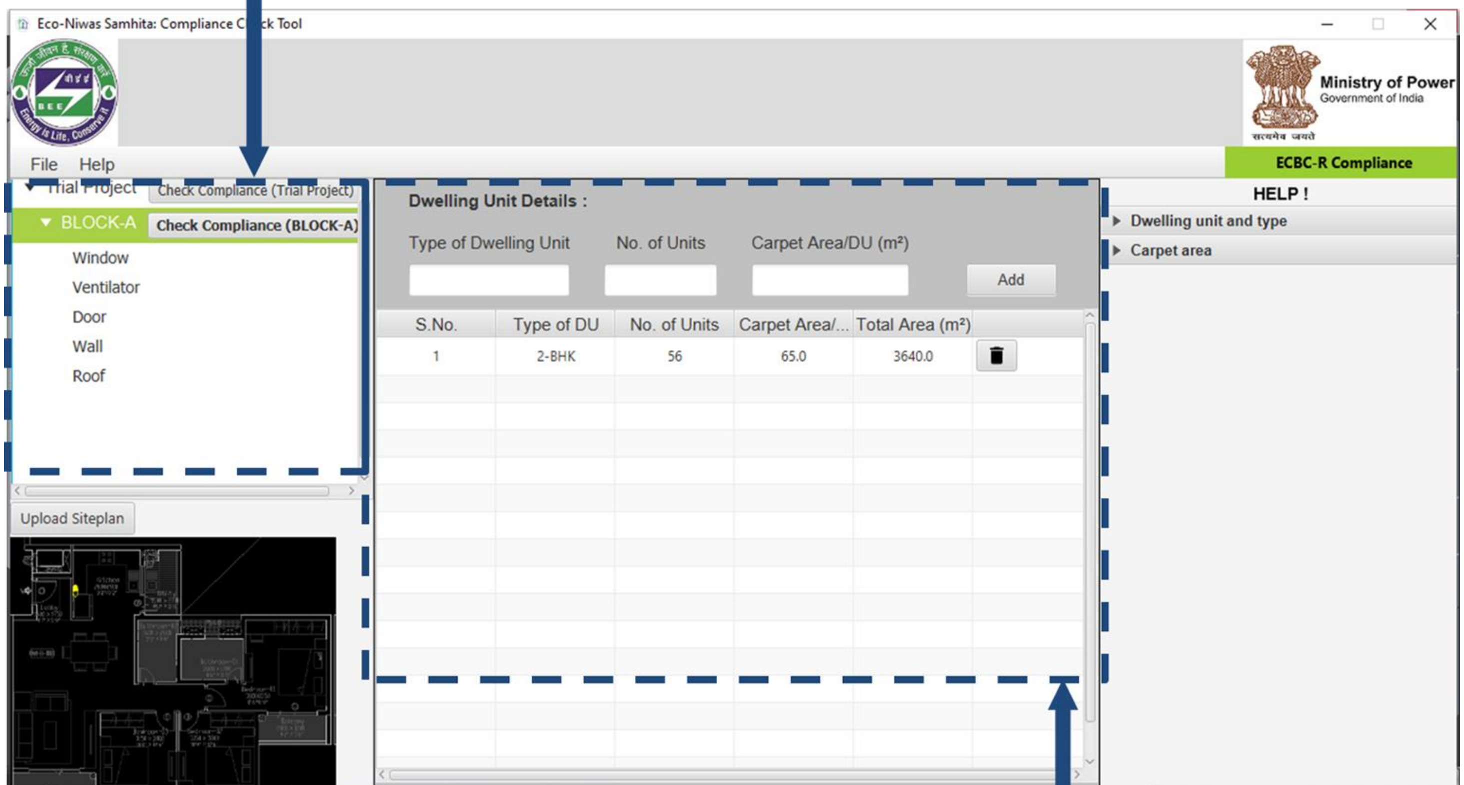
Project related details are entered in the tool for compliance check



Climate data after entering the project location details

Compliance Tool

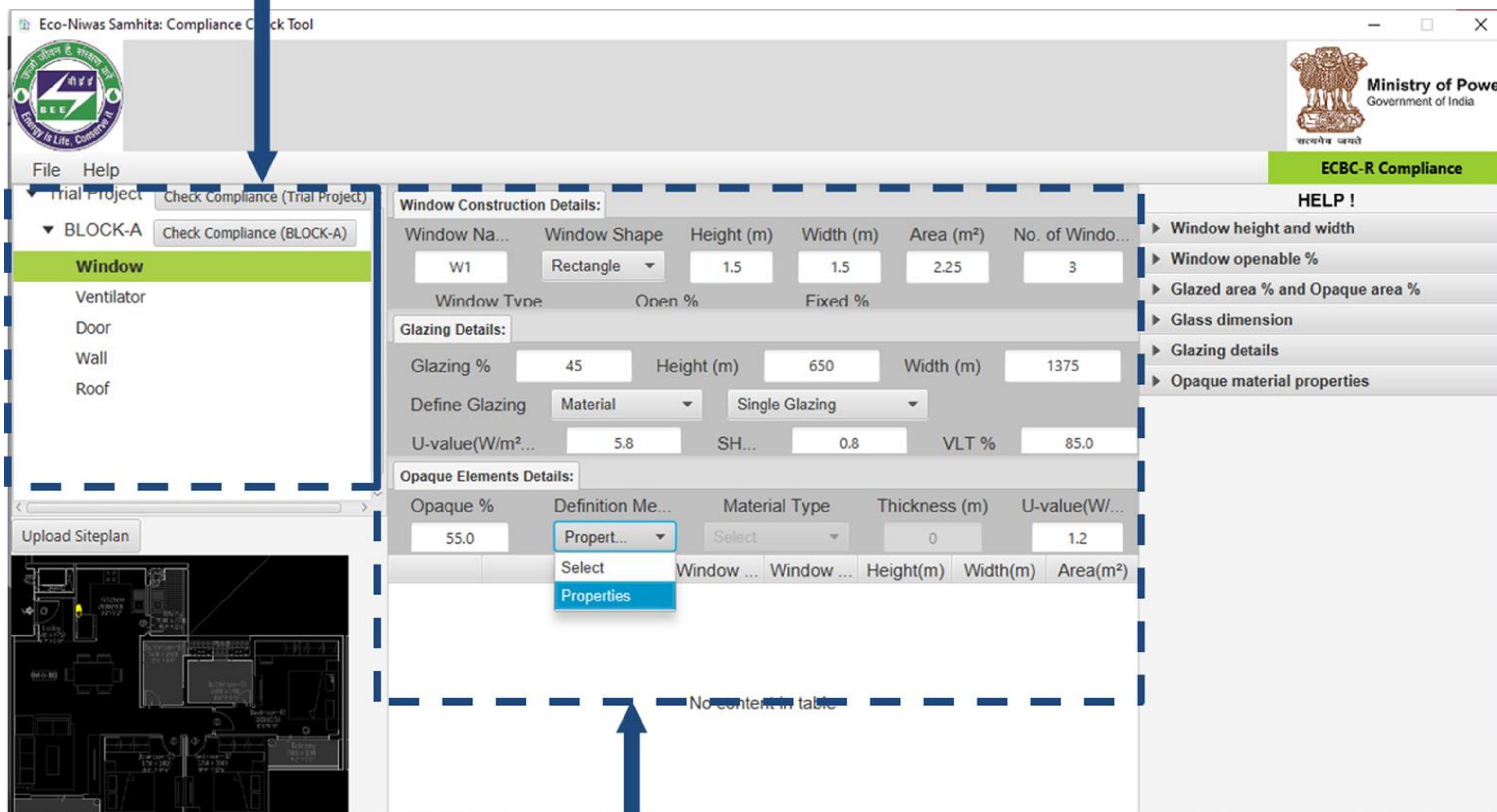
Details of various building components will be added for Compliance check- Architectural drawings(plans, sections and elevations)



Details of the blocks are submitted and can be seen here

Compliance Tool

Construction material details are entered in the tool. Window details are shown here for example



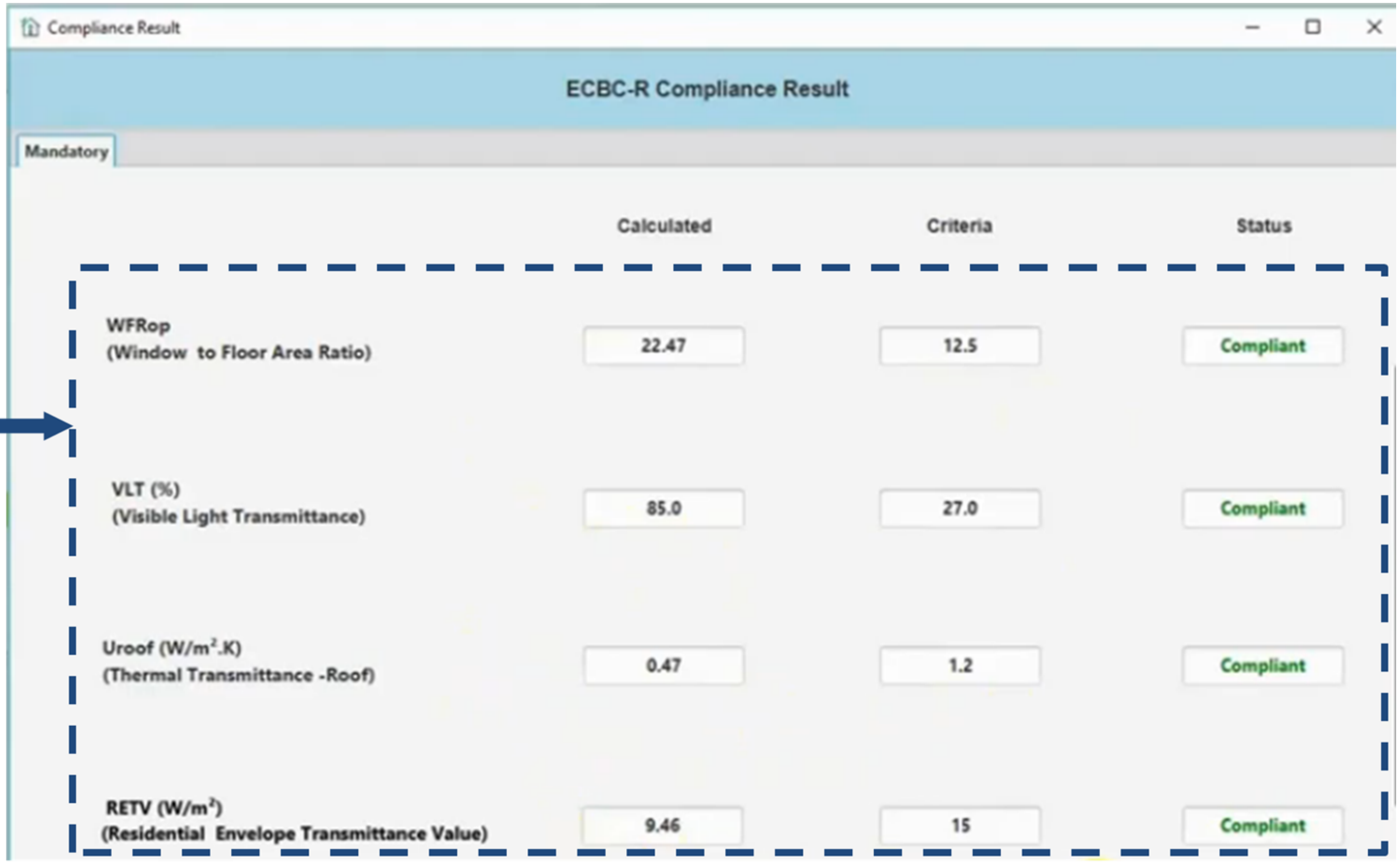
All the details related to window are submitted for the compliance

Similarly, other block details are added in the table for checking different design alternatives

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

Compliance Tool

Result of the compliance of code provisions shown

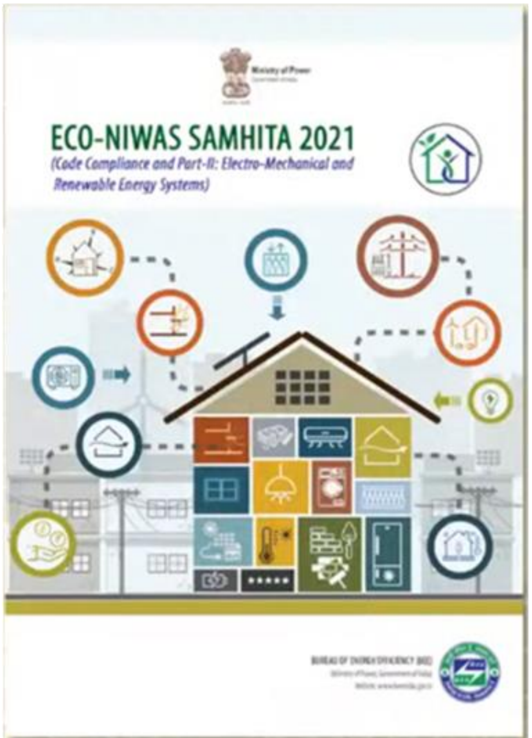


A report is generated once all the design provisions are complaint to the code

ENS Part 2

ENS – Part 2 – Services

CODE PROVISIONS



- **Building Services**
  - Common Area & Exterior Lighting
  - Elevators
  - Electrical Systems
  - Pumps
- **Indoor End Electrical Use**
  - Indoor Lighting
  - Comfort Systems
- **Renewable Energy Systems**
  - Solar Water Heating
  - Solar Photo-Voltic

ENS – Part 2 - Code Compliance

Low Rise Buildings:

A building equal or below 4 stories, and/or a building **up to 15 meters in height** (without stilt) and up to 17.5 meters (including stilt).

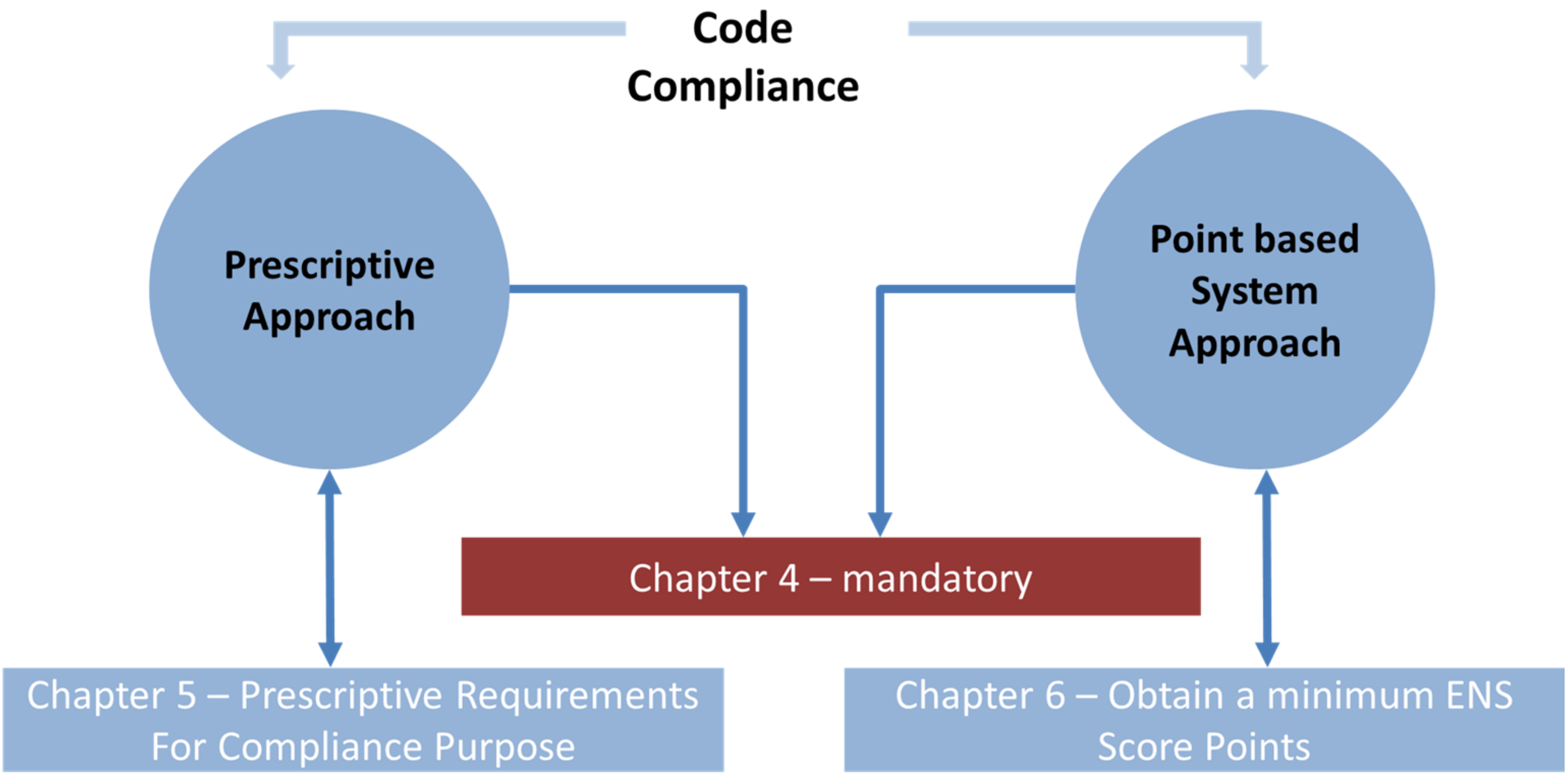
Affordable Housing Projects:

Affordable houses are Dwelling Units (DUs) with **Carpet Area less than 60 sqm**. It also includes **Economically Weaker Section (EWS) category and Lower Income Group (LIG)** category **(LIG-A: 28-40 sq. m. and LIG-B 41-60 Sq.m.**).

High Rise Buildings:

A building above 4 stories, and/or a building **exceeding 15 meters** or more in height (without stilt) and 17.5 meters (including stilt).

ENS – Part 2 - Code Compliance



ENS – Part 2 - Documentation

Building Envelope
- Opaque Construction Materials
- Fenestration U-factors
- Solar Heat Gain Coefficients (SHGC)
- Visible Light Transmittance (VLT)
- Overhangs +Fins
- Operable Window Area

\+

Building Services
- Common Area Lighting
- Pump Efficiencies
- Elevator Technologies
- Transformer Losses
- Power Factor Correction
- Basement Ventilation
- Charging Infrastructure
- Electrical Metering & Monitoring

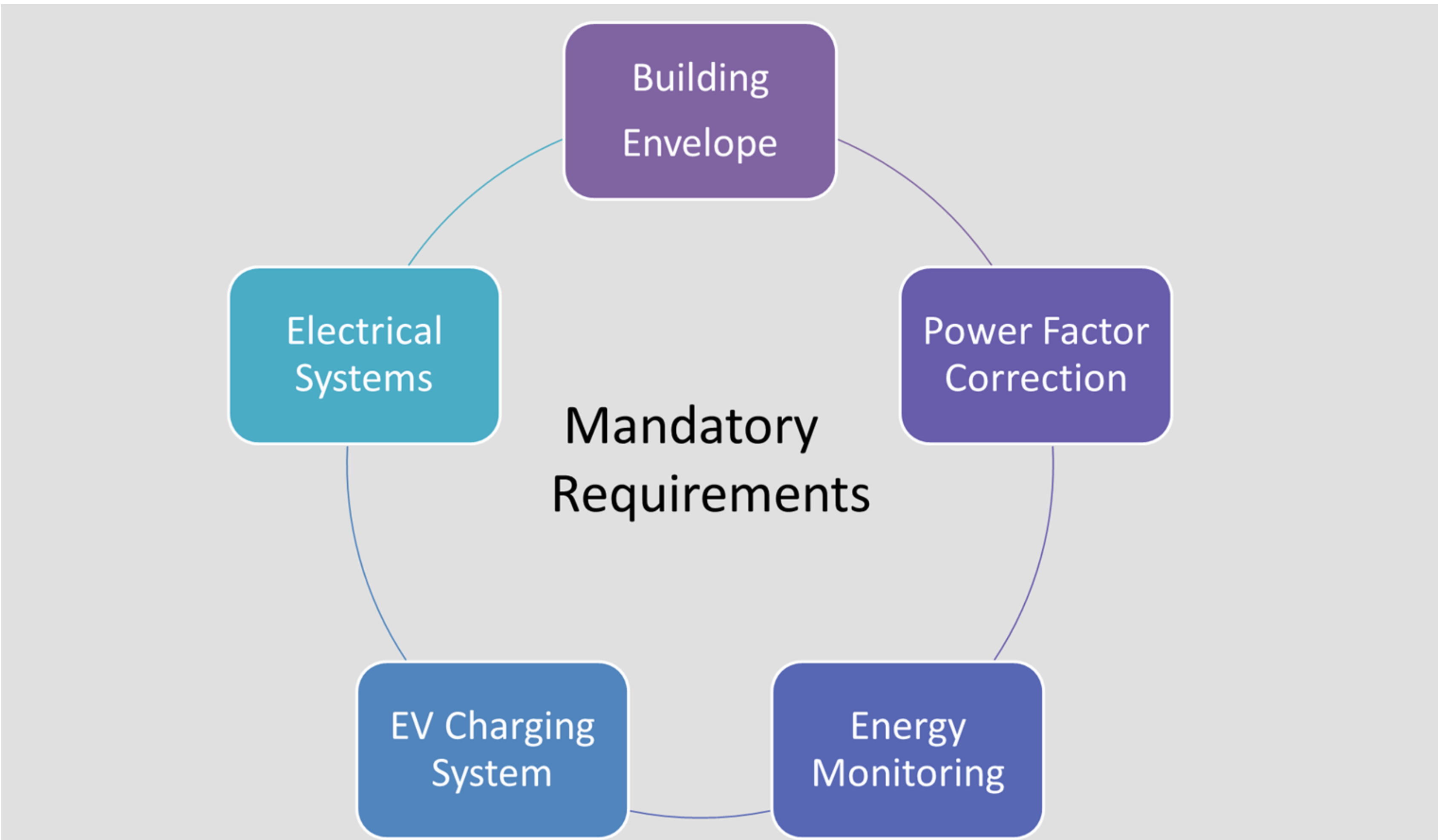
\+

Indoor Electrical End Use
- Indoor Lighting
- Automatic Lighting Shutoff
- Occupancy Sensors
- Ceiling Fan Star Labelling
- Service Hot Water
- Air Conditioner system, sizes, efficiencies and controls

\+

Renewable Energy Systems
- System Peak Generation Capacity
- Solar Water Heating System
- Technical Specifications
- Renewable Energy Zone Area

ENS – Part 2 - Mandatory Requirements



ENS – Part 2 - Mandatory Requirements

Requirement	Category
Chapter 4 of ENS Part I	Building Envelope
All 3 phase shall maintain the power factor of 0.97 at the point of connection	Power Factor Correction
Total Electrical Energy	Energy Monitoring
Electrical Consumption of Applicable End Use Systems	Energy Monitoring
Guidelines issued by Ministry of Power for EV Charging on Oct 1st 2019	EV Charging Systems
Electrical Consumption of Applicable End Use Systems	Electrical Systems

ENS – Part 2 - Prescription Requirements

Prescriptive Method:

To demonstrate compliance with ENS Code through Prescriptive method, ENS building shall meet the following:

Chapter 4 — Mandatory Requirements

Chapter 5 — Prescriptive Requirements

- Building Envelope
- Common Area Lighting
- Elevators (If applicable)
- Pumps (If applicable)
- Electrical Systems

ENS – Part 2 - Prescription Requirements

Building Envelope:

ENS Code Prescriptive Method

(Building Envelope)

- All requirements of Building Envelope including **Openable Window-to-Floor area ratio, Visible Light Transmittance** as per Chapter 4 of ENS Part 1
- **RETV for Building Envelope (except roof) for all climatic zones (except cold)** shall comply with the **Maximum RETV of 15W/m2.** Thermal Transmittance of Building Envelope for cold climate shall comply with **max U value of 1.3w/m2.K**
- **Thermal transmittance of roof** shall comply with the **maximum Uroof value of 1.2W/m2.K**

ENS – Part 2 - Code Compliance- Point Based System

Obtain a minimum ENS Score Points as in 6.1

Point based System Approach

Get Additional Points By

Project Category	Minimum ENS Score
Low Rise Buildings	47
Affordable Housing	70
High Rise Buildings	100

Additional Points
Additional Points of **Building Envelope** under section 6.4 and/or
Requirements labelled additional of **Building Services and Indoor Electrical End Use** under Section 6.5 /6.6 and/or
Requirement labelled additional of **Renewable Energy Systems** under 6.7

ENS – Part 2 - Code Compliance- Point Based System

Maximum Points are TOTAL Points available for each component

Minimum Points

- **Minimum Points** are set of points which are compulsory to achieve for each component to show compliance for ENS

Additional Points

- **Additional Points** are the set of points which are awarded for adopting additional or better energy efficiency measures in a respective component. These points are trade able with other components to achieve the total score mentioned in section 3.1.2 for ENS compliance

ENS – Part 2 - Code Compliance- Point Based System

Components	Minimum Points	Additional Points	Maximum Points
Building Envelope			
Building Envelope	47 Points	40 Points	87 Points
Building Services			
Common area & Exterior Lighting	3 Points	6 Points	9 Points
Elevators	13 Points	9 Points	22Points
Pumps	6 Points	8 Points	14 Points
Electrical Systems	1 Point	5 Points	6 Points
Indoor Electrical End Use			
Indoor Lighting		12 Points	12 Points
Comfort Systems		50 Points	50 Points
ENS SCORE	**70 Points**	**130 Points**	**200 Points**

ENS – Part 2 – Services

Common Area and Exterior Lighting

Common Areas	Maximum LPD (W/m2)	Minimum Luminous Efficacy (lm/W)
Corridor Lighting & Stilt Parking	3.0	All permanently installed lighting fixtures shall use lamps with an efficacy of at least 85 lumens per Watt
Basement Lighting	1.0	All permanently installed lighting fixtures shall use lamps with efficacy of at least 85 lumens per Watt

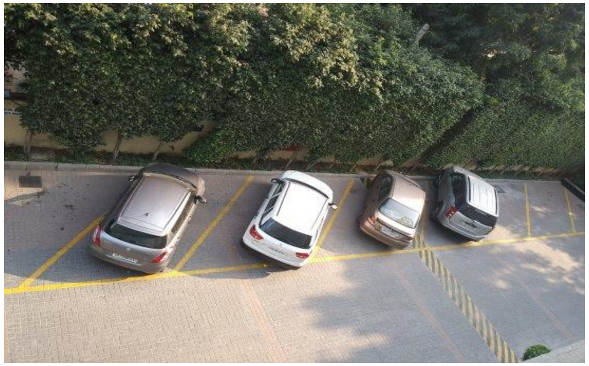
Corridor Lighting

85 LUMENS/WATT

ENS – Part 2 – Services

Common Area and Exterior Lighting

Exterior Lighting Areas/Zones	Maximum LPD (in W/m2)
Driveways and Parking	1.6
Pedestrian Walkways	2.0
Stairways	10.0
Landscaping	0.5
Outdoor Sales Areas	9.0



Parking (open/external)

Stairways

ENS – Part 2 – Services

Common Area and Exterior Lighting

Areas/Zones	Points 95lm/W	Points 105lm/W + Photo
Corridor Lighting and Stilt Parking	1	2
Basement Lighting	1	2
Exterior Lighting Areas	1	2

Basement Lighting

Exterior Lighting

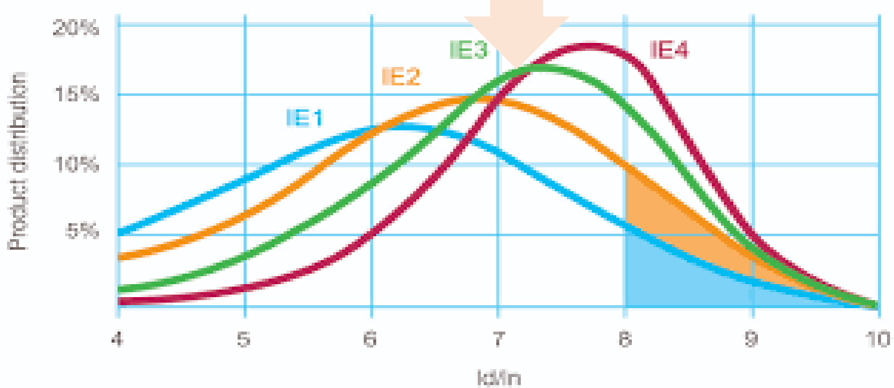
ENS – Part 2 – Services

Elevators – Maximum 22 points

High Efficacy lamps with Luminous Efficacy of 85lm/w

Auto Switch off for Light & Fan when not in use.

Min IE3 High Efficiency Motors

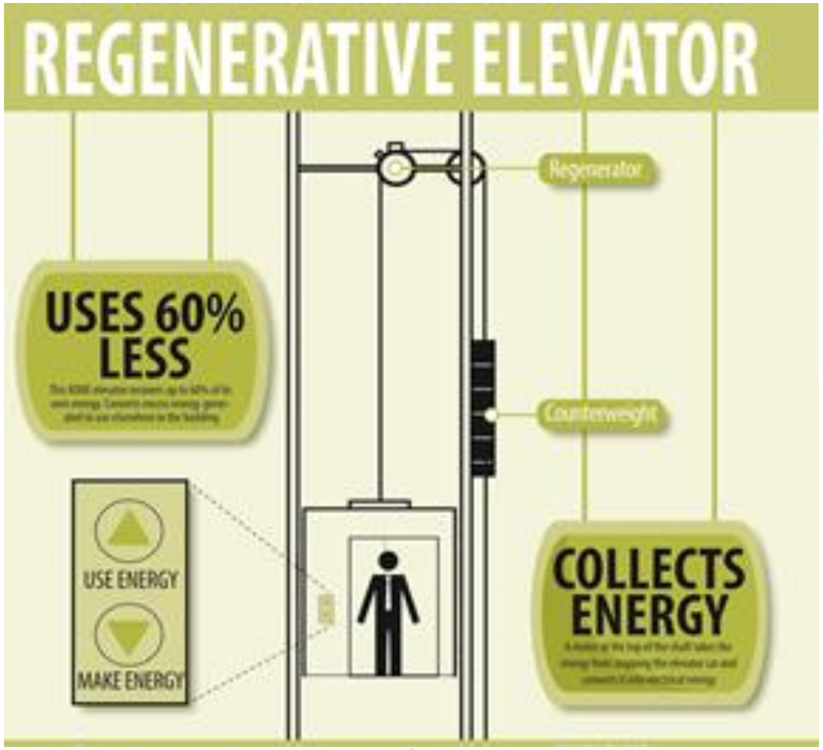


Group Automatic with Supervision

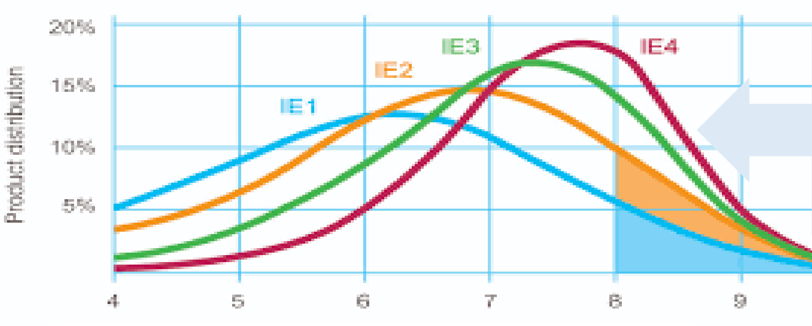
13 POINTS

ENS – Part 2 – Services

Elevators – Maximum 22 points



Regenerative Drives
(3 Points)



Class IE4 Motors
(2 Points)

Variable Voltage & Variable Frequency Drives
(4 Points)

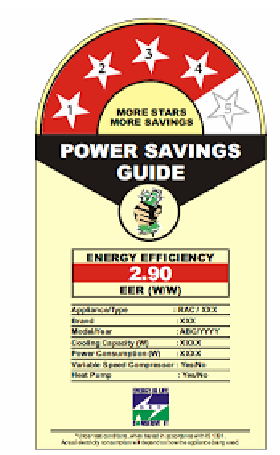
ENS – Part 2 – Services

Pumps – Maximum 14 points

Mechanical Efficiency

60%

OR



6 POINTS

HYDRO-PNEUMATIC PUMPS

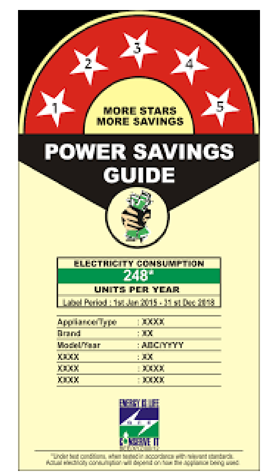
Installation of Hydro-Pneumatic Pumps or BEE Star rated pumps.

Mechanical Efficiency

70%

3 POINTS

+



5 POINTS

8 POINTS

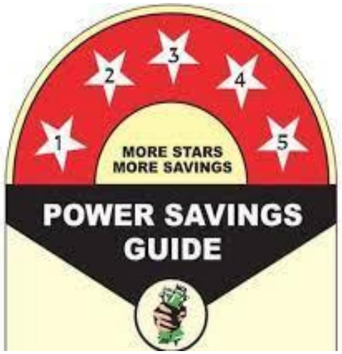
ENS – Part 2 – Services

Electrical Systems – Maximum 6 points

POWER TRANFORMERS	OIL TYPE TRANFORMERS

- Power transformers to satisfy minimum acceptable efficiency at 50%
- Permissible loss as per Table 8 for dry type and Table 9 for Oil Type transformers

(13 POINTS)



Oil Type Transformers With BEE 5 STAR

(5 POINTS)

ENS – Part 2 – Services

Indoor Lighting– Maximum 12 points

LIVING ROOM	BED ROOM	KITCHEN

85lm/W

4 POINTS

95lm/W

3 POINTS

105lm/W

8 POINTS

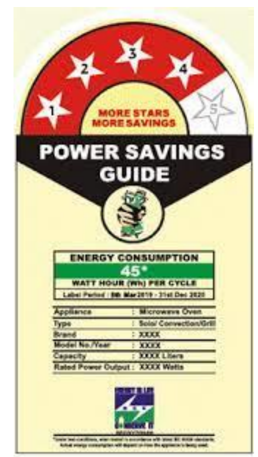
ENS – Part 2 – Services

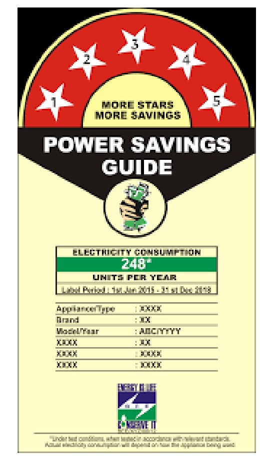
Comfort Systems– Maximum 50 points

Ceiling Fans: Points for ceiling fans will be only applicable and could be achieved if all the bedrooms and hall in all the dwelling units are having ceiling fans

- Sweep Size < 1200mm: equal or greater than 4m^3/min.Watt

- Sweep size > 1200mm: equal or greater than 5m^3/min.Watt





6 POINTS

1 POINT

3 POINTS

BEE Standards and Labelling requirements for ceiling shall take precedence over current requirements

ENS – Part 2 – Services

Comfort Systems– Maximum 50 points

Air Conditioners:

Points for air conditioners will be only applicable and could be achieved if all the bedrooms in all the dwelling units are having air conditioners (either unitary, split, VRF or centralized plant)

20 POINTS

UNITARY TYP : 5 STAR

SPLIT AC : 3 STAR

CHILLER : ECBC 2017

VRF : 3.28

ENS – Part 2 – Services

Comfort Systems– Maximum 50 points

9 POINTS

SPLIT AC 4 STAR

CHILLER : ECBC+

** VRF not applicable as on Date. Whenever BEE Star rating is launched, it will be applicable.*

21 POINTS

SPLIT AC 5 STAR

CHILLER : SUPER ECBC

ENS – Part 2 – Services

Solar Water Heating

Solar Water Heating

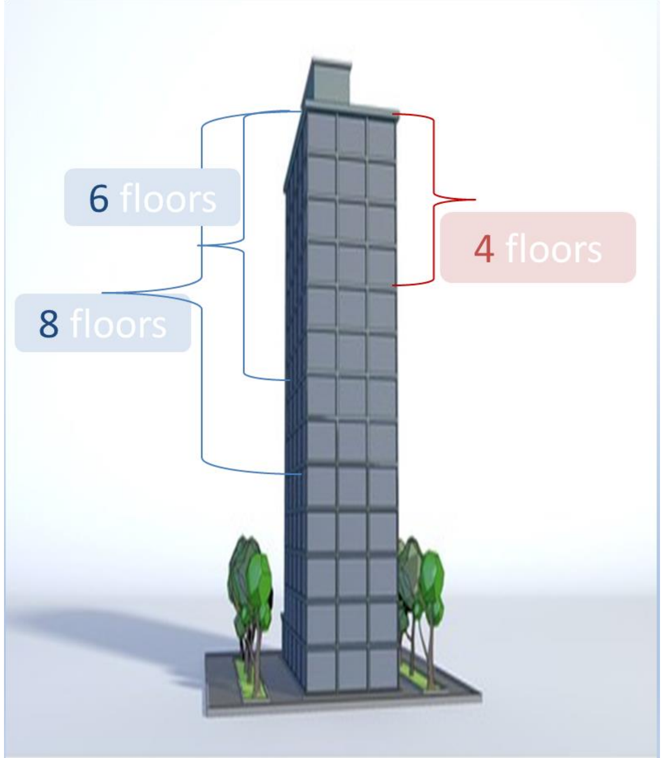
- SWH of **minimum BEE 3 Star label** and meeting 100% of Top 4 floors

OR

- 100% of Annual Hot Water demand of Top 4Floors is met by using heat recovery

6 POINTS

- 100% of Annual water demand for Top 6 floors **(2points)**
- 100% of Annual water demand for Top 8 floors **(5 points)**



TOP FLOORS

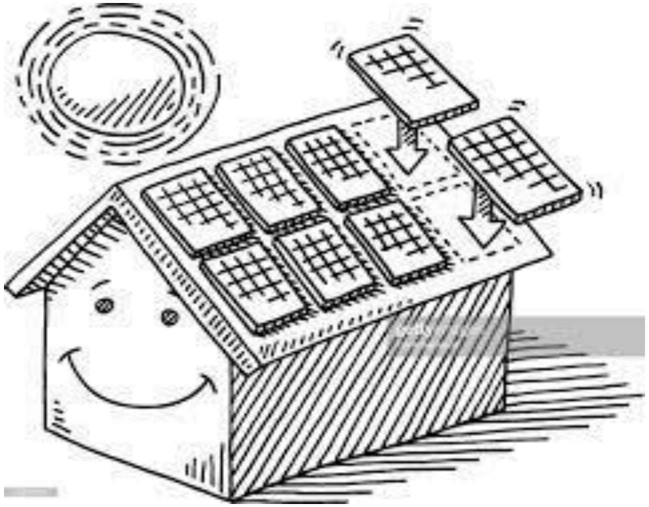
ENS – Part 2 – Services

Solar Photovoltaic

- Dedicated Renewable Energy Zone (REGZ)
- Minimum of 2kWh/m2 year of electricity

- At least 20% of roof area
- Free of any obstructions and shadows

5 Points



- Min. of 3kWh/m2 of Electricity / 30% of roof area **(2 points)**
- Min. of 4kWh/m2 of electricity /40% roof area **(5 points)**

ENS Part 1 & Thermal Comfort analysis for the LHP Chennai

LHP ENS – Part 2

Components	Minimum Points	Additional Points	Maximum Points	Obtained Points	LHP Chennai
Envelope					
U Roof	3	4	7	0	
RETV	44	36	80	48	N-S Block - RETV = 11.8 E-W Block - RETV = 14.8
Lighting					
Corridor & Stilt Lighting - 85Lumen/watt	1		3	1	100 lm/W Wipro LED lighting
95 Lumen/Watt		1		1	
105 Lumen/Watt		1		0	
Exterior Lighting - 85 Lumen/Watt	1		3	1	122 lm/W Philips LED lighting
95 Lumen/Watt		1		1	
105 Lumen/Watt		1		1	
Exterior Lighting Control	1			0	NIL
Elevators					
Lift Car Light	13	9	22	0	70 lm/W LED light installed
IE 3 Motor					OTIS China Energy Label 3 - IE2 equivalent motor installed
Auto Control - Light & Fan					Available
Group control					Not Applicable
Variable Voltage & Frequency drives		4		4	Available
Regenerative drive		3		3	Available

Recommendations:

- *Roof should have an low-cost insulation material like EPS to comply with the requirement*
- *Windows should have a casement type of frame instead of a sliding type to increase Openable area or at least should consider increasing the size of sliding windows*
- *Timer switch or Astronomical control for exterior lighting can be considered*
- *Lift car should have lights with higher lamp efficacy & motors that are IE3 efficient*
- *Group control option whenever applicable*

LHP ENS – Part 2

Pumps					
Hydro pneumatic pumps - 60% Efficiency	6		14	0	Submersible pump installed
BEE 4 star rated pumps				0	Not 4 star rated pump
Hydro pneumatic pumps - 70% Efficiency		3		0	
BEE 4 star rated pumps		5		0	
Electrical Systems					
BEE 4 star rated Oil type	1		6	0	1 star Rated Oil type Transformer is alloted
BEE 5 star rated Oil type		5		0	
Solar PV Systems					
Min 2kWh/sqm per year		5	10	5	

Recommendations:

- *Domestic & STP pumps shall be at least BEE 4-star rated equipment or should use efficient hydro-pneumatic pumps*
- *In case transformer is under state electricity board, the request shall be placed for higher efficient equipment for the project*
- *In case of Indoor lighting, fan & AC installation, BEE-rated equipment shall be used*
- *High efficient Solar Water heating can be considered if space & necessity is there*
- *Solar PV system installation without any shade or hindrance to power generation*

Session 8: GRIHA AFFORDABLE RATING SYSTEM

GRIHA

GRIHA is an acronym for **Green Rating for Integrated Habitat Assessment**. GRIHA is a Sanskrit word meaning – 'Abode'. Human Habitats (buildings) interact with the environment in various ways.

GRIHA is a **rating tool** that helps people assesses the performance of their building against certain nationally acceptable benchmarks.

It evaluates the environmental performance of a building holistically over its entire life cycle, thereby providing a definitive standard for what constitutes a '**green building**'.

With over two decades of experience on green and energy efficient buildings, TERI (The Energy & Resources Institute) has developed GRIHA (Green Rating for Integrated Habitat Assessment), which was adopted as the **national rating system** for green buildings by the Government of India in 2007.

GRIHA – Affordable Housing Rating

GRIHA FOR AFFORDABLE HOUSING

- Online registration
- Orientation workshop
- Due Diligence visit I
- Document Submission
- Preliminary Evaluation
- Final Due Diligence visit
- Final Evaluation
- Rating & Awareness Drive

GRIHA – Affordable Housing Rating

GRIHA Affordable Housing rating is a **performance-oriented** system where points are awarded for meeting the intent (appraisals) of the criteria.

Each criterion has certain number of points assigned.

GRIHA Affordable Housing rating system is a **100 point** system consisting of 30 criteria categorized under six sections such as:

- Site Planning
- Energy & Occupant Comfort
- Water Saving
- Waste Management
- Sustainable Building Materials
- Social Aspects and Bonus Points

Out of these 30criteria, three are mandatory and eight are partly mandatory, while the rest are optional.

Different levels of certification (one star to five stars) are awarded based on the number of points earned.

The minimum points required for certification is 25.

GRIHA FOR AFFORDABLE HOUSING

Rating threshold	GRIHA for Affordable Housing rating
25 – 40	*
41 – 55	**
56 – 70	***
71 – 85	****
86 and above	*****

GRIHA FOR AFFORDABLE HOUSING

ELIGIBILITY FOR AH RATING

1. **Livability index (Affordable housing built-up area thresholds) - Essential**

   Approval letter issued by government agency (Central/State) confirming that the project is being developed as per *Pradhan Mantri Awas Yojana* scheme/guidelines must be submitted.*

2. **Site Selection - Mandatory**

   The site plan must be in conformity with the development plan/master plan/UDPFI guidelines. Compliance must be demonstrated with the provisions of eco-sensitive zone regulations, coastal zone regulations, heritage areas (identified in the master plan or issued separately as specific guidelines), water body zones (in such zones, no construction is permitted in the water spread and buffer belt of 30 meter minimum around the FTL), various hazard prone area regulations, and others if the site falls under any such area.

3. **Optimum availability of water - Indicative**

   Total water requirement estimation for the site and approval document (with assurance on the supply of the required water quantity) from the local municipal authority highlighting the total water which will be available for the development must be submitted.

GRIHA – Affordable Housing Rating

SECTION I

Site Planning

GRIHA FOR AFFORDABLE HOUSING

Criterion Number	Criterion Name	Maximum Points
Criterion 1	Low-impact design	6
Criterion 2	Design to mitigate UHIE	3
Criterion 3	Preservation and protection of landscape during construction	3
Criterion 4	Storm water management	2
Criterion 5	Reduction in air and soil pollution during construction	2
	Total Weightage	**16**

GRIHA – Affordable Housing Rating

SECTION II

Energy & Occupant Comfort

GRIHA FOR AFFORDABLE HOUSING

Criterion Number	Criterion Name	Maximum Points
Criterion 6	Envelope Thermal Performance	8
Criterion 7	Occupant Visual Comfort (Daylight)	5
Criterion 8	Efficient Lighting	2
Criterion 9	Energy Efficient Equipment	2
Criterion 10	Renewable Energy	6
Criterion 11	Energy Metering	2
	Total Weightage	**25**

GRIHA – Affordable Housing Rating

SECTION III

Water Savings

GRIHA FOR AFFORDABLE HOUSING

Criterion Number	Criterion Name	Maximum Points
Part A : Construction phase		
Criterion 12	Efficient use of water during construction	2
Part B : Post Construction phase		
Criterion 13	Optimization of building and landscape water demand	9
Criterion 14	Water reuse	7
Criterion 15	Water metering	1
	Total Weightage	**19**

SECTION IV

Waste Management

GRIHA FOR AFFORDABLE HOUSING

Criterion Number	Criterion Name	Maximum Points
	Part A : Construction phase	
Criterion 12	Efficient use of water during construction	2
	Part B : Post Construction phase	
Criterion 13	Optimization of building and landscape water demand	9
Criterion 14	Water reuse	7
Criterion 15	Water metering	1
	Total Weightage	**19**

GRIHA – Affordable Housing Rating

SECTION V

Sustainable Building Materials

GRIHA FOR AFFORDABLE HOUSING

Criterion Number	Criterion Name	Maximum Points
Criterion 18	Reduction in environmental impact of construction	6
Criterion 19	Use of low-environmental impact materials in building interiors	5
Criterion 20	Use of recycled content in roads and pavements	4
Criterion 21	Low VOC paints, adhesives, sealants and composite wood products	2
Criterion 22	Zero ODP materials	Mandatory
	Total Weightage	**17**

GRIHA – Affordable Housing Rating

SECTION VI

Social Aspects

GRIHA FOR AFFORDABLE HOUSING

Criterion Number	Criterion Name	Maximum Points
Criterion 23	Facilities for construction workers	1
Criterion 24	Universal Accessibility	2
Criterion 25	Proximity of transport & basic services	10
Criterion 26	Environmental Awareness	2
Criterion 27	Tobacco Smoke Control	Mandatory
Criterion 28	Water Quality	Mandatory
Criterion 29	Provision of Access to Clean Sources of Cooking Fuel	1
	Total Weightage	**16**

BEE Star Labelling for Residential Buildings

BEE – STAR LABELLING

Table for Building Energy Star Rating Programme More than 50 % air conditioned built up area

Climatic Zone- Composite

EPI(Kwh/sqm/year)	Star Label
190-165	1 Star
165-140	2 Star
140-115	3 Star
115-90	4 Star
Below 90	5 Star

Climatic Zone - Warm and Humid

EPI(Kwh/sqm/year)	Star Label
200-175	1 Star
175-150	2 Star
150-125	3 Star
125-100	4 Star
Below 100	5 Star

Climatic Zone - Hot and Dry

EPI(Kwh/sqm/year)	Star Label
180-155	1 Star
155-130	2 Star
130-105	3 Star
105-80	4 Star
Below 80	5 Star

Table for Building Energy Star Rating Programme Less than 50 % air conditioned built up area

Climatic Zone- Composite

EPI(Kwh/sqm/year)	Star Label
80-70	1 Star
70-60	2 Star
60-50	3 Star
50-40	4 Star
Below 40	5 Star

Climatic Zone - Warm and Humid

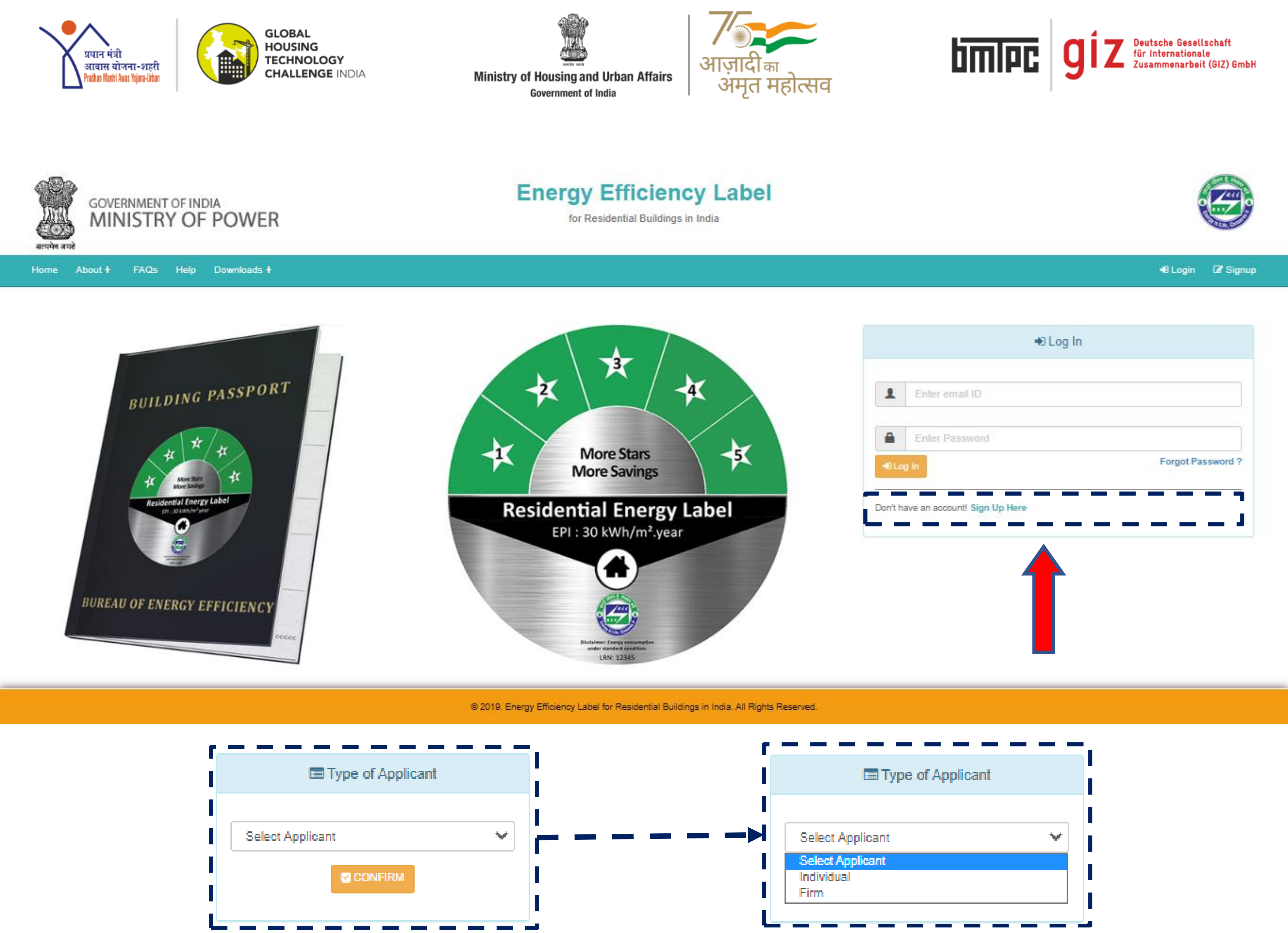
EPI(Kwh/sqm/year)	Star Label
85-75	1 Star
75-65	2 Star
65-55	3 Star
55-45	4 Star
Below 45	5 Star

Climatic Zone - Hot and Dry

EPI(Kwh/sqm/year)	Star Label
75-65	1 Star
65-55	2 Star
55-45	3 Star
45-35	4 Star
Below 35	5 Star

The program would rate office buildings on a 1-5 Star scale with 5 Star labeled buildings being the most efficient. Five categories of buildings - **office buildings, hotels, hospitals, retail malls, and IT Parks** in five climate zones in the country have been identified for this programme.

Those buildings having a **connected load of 100 kW** and above would be considered for BEE star rating scheme.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Pradhan Mantri Awas Yojana-Urban
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Presented by:

GIZ and South Cluster Cell

chennai.gizcsbcell@gmail.com