Training Program on Innovative Construction Technologies & Thermal Comfort in Affordable Housing

RACHNA
RESILIENT, AFFORDABLE AND COMFORTABLE HOUSING THROUGH NATIONAL ACTION

RACHNA for Practitioners on 17th June 2022, Friday

Venue: Viceroy and Residency, La Place Sarovar Portico 6, Shahnajaf Road, La Place, Hazratganj, Lucknow, Uttar Pradesh 226001

Time: 10:00 AM to 5:30 PM

'RACHNA for Officers' training program delivered in-depth knowledge on thermal comfort, its nuances, and its relationship with building physics. Moreover, it discussed design strategies, construction techniques, policy documents, building codes, international practices, and other aspects relevant to thermal comfort in affordable housing through a suite of case studies. Additionally, it familiarized participants with the evaluation process of thermal comfort, the statistics, and indicators involved as well as affordable cooling technologies and their applicability in various climates.

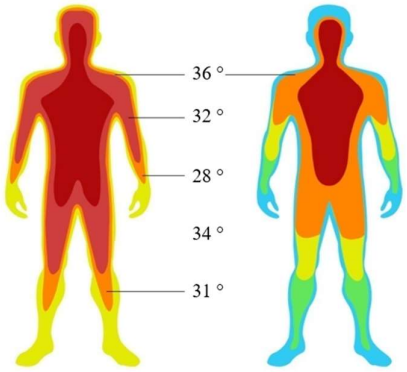
Session proceedings

Day 1- June 17th, 2022 (Friday) **all names of the presenters/faculty are placeholders*		
10h00 – 10h05	**Welcome Address and Introduction to PMAY-U**	**MoHUA**
10h05 – 10h10	**Introduction to Climate Smart Buildings Programme (IGEN – CSB) and overview of workshop**	**GIZ**
10h10 – 10h15	**Session 1: Overview of the workshop, the introduction of the project, and introduction of the trainers.**	**Dr. Rajan Rawal**

10h15 – 11h15	**Session 2 (Technical): Importance of Thermal Comfort**	**Dr. Rajan Rawal**

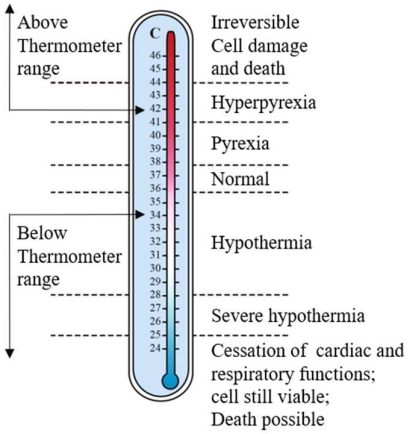
This session established the importance of thermal comfort.

Importance of thermal comfort : Conditioning and Comfort



30 °C – Ambient temperature – 20 ° C

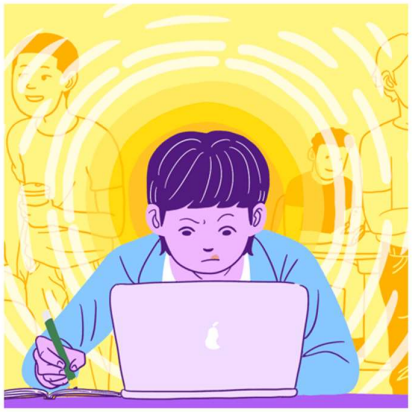
Human Body Condition in two set of environment



Human Body Condition beyond comfort bands

It provided an insight into the connections between comfort, physiology, health, and productivity.

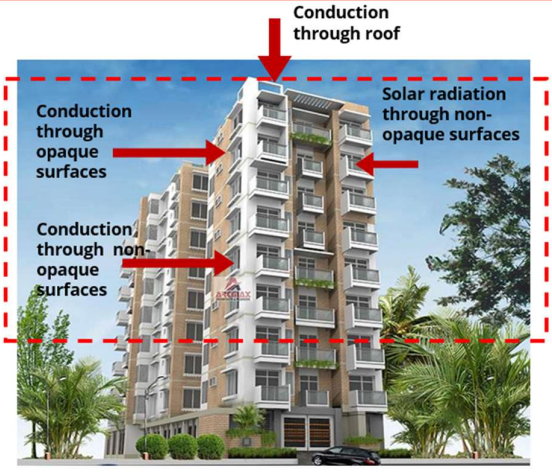
Importance of thermal comfort : Conditioning and Comfort



- In ability to shed excess heat leads to rise in core body temperature.
- Increase heart rate
- Loss of concentration
- Irritation
- Sickness and Vomiting
- Unconsciousness
- Death

It briefly exposed the audience to the connection between buildings and comfort.

ECO NIWAS Samhita: ECBC Residential



To limit the heat gain/loss from the building envelope, the code specifies:

Maximum value of thermal transmittance of roof (U_{roof}= 1.2 W/m^2.K) for all climate zones

Maximum value of Residential Envelope Transmittance Value (RETV) for building envelope (except roof)

It provided overarching guidance about the ways and means to achieve comfort in buildings.

Importance of thermal comfort : Ways to achieve it

- Electrical – Mechanical Systems
- Change of Air
- Air Velocity
- Cooling
- Heating

With the help of examples, the factors affecting thermal comfort were explained.

Factors Affecting Thermal Comfort: Others

Short term physiological adjustments

Long term physiological adjustments

- **Acclimatization**
  - Short-term physiological adjustments
  - Long-term endocrine adjustments
- **Body shape and fat**

Age

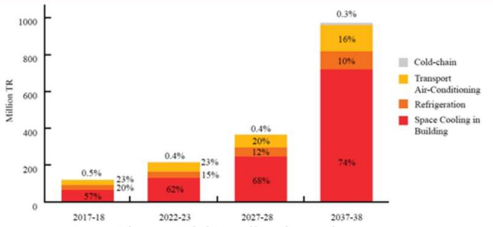
Gender

Health and Wellbeing

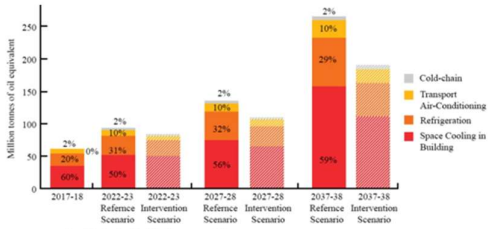
- **Age and gender**
- **Status of health**

The session ended with establishing a relation between comfort and associated energy consumption through cooling needs.

Impact of need of Thermal Comfort: India Cooling Action Plan



Sector wise growth in cooling demand



India's TPES for cooling

India's cooling demand

- 8 times by 2037-38
- 11 times for Building Sector compared to the baseline 2017-18
- India's Total Primary Energy Supply (TPES) for Cooling 4.5 times in 2037-38
- 30% reduction possible due to intervention – from better design and technology

Source: India Cooling Action Plan

11h15 – 11h30	**Questions and Answers**	
11h30 – 11h45	**Health Break**	
11h45 – 12h45	**Session 3 (Technical): Building Physics and its relationship with Thermal comfort** This session will deal with building envelop, its heat transfer	**Dr. Rajan Rawal**

	mechanism and its effect on the thermal comfort. Each heat transfer mode will be discussed in detail with its associated building elements. The session also will discuss climate context in detail and the impact of building elements on the comfort. The session will also provide selected case studies that demonstrates the correlation between envelop thermal performance, HVAC energy consumption and thermal comfort.	

Heat Transfer in Buildings: Influencing Factors

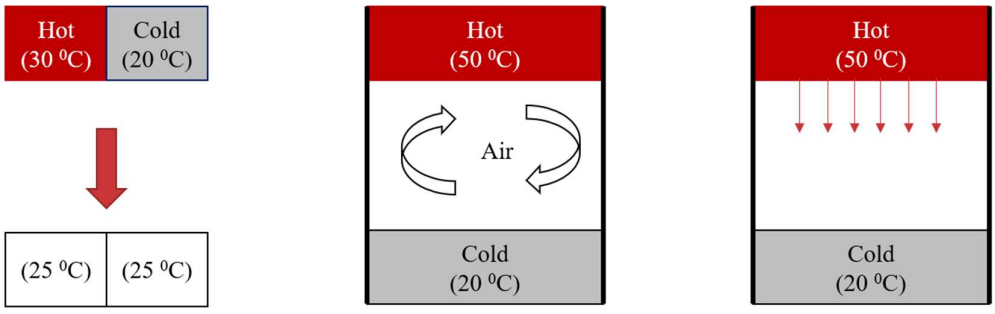
Spatial Design

- Geometry - Massing
- Orientation of bldg. mass
- External Surface to Building Volume Ratio
- Extent of fenestration and characteristics of it
- Internal Volume
  - Stack Ventilation
- Location of Fenestration
  - Pressure Driven Ventilation

Materials and Methods

- Thermal properties of the material
- Optical properties of the material
- Surface Characteristics
- Construction Method
- Assembly formation

Heat Transfer in Buildings: Principles



Source: Rawal, R. (2021, December 22). Heat Transfer and Your Building Envelope. Solar Decathlon India. Retrieved April 13, 2022, from https://solardecathlonindia.in/events/

Heat Transfer in Buildings: Design Strategies - Heat Transfer

	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 – Stake Ventilation	X	HD	X
Location of Fenestration – Pressure Driven Ventilation	X	WH	X

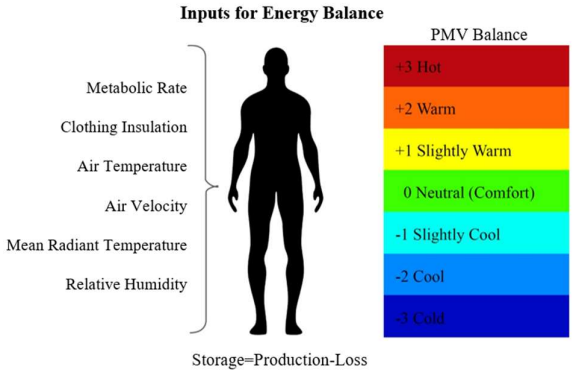
WH: Warm Humid
HD: Hot-Dry
TE: Temperate
CM: Composite
CO: Cold

V. Low
Low
Neutral
High
V. High

ource: Rawal, R. (2021, December 22). Heat Transfer and Your Building Envelope. Solar Decathlon India. Retrieved April 13, 2022, from https://solardecathlonindia.in/events/

12h45 – 13h00	**Questions and Answers**	
13h00 – 14h00	**Lunch Break**	
14h00 – 14h45	**Session 4 (Technical): Fundamentals of Thermal Comfort** This session will provide an insight into the connections between comfort and human behavior, physiology, and psychology in detail. The session will further provide advanced understanding about local discomfort, thermal asymmetry. It will discuss various theories of thermal comfort, thermal comfort induced behavior and emerging trends in thermo-physiology. It will provide overarching guidance about the ways and means to measure thermal comfort among occupants along with explanation of the metrics involved.	**Dr. Rajan Rawal**

Thermal Comfort Metrics: Preference, Comfort and Acceptability

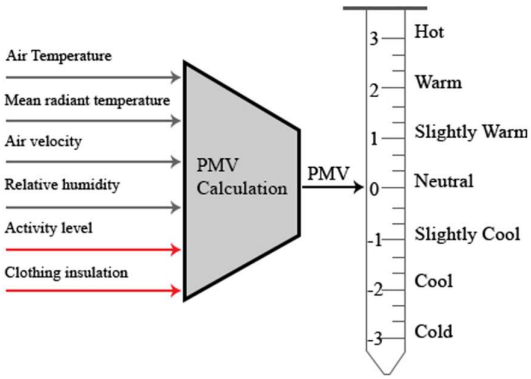


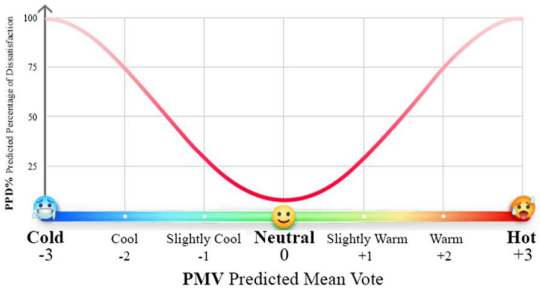
The measure of Thermal Comfort - Subjective

- Thermal Sensation
- Thermal Acceptance (Thermal Comfort)
- Thermal Preference
- Thermal Satisfaction

Prediction of Thermal Comfort

Thermal Comfort Metrics: PMV and PPD

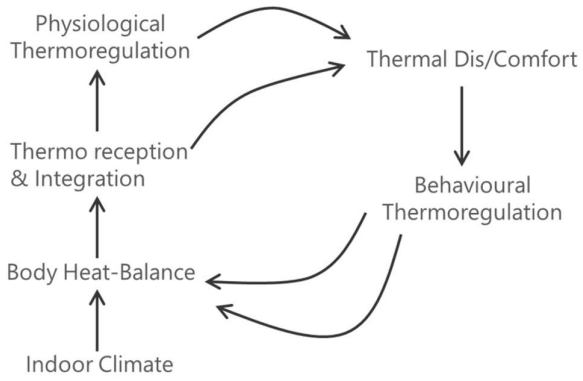




- Predicted Mean Vote (PMV)
- Predicted Percentage of Dissatisfied (PPD)
- Computer aided calculation for PMV - PPD

Source: Guenther, S. (2021). What Is Pmv? What Is Ppd? The Basics of Thermal Comfort. Simscale. Simscale. Retrieved from https://www.simscale.com/blog/2019/09/what-is-pmv-ppd/

Comfort Theory: Adaptive Thermal Comfort Method



Human Thermal Comfort Depends upon

- Physiology
- Psychology
- Behaviour

"If a change occurs that produces discomfort, people will tend to act to restore their comfort."

14h45 – 15h00	**Questions and Answers**	
15h00 – 15h45	**Session 5 (Technical): Affordable Housing Passive Design Strategies**	**Dr. Rajan Rawal**

This session started with the introduction of passive design and its importance.

What is Passive Design?

- No universally accepted definition
- Use of building envelop components to ensure thermal comfort
  - Material Use
  - Spatial Configuration

It provided a quick overview of various strategies that are important to be incorporated in affordable housing.

Passive Design Parameters : Spatial Configuration & Construction

Radiation — Orientation

Shading / Brise Solil

Convection

Space Volumes

Building Form – Form of Roof, Plan

Conduction — Material and construction

The session provided insights into the site level design decisions as well as building-level design decisions.

Other Passive Design Strategies: Spatial Configuration




Orientation: Positive, Negative and Neutral

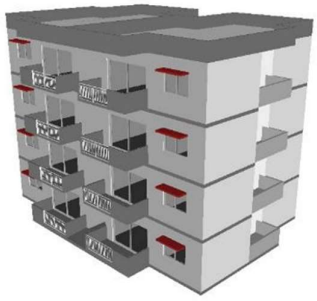
Optimizing Radiation

Wind Direction and Speed

Rectangular Plan
Less ‘tight’ buildings

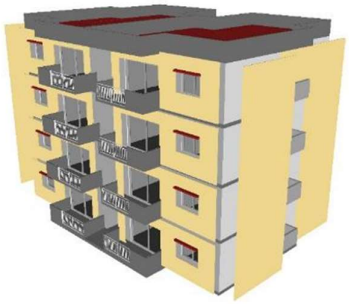
It further provided a comparative understanding of appropriate orientation & use of building mass to reduce radiative heat gains in warm climates

Passive Design : Residential Envelop Transmittance Value (RETV) Use of Material



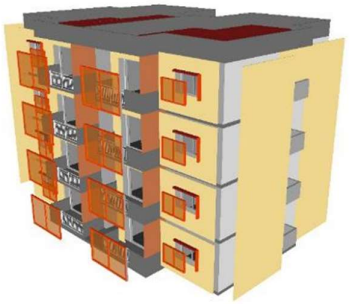
RETV 21.0 W/m²

Business As Usual Building Envelop



RETV 18.0 W/m²

Better Insulation on wall and roof (U value)
Higher Solar Reflectance On the roof (SRI)



RETV 15.0 W/m²

Better Windows (U Value, SHGC, VLT)

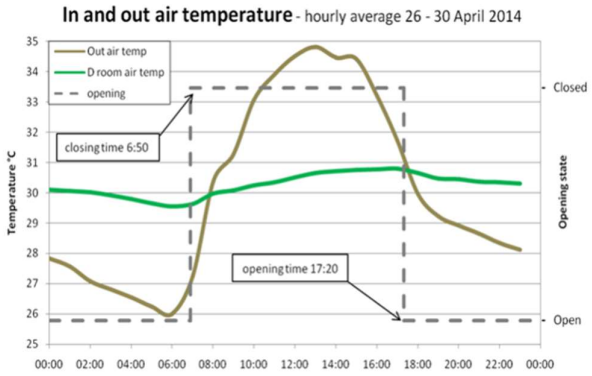
It will guide fenestration design, location, and shading design appropriate for affordable housing. The use of appropriate ventilation for comfort and well-being was also covered in this session.

Other Passive Design Strategies: Spatial Configuration

- E-W Longer Axis
- E-W Vertical ,
- S Horizontal
- Latitude
- *Climate Zone?*

The session also provided selected case studies that have adopted best practice approaches at the site and at the building level to implement passive design strategies.

Blessings House: Auroville



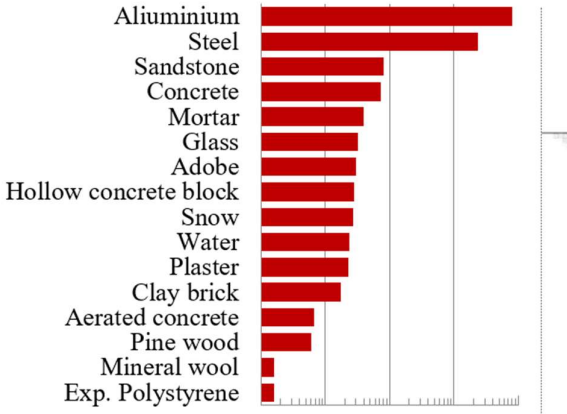
- Balancing Thermal Mass and Insulation
- NV operation with controlled Ventilation
- Warm Humid Climate

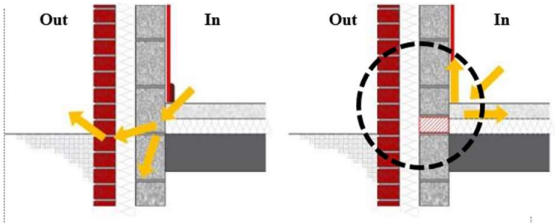
Day shutting and nighttime comfort strategy show good results in preventing excessive temperature rise in the building

15h45 – 16h00	**Questions and Answers**	
16h00 – 16h15	**Health Break**	
16h15 – 17h15	**Session 6 (Technical): Building Materials and Methods of Construction for Affordable Housing** This session will start with the overview of affordable walling, roofing and fenestration materials and technologies. It will further detail the appropriateness of materials and methods of the construction for housing and its applicability in various housing typologies. The session further enhances the understanding of the reader to adopt materials and methods according to the climate context. The focus would also be given to alternative construction technologies, low embodied carbon materials, availability of material locally and economics of it. The session will also provide selected case studies that have adopted best practice approaches at the building level with construction technologies and materials.	**Dr. Rajan Rawal**

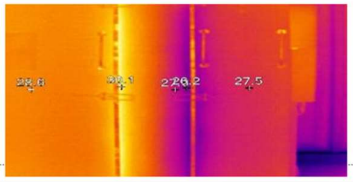
This session started with the overview of affordable walling, roofing and fenestration materials and technologies.

Walling Materials and Methods : Conductivity & Thermal Bridge





Air = 1
0.0002 Sq mts of aluminium (2 Sq Cms) = 1 Sq mts of insulation



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

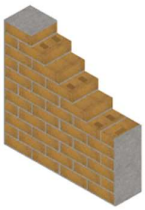
It further detailed the appropriateness of materials and methods of the construction for housing and its applicability in various housing typologies.

Nonhomogeneous Walling Technologies, Traditional

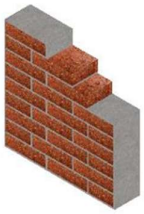
Bamboo-Crete
U - VALUE (W/m² K)= 1.82

Wattle and Daub
U - VALUE (W/m² K)= 2.09

Stabilized Adobe
U - VALUE (W/m² K)= 1.50



Laterite block wall
U - VALUE (W/m² K)= 1.61

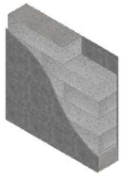


Unstabilized Adobe
U - VALUE (W/m² K)= 1.57

Compressed Stabilized Earth block wall
U - VALUE (W/m² K)= 1.59

Unstabilized Compressed Earth block wall
U - VALUE (W/m² K)= 1.42

AAC block wall
U - VALUE (W/m² K)= 0.45

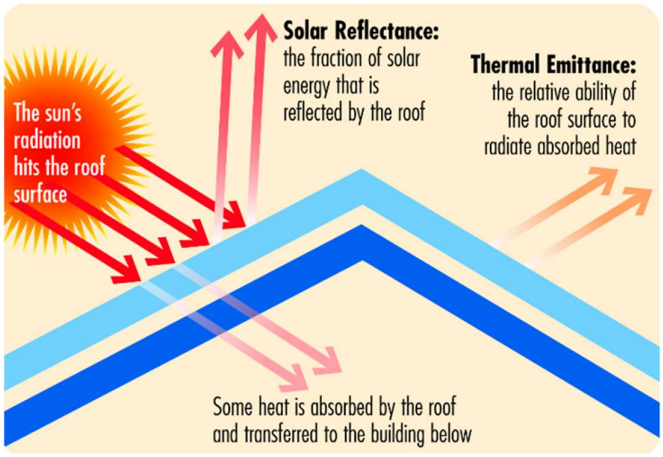


Unstabilized Rammed Earth Wall assembly
U - VALUE (W/m² K)= 1.68

Stabilized Rammed Earth Wall assembly
U - VALUE (W/m² K)=

The session further enhanced the understanding of the audience to adopt materials and methods according to the climate context.

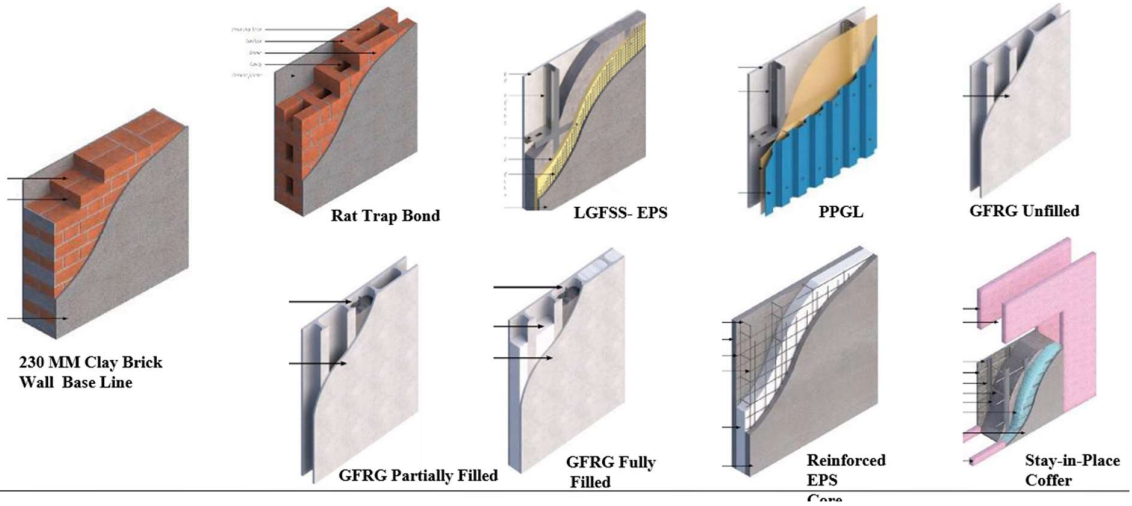
Roofing Coating Material and Solar Reflectance Index



- Reflectance
- Thermal Emittance.
- Emissivity
- Solar Reflectance Index (SRI)

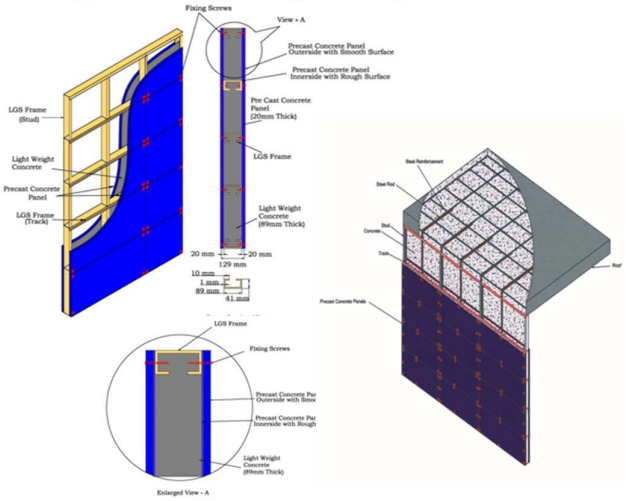
The focus was on alternative construction technologies, low embodied carbon materials, availability of material locally and economics of it.

Nonhomogeneous Walling Technologies, Industrial



The session also provided selected case studies of construction technologies that have been adopted in LHPs.

Light House Project: Agartala



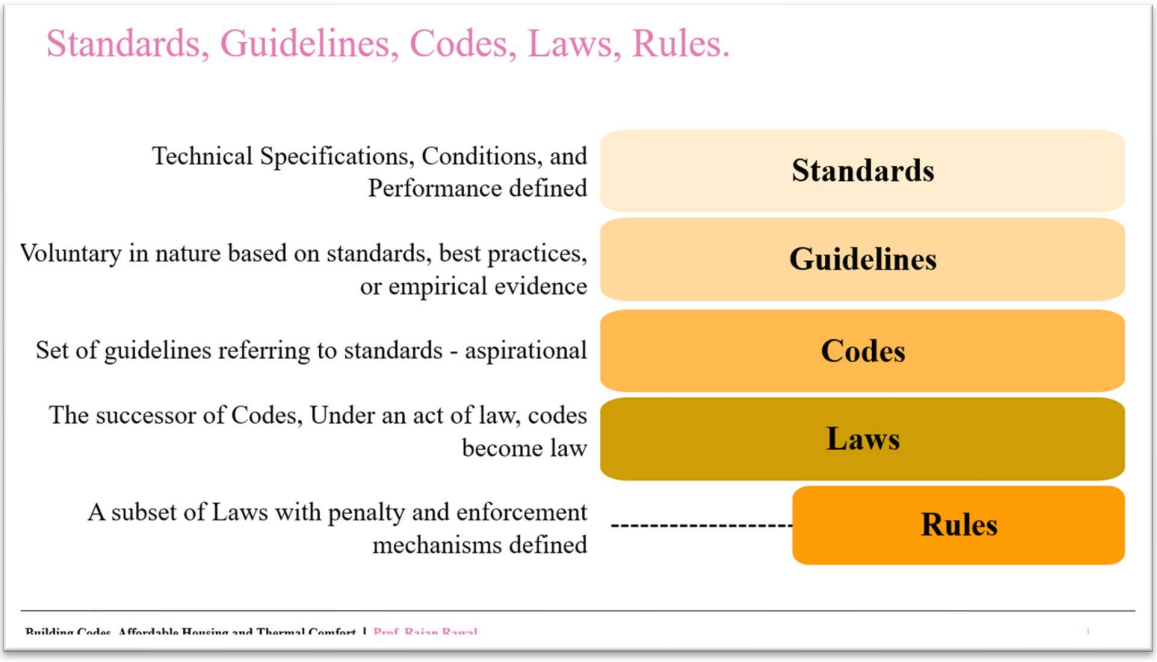
- Light Gauge Steel Framed Structure with Infill Concrete Panels (LGSFS-ICP)
- Ground and 06 Floors
- Weight of the LGSFS-ICP building is about 20-30% lighter
- The LSG frames manufactured using numerically controlled roll
- forming machine using CAD design

Light House Project: Lucknow

- PVC Stay in Place Formwork System
- S and 13 Floors
- Rigid poly-vinyl chloride (PVC) based form work system serve as a permanent stay-in-place durable finished form-work for concrete walls
- The PVC extrusions consist of the substrate (inner) and Modifier (outer). The two layers are co- extruded during the manufacturing process to create a solid profile.

17h15 – 17h25	**Questions and Answers**	
17h25 – 17h30	**Session 7: Day 1 concluding remarks**	**Dr. Rajan Rawal**

Day 2- June 18th, 2022 (Saturday) **all names of the presenters/faculty are placeholders*	
10h00 – 10h15	**Session 8: Day 1 Recap**
10h15 – 11h15	**Session 9 (Technical): Building Codes, Affordable Housing and Thermal Comfort** *Understanding of the provision of various thermal comfort-related clauses in the National Building Code, Eco Niwas Samhita, various guidelines provided by the government. It also will provide insights into the implementation of policy. The reader will be able to comprehend the process of implementing the code at the local level. It will discuss the programming of code implementation, the economics of it as well as the benefits of the codes. Further, this section will outline the codes implemented internationally through the voluntary market based systems, government byelaw, provisions in ISO, and ASHRAE standards.*



Code Provision: Heat Gain

Reducing Heat Gain:

Maximum RETV for building envelope (except roof)

$RETV \leq 15\ W/m^2$

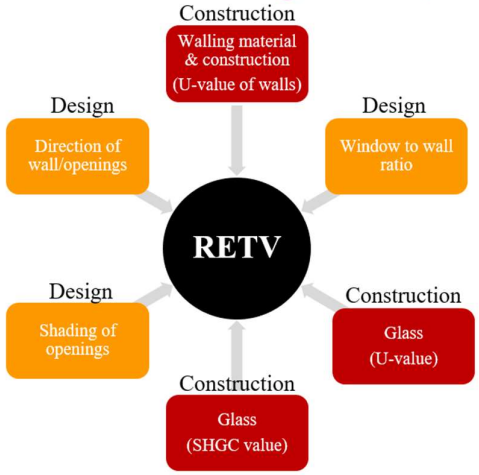
For all climate zones except Cold

Roofing material's maximum thermal transmittance value (for all climate zones)

$U_{roof} \leq 1.2\ W/m^2K$

urce: Bureau of Energy Efficiency, Government of India, & Ministry of Power. (2018). Eco-Niwas Samhita- Part I: Building Envelope. Retrieved from

RETV: Influencing Factors, Design and Construction



The net heat gain rate (over the cooling period)

through the building envelope (excluding the roof)

divided by the area of the building envelope (excluding the roof), measured in W/m^2.

Source: Bureau of Energy Efficiency, Government of India, & Ministry of Power. (2018). Eco-Niwas Samhita- Part I: Building Envelope. Retrieved from https://www.beeindia.gov.in/sites/default/files/ECBC_BOOK_Web.pdf

11h15 – 11h30	**Questions and Answers**
11h30 – 11h45	**Health Break**

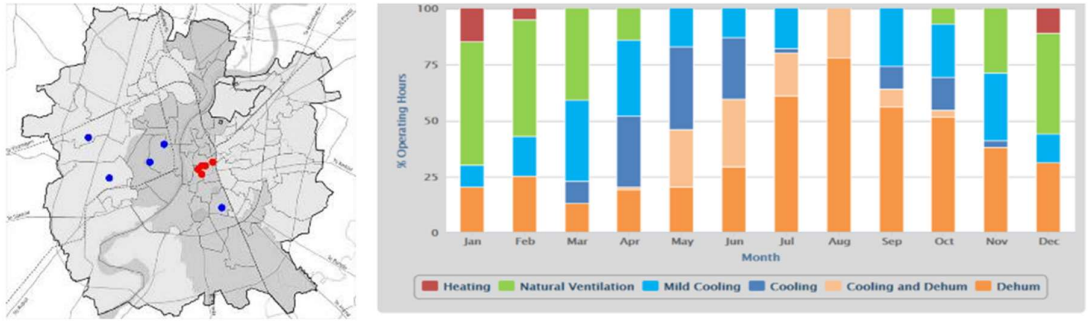
11h45 – 12h30	**Session 10 (Technical): Application of Thermal Comfort in Affordable Housing- A Suite of Case Studies** *This session will bring salient features of the projects that have demonstrated approaches to achieve thermal comfort in affordable housing. This session will include the projects that were conceived using integrated design practices. The case studies in this session will highlight more than one aspect of the project that meets the objective of affordability and comfort. The on-site performance of the housing also will be included to help the participants understand the methods of field performances.*

Thermal and Comfort Performance of NE India vernacular house

Case studies : Vernacular: Imphal **Case studies : Vernacular: Tejpur**

ource: Singh, M. K., Mahapatra, S., & Atreya, S. K. (2010). Thermal performance study and evaluation of comfort temperatures in vernacular buildings of northeast India. Building and Environment, 45(2), 320–29. https://doi.org/10.1016/j.buildenv.2009.06.009

Thermal and Comfort Performance of Pol vernacular house

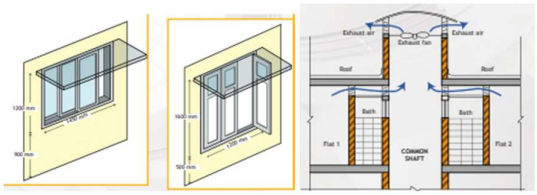


City map of Ahmedabad showing the location of PH (red) and CH (blue)

Estimated operation modes for a typical building in Ahmedabad

Source: Singh, M. K., Mahapatra, S., & Atreya, S. K. (2010). Thermal performance study and evaluation of comfort temperatures in vernacular buildings of northeast india. Building and Environment, 45(2), 320–329. https://doi.org/10.1016/j.buildenv.2009.06.009

Rajkot Smart Ghar 3



- Indo Swiss Building Energy Efficiency Project – Bureau of Energy Efficiency
- 1176 Units of 33.6 m^2/each
- U value of 0.8 W/m^2 achieved using AAC Blocks, South sidewall with 50mm air cavity leading to 0.3 W/ m^2
- Roof with PU foam 0.56 W/ m^2
- Window shutter glazing area reduced to 30%
- Improved ventilation through common service shaft

ource: Ministry of Power, & Bureau of Energy Efficiency. (n.d.). Indo-Swiss, Building Energy Efficiency Project, Case Study on "Green" Affordable Housing: Smart GHAR III, Rajkot. Retrieved from ttps://www.beepindia.org/wp-content/uploads/2013/12/Smart-GHAR_final_0_14.pdf

12h30 – 12h45	**Questions and Answers**
12h45 – 13h00	**Discussions on quiz-questionnaires**
13h00 – 14h00	**Lunch Break**
14h00 – 15h00	**Session 11 (Technical): Thermal Comfort Study** **Methods** *This session will outline the field-based methods, theorybased method and laboratory-based methods adopted in the past and in the contemporary world to understand the thermal comfort. It will demonstrate the applicability of various methods. The session also will introduce some handheld tools and research protocols that can help derive thermal comfort studies. The session further will help to develop an understanding of the analytical approach for data collection and data analysis using appropriate methods of statistics.*

Thermal Comfort Study Methods

Indoor Environment (Physical)

Air Temp.
Relative Humidity
Air Velocity
Mean Radiant Temperature (Globe Temp)

Human Body (Physical)

Metabolic Rate
Clothing Value
Skin Temp
Core Body Temp
Skin Temp/Heat Flux of Body Parts

Human Body (Psychological)

Votes on Comfort

Air Quality
Overall acceptance

Source: freepik. (n.d.). Tape Measure. freepik. Retrieved from https://www.freepik.com/free-photos-vectors/tape-measure , freepik. (n.d.). Stethoscope. freepik. Retrieved from https://www.freepik.com/search?format=search&query=stethoscope , freepik. (n.d.). Vote. freepik. Retrieved from https://www.freepik.com/search?format=search&query=vote

Thermal Comfort Study Methods

Field Studies

Occupant Comfort
User Behaviour
Productivity

Laboratory Studies

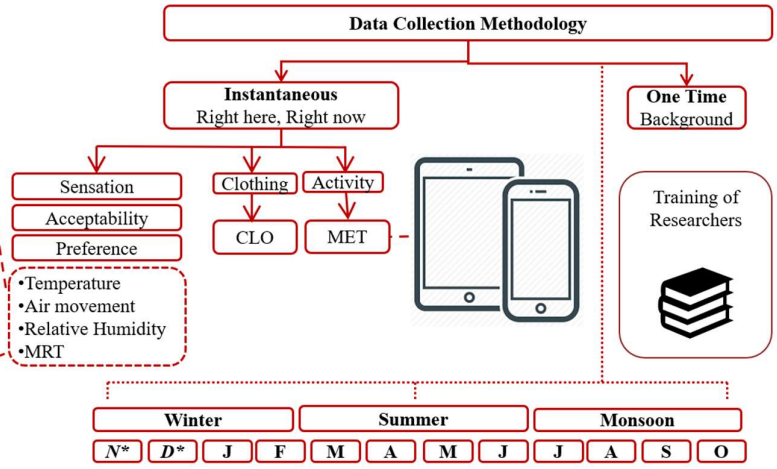
Thermal Comfort
Body Parts
Cooling Systems
Control Systems
Productivity

Digital Simulations

Thermal Comfort
Body Parts
Cooling Systems
Control Systems

Source: freepik. (n.d.). Field studies. freepik. Retrieved from https://www.freepik.com/search?format=search&query=field%20studies , freepik. (n.d.). Laboratory Studies. freepik. Retrieved from https://www.freepik.com/search?format=search&query=Laboratory%20Studies , freepik. (n.d.). Desert. freepik. Retrieved from https://www.freepik.com/photos/desert

Field Studies: Execution



Laboratory Studies: Controlled Environment – Thermal Comfort Chambers

Controlled Environments: Measurements

Controlled Environments: Occupants

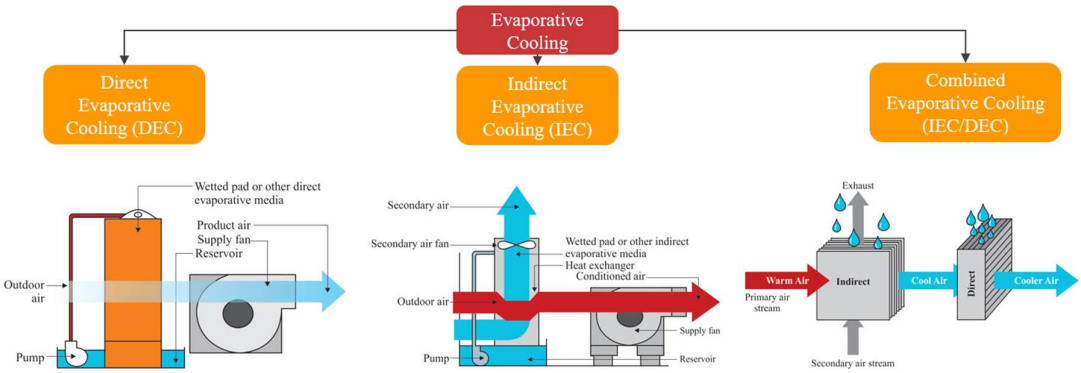
Controlled Environments: Mannequins

Controlled Environments: Digital Simulation

15h00 – 15h15	**Questions and Answers**

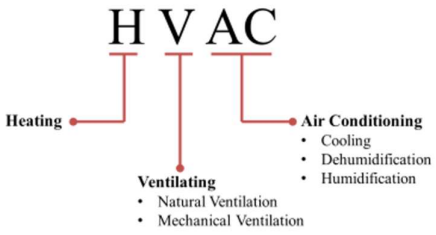
15h15 – 16h15	**Session 12 (Technical): Low Energy Cooling Technologies and Comfort** *This session will familiarize the participants with low energy cooling systems and technologies in gaining comfort. It will provide climate specific guidance as well as insights into their benefits and challenges. The participants will be able to comprehend the design and operation aspects of the low energy cooling system that can work in sync with building envelop. The session also will discuss spatial configuration of the building envelop to accommodate some of the low energy cooling systems.*

Evaporative Cooling (and its variations): Low Energy Cooling Systems



Source: Kanzari, M., Boukhanouf, R., & Ibrahim, H. (2013). Mathematical Modeling of a Sub-Wet Bulb Temperature Evaporative Cooling Using Porous Ceramic Materials. Retrieved from https://www.researchgate.net/publication/267209957_Mathematical_Modeling_of_a_Sub-Wet_Bulb_Temperature_Evaporative_Cooling_Using_Porous_Ceramic_Materials , Condair. (2021, January 5). Direct vs. Indirect Evaporative Cooling: What's the Difference? Direct vs indirect evaporative cooling whats the difference. Retrieved April 16, 2022, from https://www.condair.com/humidifiernews/blog-overview/direct-vs-indirect-evaporative-cooling-whats-the-difference , ategroup. (n.d.). Evaporative cooling system: Indirect direct evaporative cooler. A.T.E. India. Retrieved April 16, 2022, from https://www.ategroup.com/hmx/why-evaporative/

Introduction: Low Energy Cooling Systems



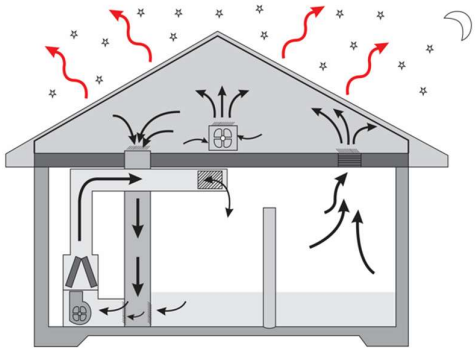
- Night Cooling by Natural Ventilation
- Night Cooling by Mechanical Ventilation
- Evaporative Cooling (and its variations)
- Desiccant Cooling
- Displacement Ventilation
- Ground and Aquifer Cooling
- Radiative Cooling (*now*)

Also (although they use a refrigerant cycle)

- Chilled Ceilings and Chilled Beams
- Radiant Cooling (Structural – Non-Structural)

Source: Rawal, R., Shah, A., Shukla, Y., Ranjan, A., Jani, M., Pandya, H., (2018). Low Energy Cooling products, technical potential and market analysis. Ahmedabad: Centre for Advanced Research in Building Science and Energy

Night Cooling by Mechanical Ventilation: Low Energy Cooling Systems



- **Favorable Factors**
  - Low nighttime DBT
  - Less and Periodic internal loads
  - Uninterrupted electricity
- **Unfavorable Factors**
  - No possibility of fresh air intake
  - Low ceiling to floor height
  - Poor insulation / no thermal mass

Highly efficient, low noise fans and low-pressure drop needed, nigh cooling for high mass can offset ~20-30 W/m^2 heat gains

Source: Nwaigwe, K. N., Anthony, O. C., Ogueke, N., Ugwuoke, P. E., & Anyanwu, E. E. (2012). Transient Analysis and Performance Prediction of Nocturnal Radiative Cooling of a Building in Owerri, Nigeria. Retrieved from https://www.researchgate.net/publication/274066021_Transient_Analysis_and_Performance_Prediction_of_Nocturnal_Radiative_Cooling_of_a_Building_in_Owerri_Nigeria

Case studies

Case Study 1	Case Study 2	Case Study 3
Location: Nadiad, Gujarat System type: 1-DECs & 1-IDECs System Capacity: 30,000 CFM	Location: Ahmedabad, Gujarat System type: 4-DECs System Capacity: 30,000 CFM	Location: Gandhinagar, Gujarat System type: 2-DECs & 1-PDECs System Capacity: 20,000 CFM
		

16h15 – 16h30	**Questions and Answers**

16h30 – 17h00	**Overview of Innovative construction technologies implemented in Light House Projects (LHPs)* This session will highlight the following innovative technologies being implemented in six LHPs:** 1. *Chennai: Industrialized '3-S' Prefab Technology* 2. *Rajkot: Tunnel Formwork* 3. *Lucknow: Stay-in-Place Formwork System* 4. *Indore: Prefabricated Sandwich Panel System* 5. *Ranchi: Precast Concrete Construction – 3D Volumetric* 6. *Agartala: Light Gauge Steel Structural System & Pre-engineered Steel Structural System*
17h00 – 17h15	**Session 13: Discussions on quiz-questionnaires**
17h15 – 17h30	**Session 14: Feedback from Participants and Concluding Remarks**