2^{nd} International Conference and Exhibition on Building Energy Efficiency – ANGAN (Augmenting Nature by Green Affordable New-Habitat)

Department of Energy Science and Engineering

Indian Institute of Technology Delhi-110016

Emerging Construction Practices and Technologies

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Preface

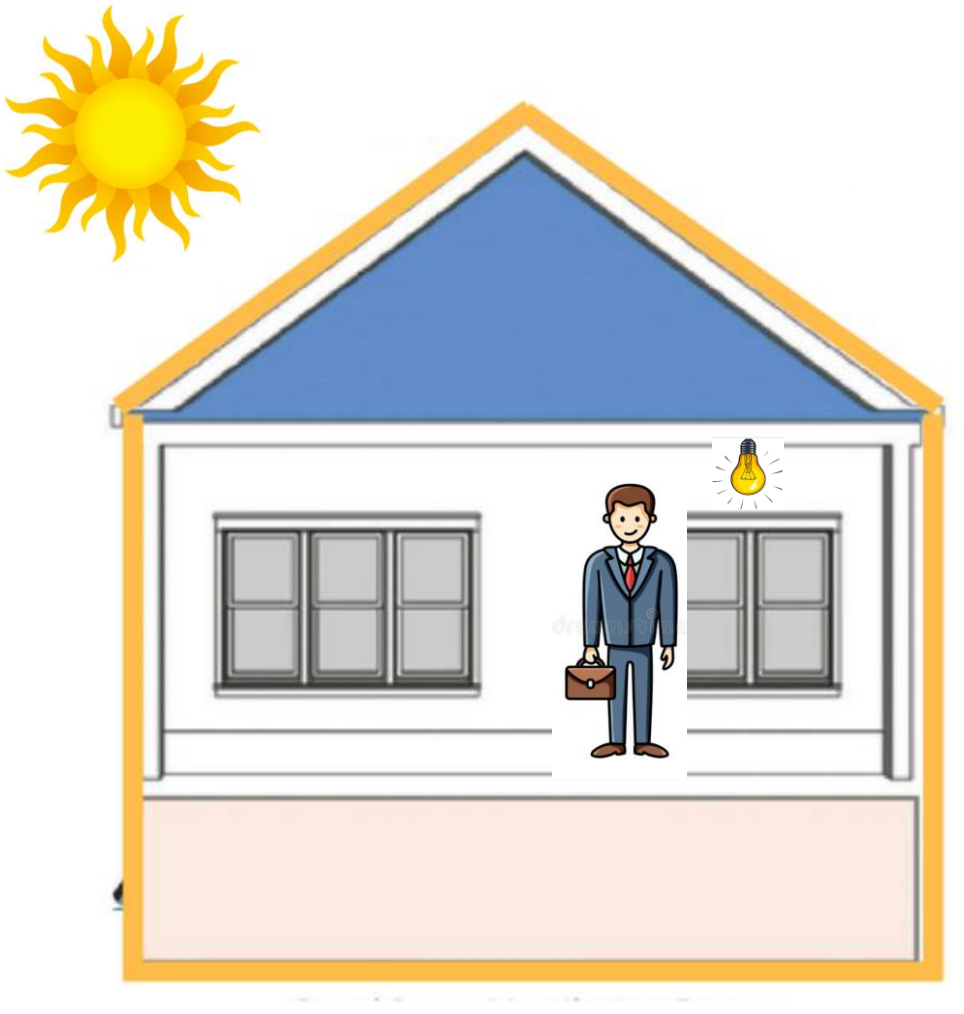
The humid and hot, climate of Indian Subcontinent steers air conditioning (AC) ownership.
With passing time these conditions are made worse by global climate change and the "heat island effect".

India's energy outlook report predicts growth in electricity consumption for cooling by sixfold to 650 TWh by 2040, more than Germany's total today, and accounts for more than half of all building electricity consumption.

Further, with the onset of COVID-19, the health and air-conditioning societies have modified guidelines and suggested incorporating fresh air from ambient conditions to dilute the indoor air and reduce the contaminant level.

“For energy efficient buildings, ***building envelope*** design is the key factor ” - ECBC

Façade
Design
&Material
Selection

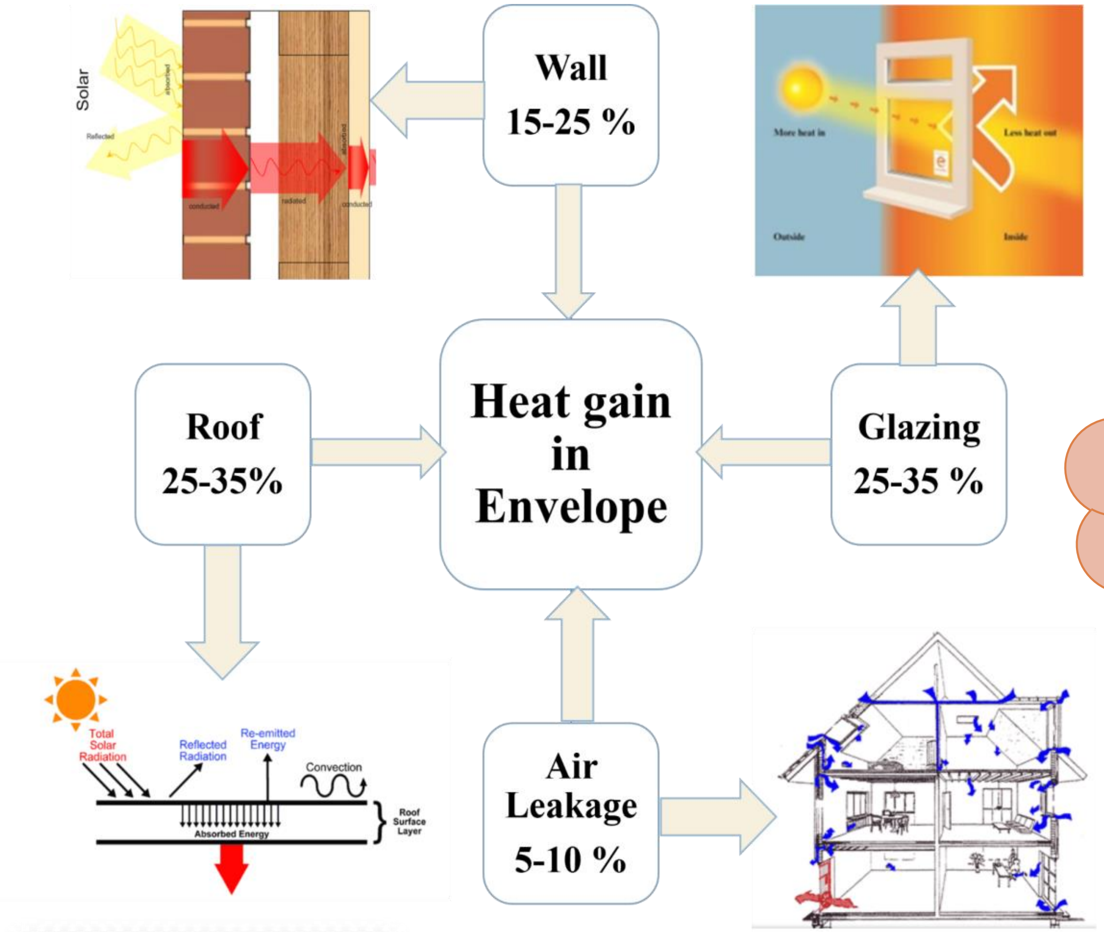


External Factors-

- Sun (Convection Radiation)
- Roofs &Walls
- Windows
- Leakage

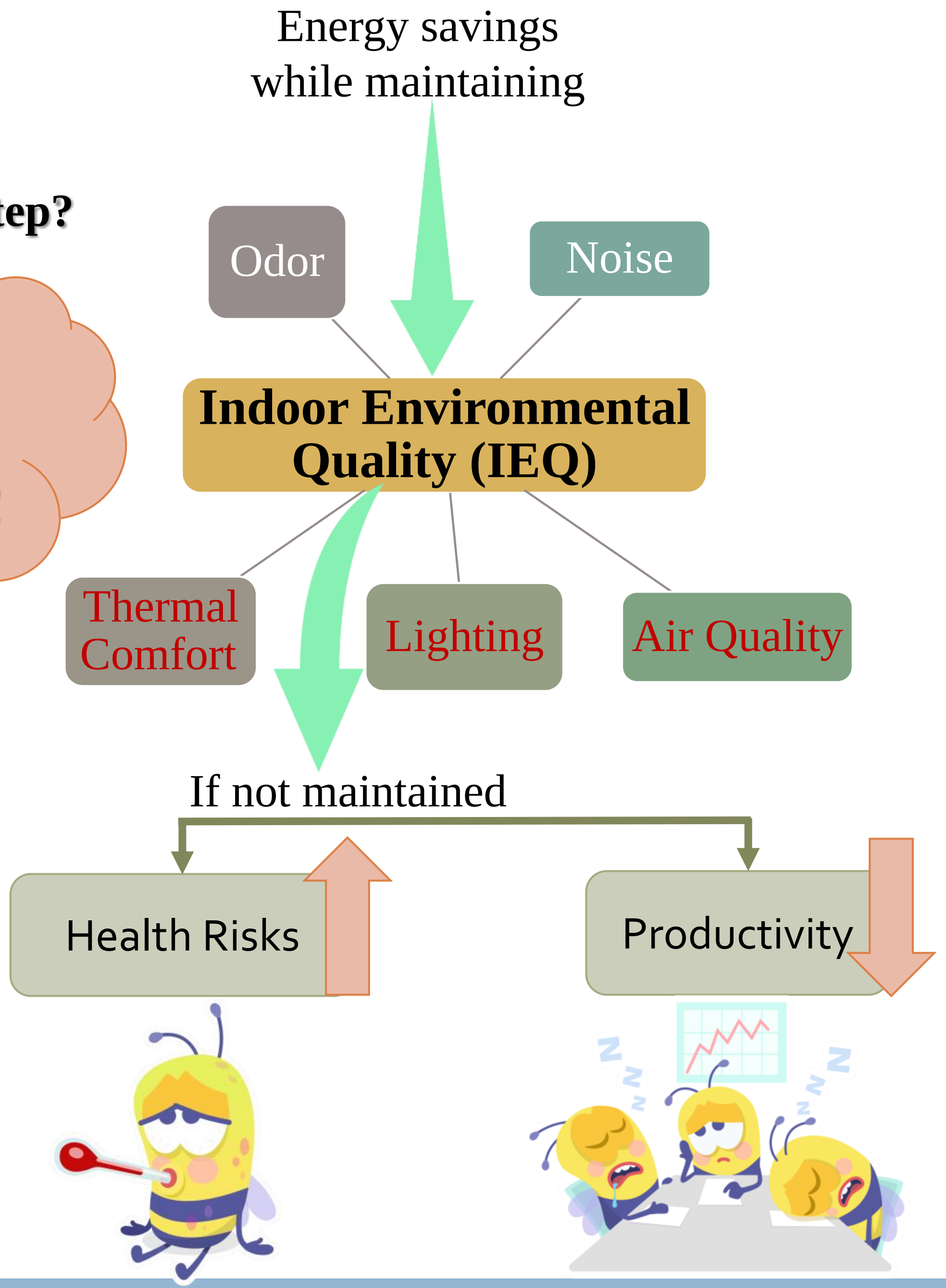
Internal Factors-

- Light
- Appliances
- Occupants



First logical step?

Employ Passive Techniques!!



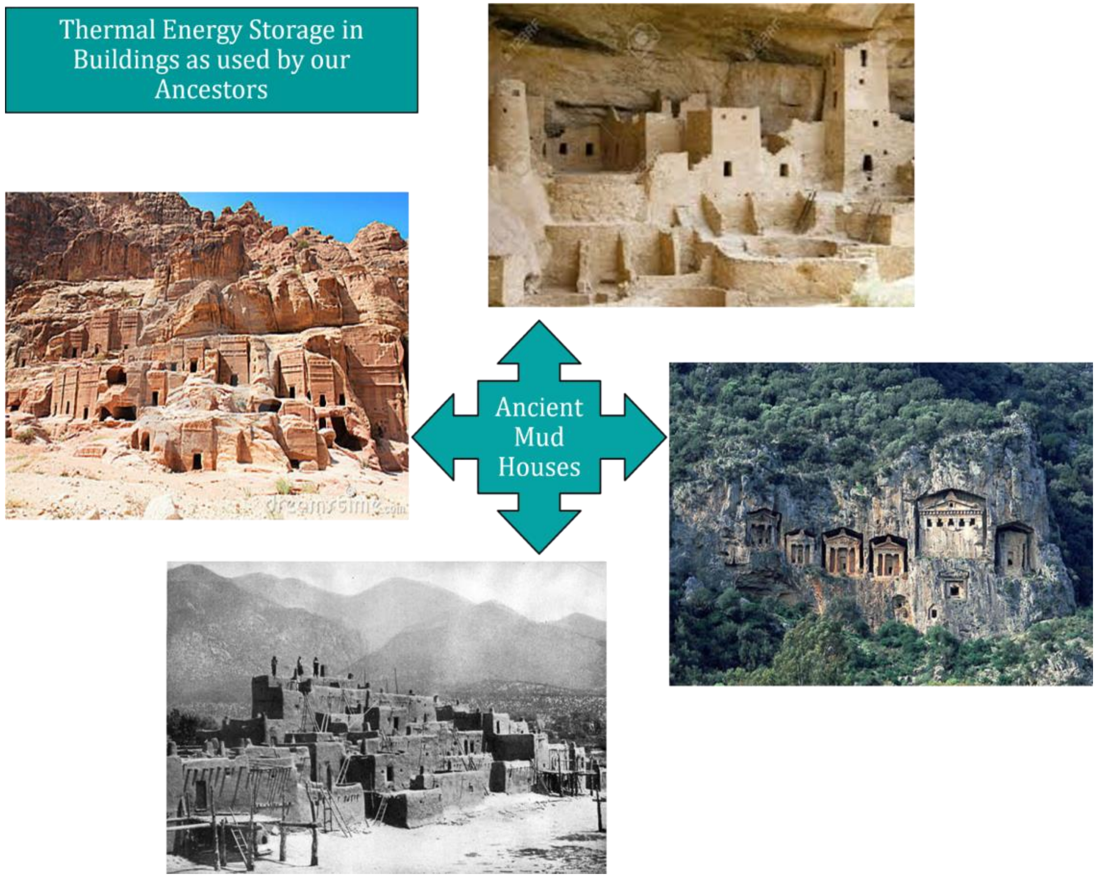
- Buildings => ≈ ***30%-50%*** energy savings potential => significant energy saving possible from *changes in building construction, climate sensitive design, use of locally appropriate material, and operations* (BEE)

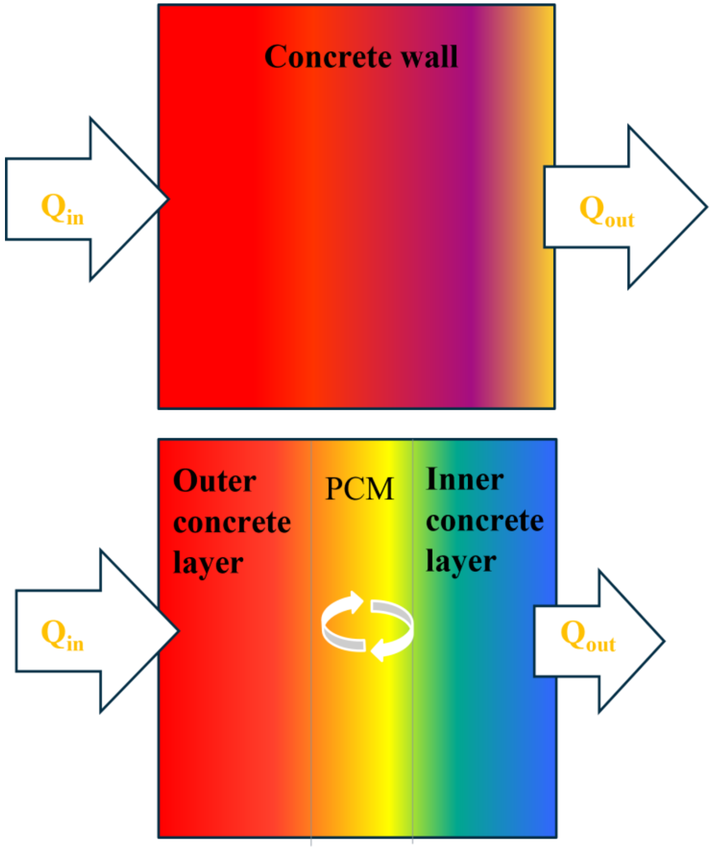
Building energy efficiency related studies

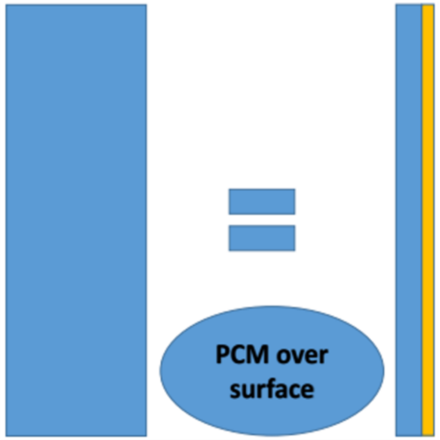
Performance Evaluation based on Thermal Modelling of PCM Embedded Walls/ Roof

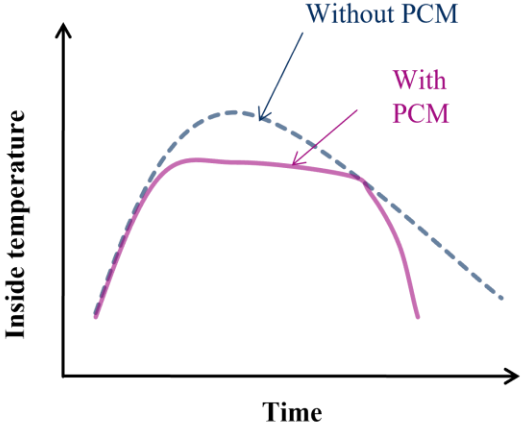
Why PCMs?

With the rapid growth in urban population there is a constraint to building space and material usage. We need to increase the thermal mass of buildings without going back to the heavy vernacular constructions (mud houses).







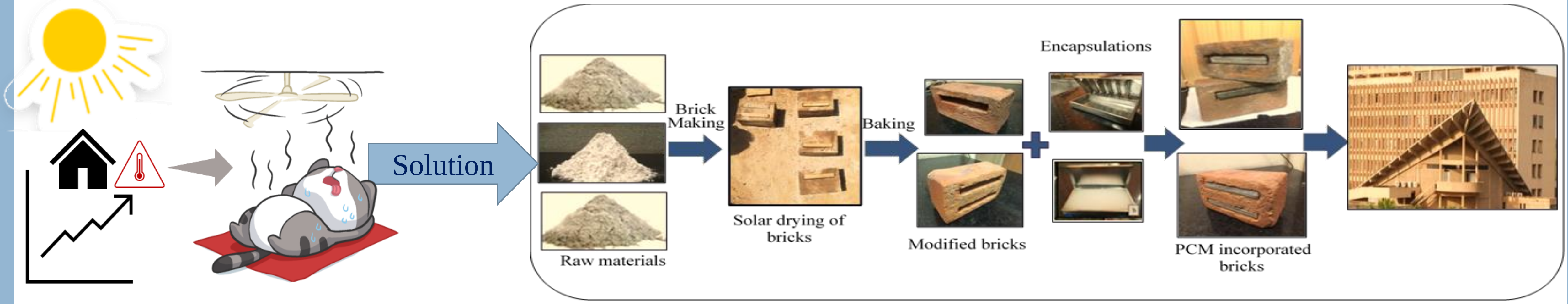


Performance Evaluation based on Thermal Modelling of PCM Embedded Walls/ Roof

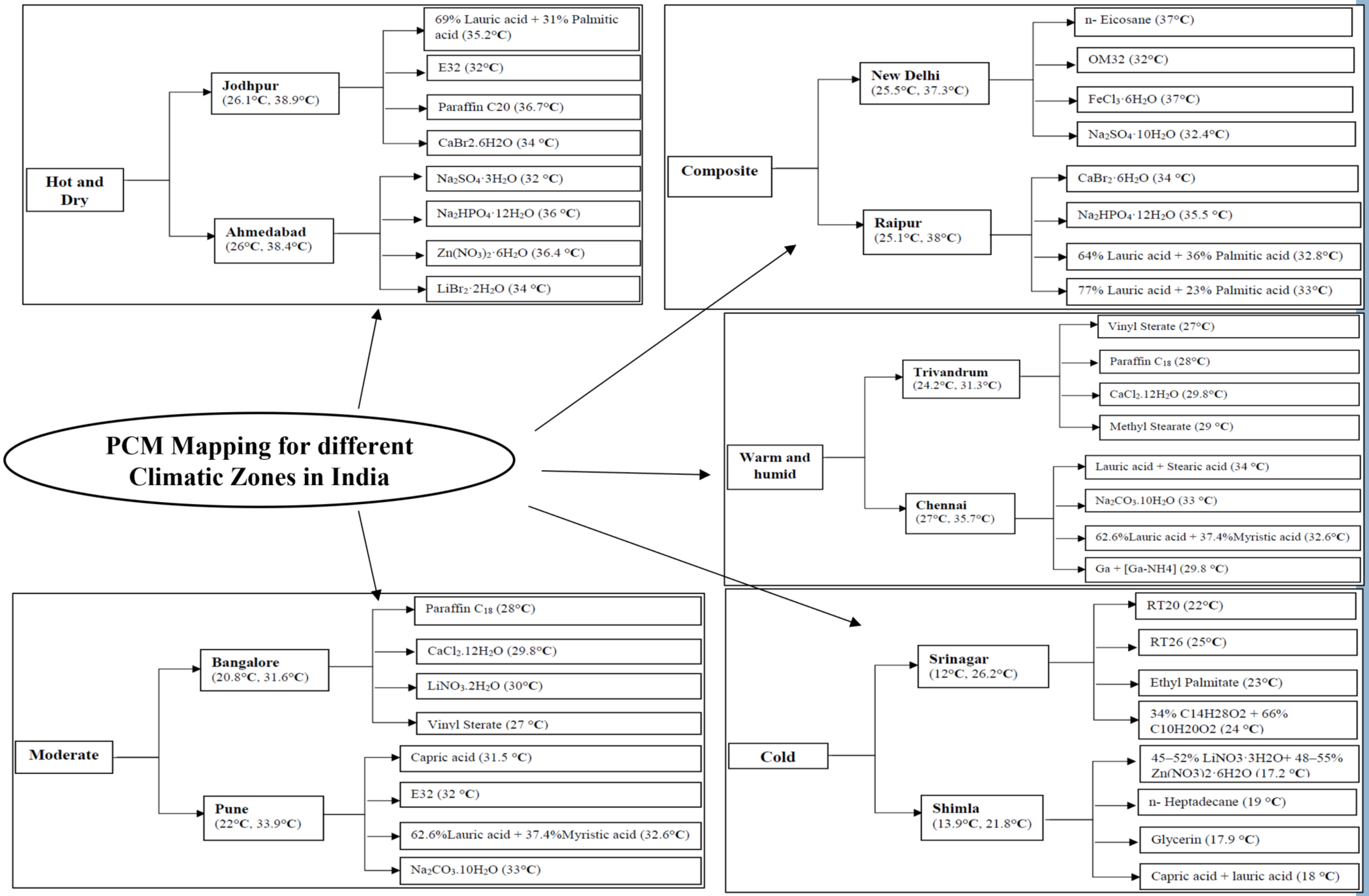
- Aimed to target *temperate climate zones in India* (where temperatures in summer > 35ºC)

People living in villages with no electrical power → temperature within their houses increases substantially → ∴ aimed to ***reduce peak inside room temperatures,*** thereby ***increasing thermal comfort*** → ***energy savings*** in terms of cooling loads in summers for buildings and houses in urban areas → ***savings in terms of CO_2 emissions*** during generation

- Study gives a systematic procedure for analyzing a PCM and assessing its suitability for application in a particular climatic condition.
- New product development (PCM incorporated brick/block conforming to Indian Standards) will offer a feasible solution to reduce cooling energy demand of buildings and can be implemented in housing schemes of the government such as ***Pradhan Mantri Awas Yojna.***



Segregating PCMs based on their melting temperatures and assessing their suitability for different Indian climates => ***beneficial for implementing agencies and end users to identify and select the best possible option.***



Performance Evaluation based on Thermal Modelling of PCM Embedded Walls/Roof

<table>
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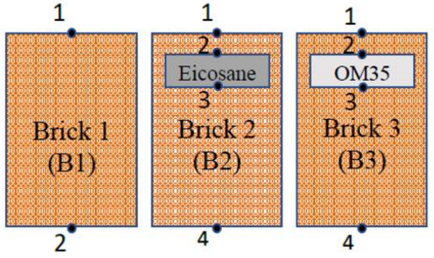
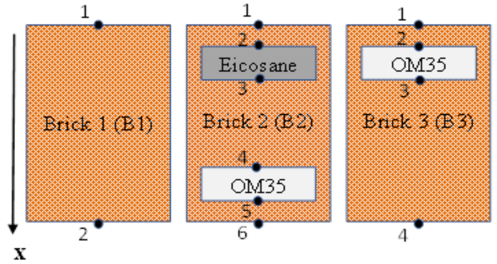
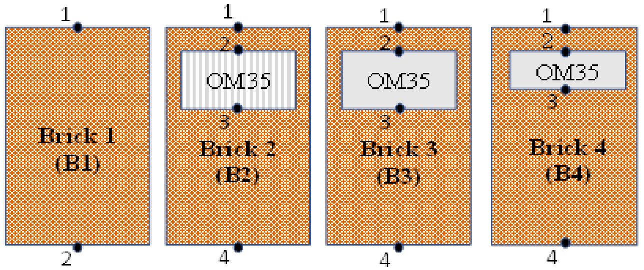
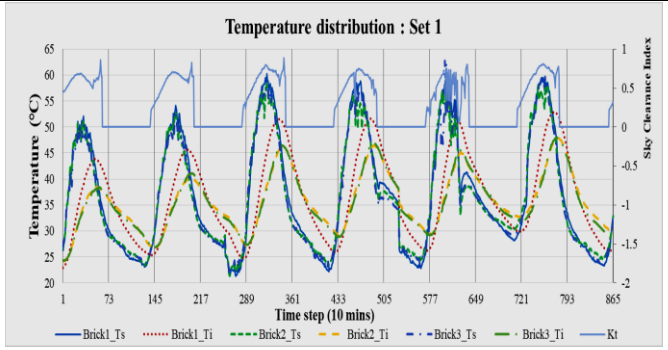
<tr><td>Configuration</td>
<td>

*R. Saxena, D. Rakshit, S. C. Kaushik, “Phase Change Material (PCM) incorporated bricks for energy conservation in composite climate: A sustainable building solution”, Elsevier Solar Energy, vol. 183, pp. 276–284, 2019. DOI: https://doi.org/10.1016/j.solener.2019.03.035.</td>
<td>

R. Saxena, D. Rakshit, S. C. Kaushik, “Experimental assessment of Phase Change Material (PCM) embedded bricks for passive conditioning in buildings”, Renewable Energy, vol. 149, pp. 587-599, 2020. DOI: https://doi.org/10.1016/j.renene.2019.12.081</td>
<td>

R. Saxena, D. Rakshit, S. C. Kaushik, “Experimental assessment of Phase Change Material (PCM) embedded bricks for passive conditioning in buildings”, Renewable Energy, vol. 149, pp. 587-599, 2020. DOI: https://doi.org/10.1016/j.renene.2019.12.081</td></tr>
<tr><td>Temperature Distribution</td>
<td>
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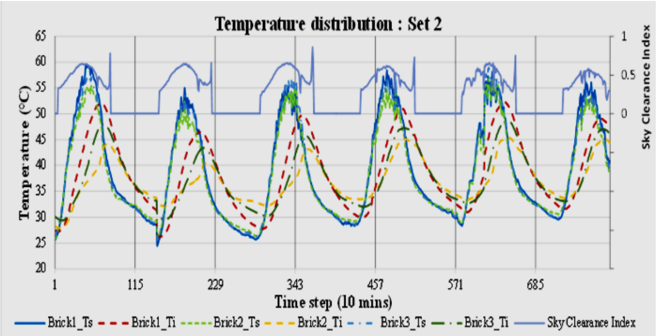
<td>
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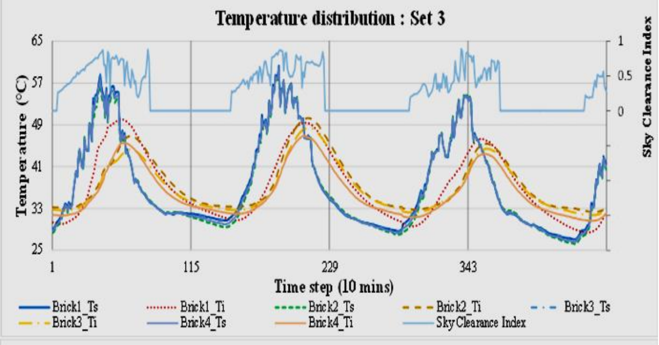
<td>
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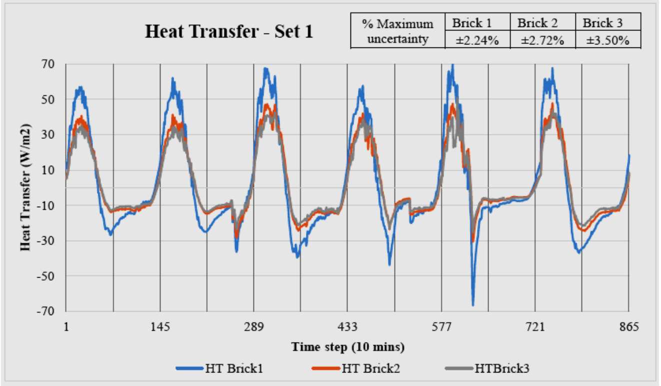
<td>
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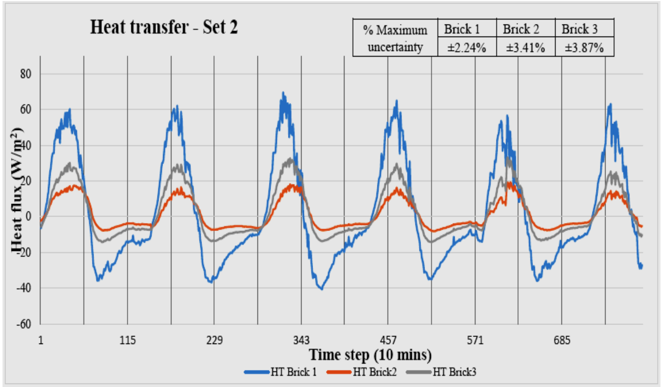
<td>
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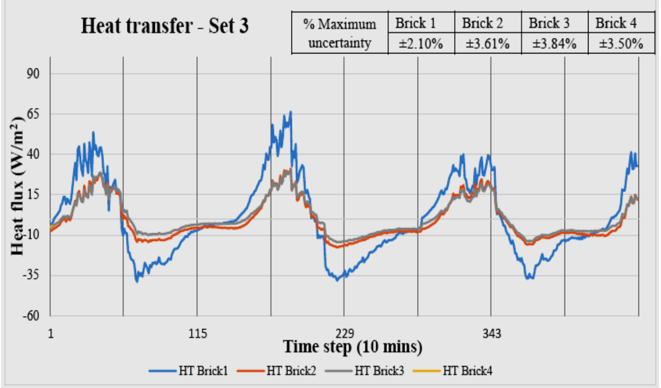
<td>
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Performance Evaluation based on Thermal Modelling of PCM Embedded Walls/ Roof

- ***PCM mapping necessary*** for their effective utilization.
- For Delhi, phase change temperature range of ***34 °C to 38 °C*** is optimum for summer (from thermal modelling results)* => ***Eicosane*** and ***OM35*** rendered suitable for application (both discharged during off sun-shine hours, ensuring effective utilization of these PCMs)**
- ***Reduction (up to 10°C) in temperature fluctuation*** with PCM incorporated bricks***
- ***Inside temperature reduction between 4.5 °C - 7 °C***, during peak hours of the day, compared to conventional bricks***
- The ***heat gain reduced by 8% and 12%*** with incorporation of Eicosane and OM35 for experiments carried out in third week of May 2018, compared to conventional bricks***
- A ***temperature reduction up to 9.5°C for dual PCM layer*** within the brick and a ***temperature reduction of 6°C*** is ***achieved for single layered PCM brick*******
- ***Heat gain reduction up to 70%*** is observed ***for dual PCM layer brick*** and ***around 50% for single layer PCM brick*** during the day. (This however is not the case during the night when PCMs are rejecting heat but as the temperature during the night is much lower thus, outside air may be used for the cooling purpose)****
- A ***PCM thickness from 1 cm to 1.3 cm*** have been tested experimentally and ***found suitable in achieving a peak temperature reduction by around 6 °C*******

*R. Saxena, K. Biplab, D. Rakshit, Quantitative Assessment of Phase Change Material Utilization for Building Cooling Load Abatement in Composite Climatic Condition, ASME J. Sol. Energy Eng. 140 (2017) 11001, https://doi.org/10.1115/1.4038047

**R. Saxena, N. Agarwal, D. Rakshit, S.C. Kaushik, Suitability assessment and experimental characterization of PCMs using DSC for thermal management of buildings in composite climate, ASME J. Sol. Energy Eng. 142 (2020) 011014, https://doi.org/10.1115/1.4044568

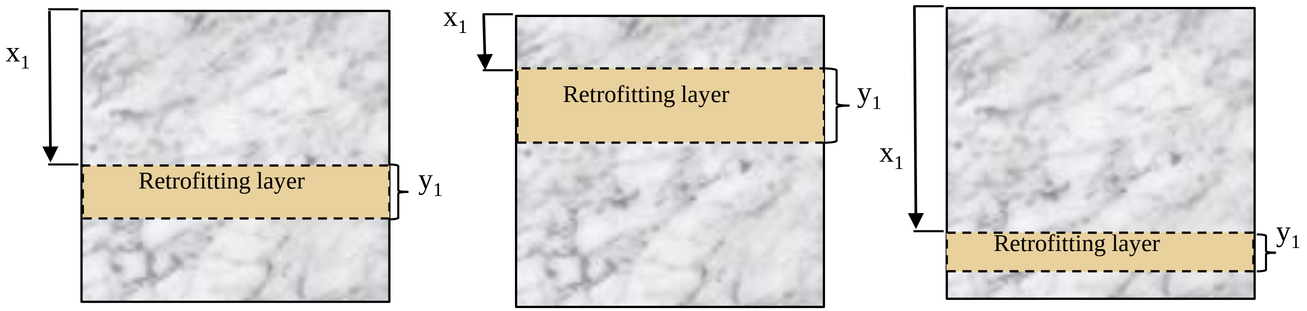
***R. Saxena, D. Rakshit, S. C. Kaushik, Phase Change Material (PCM) incorporated bricks for energy conservation in composite climate: A sustainable building solution, Elsevier Solar Energy 183 (2019) 276–284 https://doi.org/10.1016/j.solener.2019.03.035

****R. Saxena, D. Rakshit, S. C. Kaushik, "Experimental assessment of Phase Change Material (PCM) embedded bricks for passive conditioning in buildings", Renewable Energy, vol. 149, pp. 587-599, 2020.

Building envelope retrofit: the thickness-location conundrum

Present scenario:

- Optimization of envelope configuration: only comparison among a limited number of predefined configurations
- Thickness or position: only one parameter can be changed at a time



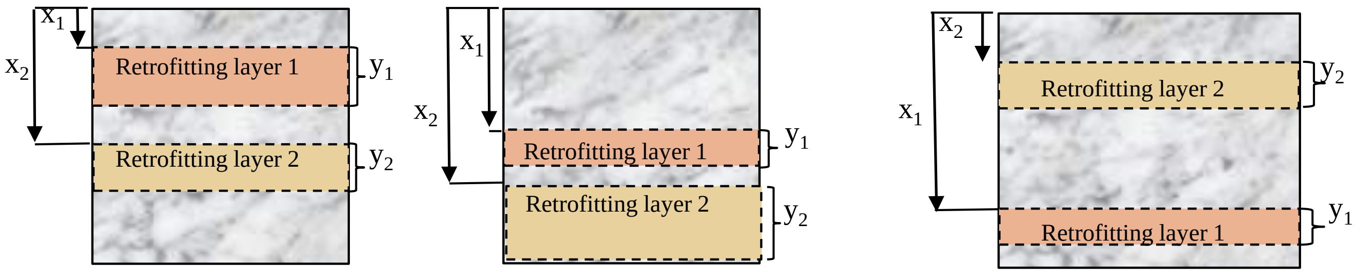
Different configurations of a roof section depending upon the location and thickness of single retrofitting layer

What more is required:

- All the possible variations of different members' thickness and location should be checked

(Climatic Zones)

- Thickness and position: simultaneous variation of both parameters



Different configurations of a roof section depending upon the location and thickness of two retrofitting layers

Solution: Genetic Algorithm

Pranaynil Saikia, Marmik Pancholi, Divyanshu Sood, Dibakar Rakshit, Dynamic optimization of multi-retrofit building envelope for enhanced energy performance with a case study in hot Indian climate, Energy, Vol. 197 (117263), 2020. doi: https://doi.org/10.1016/j.energy.2020.117263.

Genetic Algorithm for Building Envelope optimization

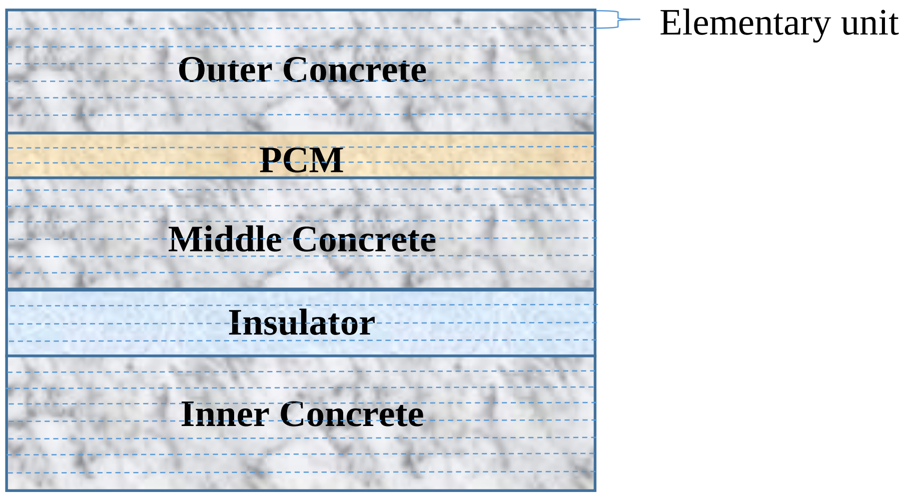
- Objective function:

$$\text{Minimize interior heat gain} = h_i(T_{\text{inner surface}} - T_{\text{interior}})dt$$

- $T_{\text{inner surface}}$ (concrete inner surface temperature) depends upon outside ambient temperature, incident solar radiation and the envelope material properties
- Constraint: Total thickness of wall or roof (0.25 m for wall, 0.1524 m for roof)
- Decision variables: Number of elementary units of different material layers

GA parameters:

- Population size: 50
- Number of generations: 60
- Crossover rate: 0.8
- Mutation probability: 0.1
- Chromosome length (for each parameter): 8



Composite envelope with retrofitting materials

Pranaynil Saikia, Marmik Pancholi, Divyanshu Sood, Dibakar Rakshit, Dynamic optimization of multi-retrofit building envelope for enhanced energy performance with a case study in hot Indian climate, Energy, Vol. 197 (117263), 2020. doi: https://doi.org/10.1016/j.energy.2020.117263.

Experimental Validation

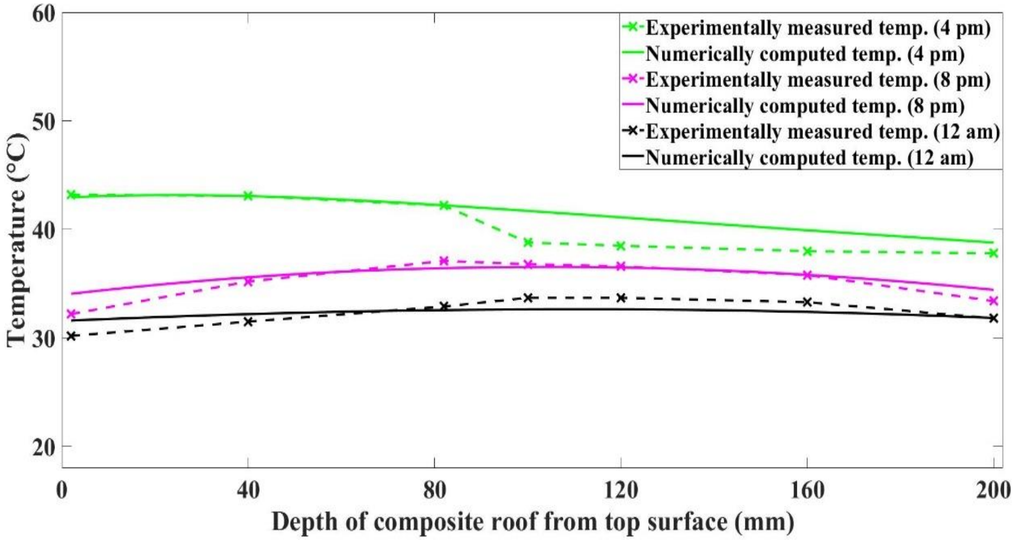
(a)

(b)

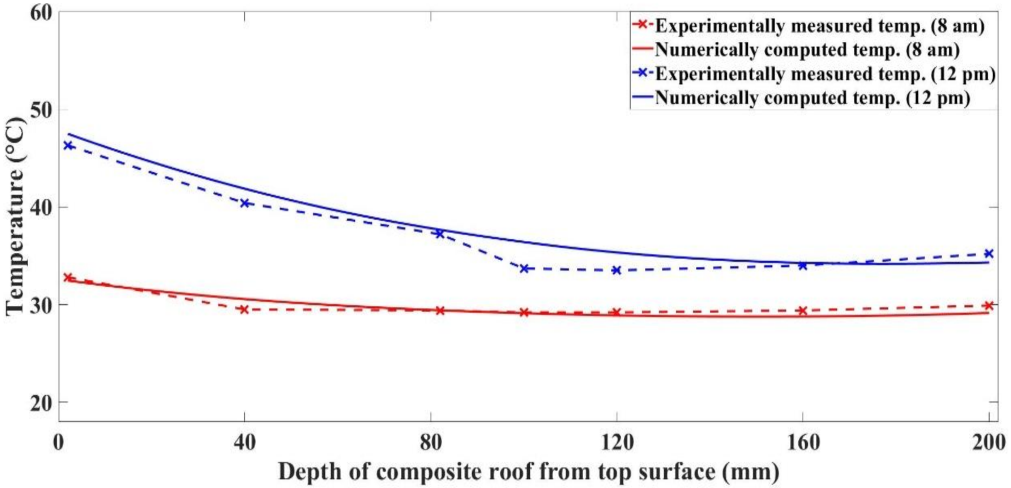
(a) Complete experimental setup

(b) Layers of concrete slabs with thermocouples inserted at the interfaces

(a)



(b)



(a),(b): Validation of numerical model with experimental data

Pranaynil Saikia, Marmik Pancholi, Divyanshu Sood, Dibakar Rakshit, Dynamic optimization of multi-retrofit building envelope for enhanced energy performance with a case study in hot Indian climate, Energy, Vol. 197 (117263), 2020. doi: https://doi.org/10.1016/j.energy.2020.117263.

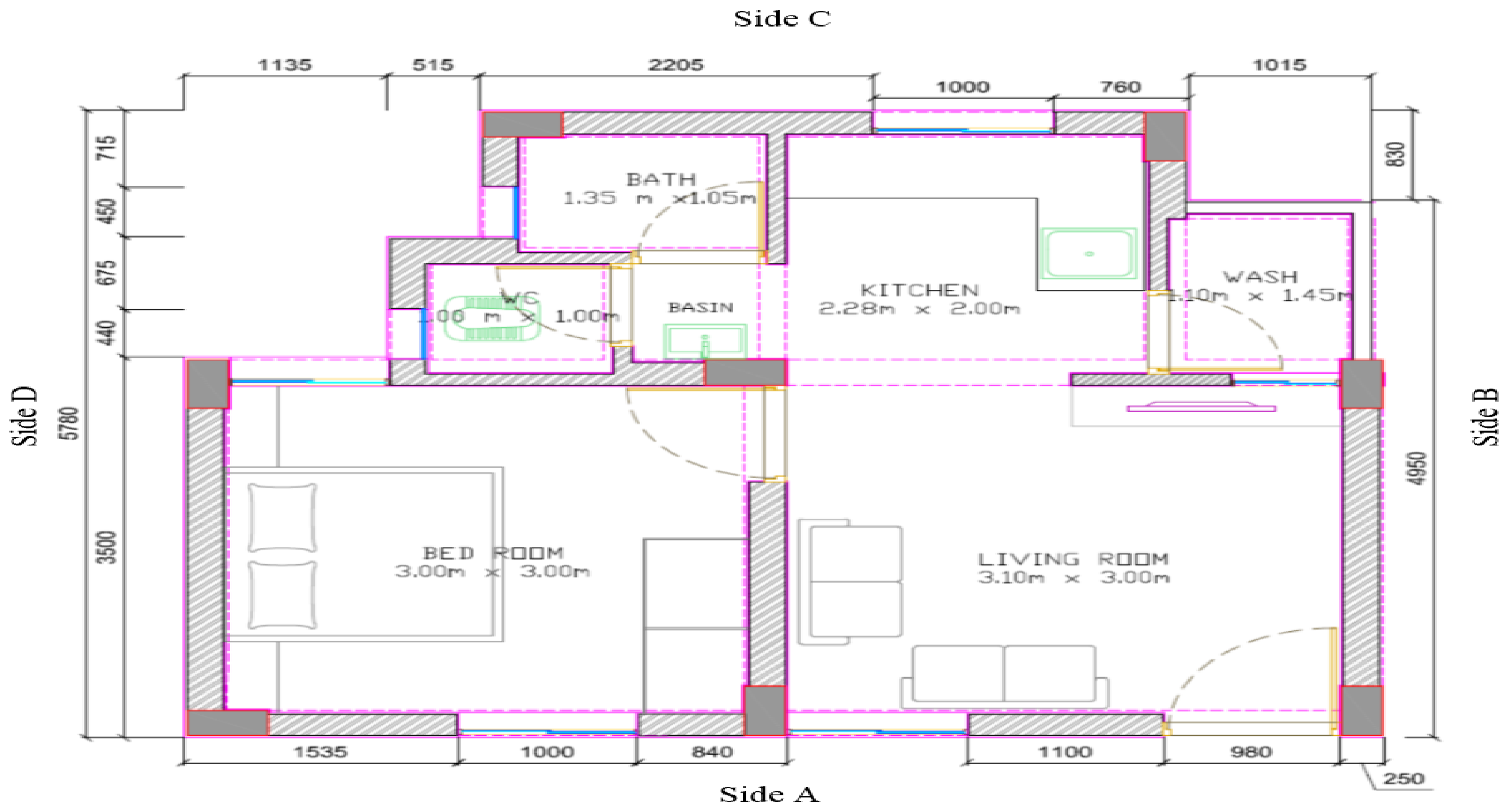
Outcomes of GA Powered Optimization

Table: Optimum configurations for CPCIC

CPCIC	Wall orientation	Outer Concrete thickness (m)	PCM thickness (m)	Middle concrete thickness (m)	Insulator thickness (m)	Inner concrete thickness (m)	Total thickness (m)	Heat gain (kJ/m^2-day)	Heat gain (kWh/m^2-day)	Decrement Factor
ZNH-Polystyrene	North	0.186	0.014	0.016	0.036	0.024	0.276	1542.4	0.4284	0.1678
	East	0.01	0.01	0.054	0.044	0.158	0.276	1687.6	0.4688	0.1783
	West	0.026	0.006	0.194	0.008	0.042	0.276	1664.3	0.4623	0.1299
	South	0.102	0.014	0.038	0.016	0.106	0.276	1578.2	0.4384	0.1497
	Roof	0.036	0.006	0.062	0.024	0.04	0.168	2297	0.6381	0.3496
ZNH-PUF	North	0.076	0.008	0.028	0.036	0.128	0.276	1542.4	0.4284	0.1714
	East	0.01	0.01	0.128	0.048	0.078	0.274	1695.5	0.471	0.1684
	West	0.162	0.02	0.01	0.046	0.038	0.276	1745.3	0.4848	0.1157
	South	0.102	0.012	0.038	0.016	0.108	0.276	1578.2	0.4384	0.146
	Roof	0.034	0.006	0.042	0.028	0.058	0.168	2299.8	0.6388	0.3271
CCH-PUF	North	0.108	0.01	0.034	0.016	0.106	0.274	1392.9	0.3869	0.1
	East	0.108	0.01	0.028	0.022	0.106	0.274	1602.4	0.4451	0.1418
	West	0.104	0.006	0.03	0.032	0.106	0.278	1580.2	0.4389	0.1206
	South	0.116	0.006	0.074	0.05	0.03	0.276	1409.2	0.3915	0.0799
	Roof	0.066	0.006	0.062	0.024	0.01	0.168	2259.6	0.6277	0.3253
CCH-Polystyrene	North	0.108	0.01	0.034	0.016	0.108	0.276	**1387.3**	0.3854	0.1027
	East	0.126	0.01	0.024	0.012	0.104	0.276	**1579.5**	0.4388	0.1254
	West	0.118	0.01	0.026	0.026	0.096	0.276	**1577.1**	0.4381	0.1156
	South	0.116	0.006	0.056	0.022	0.076	0.276	**1409**	0.3914	0.0871
	Roof	0.114	0.006	0.01	0.018	0.02	0.168	**2194.5**	0.6096	0.2374

Pranaynil Saikia, Marmik Pancholi, Divyanshu Sood, Dibakar Rakshit, Dynamic optimization of multi-retrofit building envelope for enhanced energy performance with a case study in hot Indian climate, Energy, Vol. 197 (117263), 2020. doi: https://doi.org/10.1016/j.energy.2020.117263.

Practical Implementation : Pradhan Mantri Awas Yojana (PMAY)

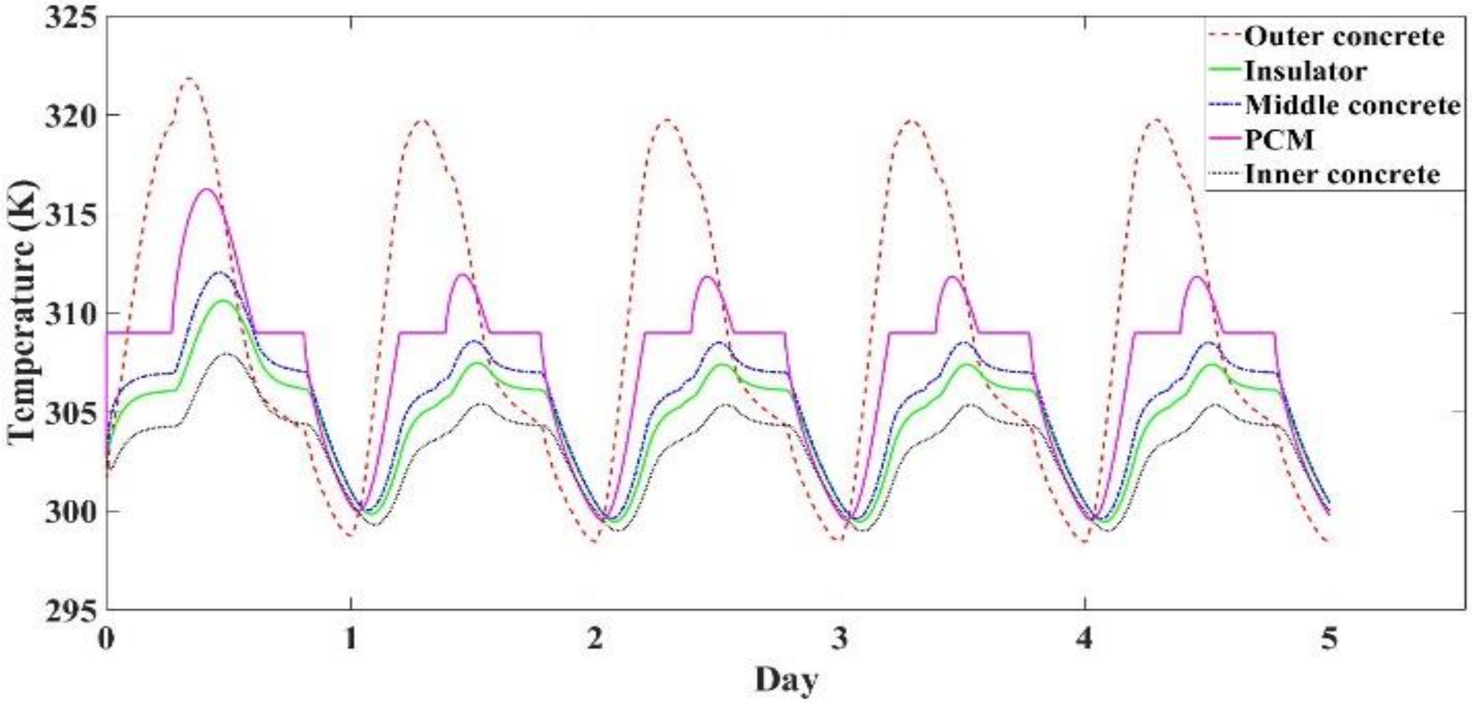


PMAY house schematic (Top view)

Pranaynil Saikia, Marmik Pancholi, Divyanshu Sood, Dibakar Rakshit, Dynamic optimization of multi-retrofit building envelope for enhanced energy performance with a case study in hot Indian climate, Energy, Vol. 197 (117263), 2020. doi: https://doi.org/10.1016/j.energy.2020.117263.

Key Insights for PMAY employing ECBC and Genetic Algorithm

- Heat gain for an optimized concrete envelope: 54.53 kWh/day
- Heat gain for a non-optimized concrete envelope: 82.00 kWh /day
- Heat gain reduction in a single PMAY house: 27.47 kWh/day (33.5%) or 9.2 kWh/day of electricity saving for an A/C with COP=3.



Sample temperature-time profile of envelope components (ZNH-Polystyrene CPCIC)

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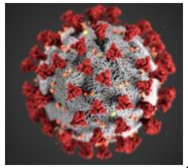
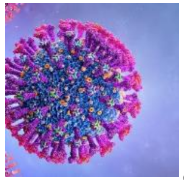
Global history of Pandemics





Pandemic:	Spanish Influenza	Asian Influenza	Hong Kong Influenza	SARS	Novel Influenza A	MERS	COVID-19	Delta wave, Omicron
	1918	**1957**	**1968**	**2002**	**2009**	**2012**	**2020**	**2021**
Death toll:	50 Million	1.1 Million	1 Million	774	151700 - 575400	866	5.2 Million	

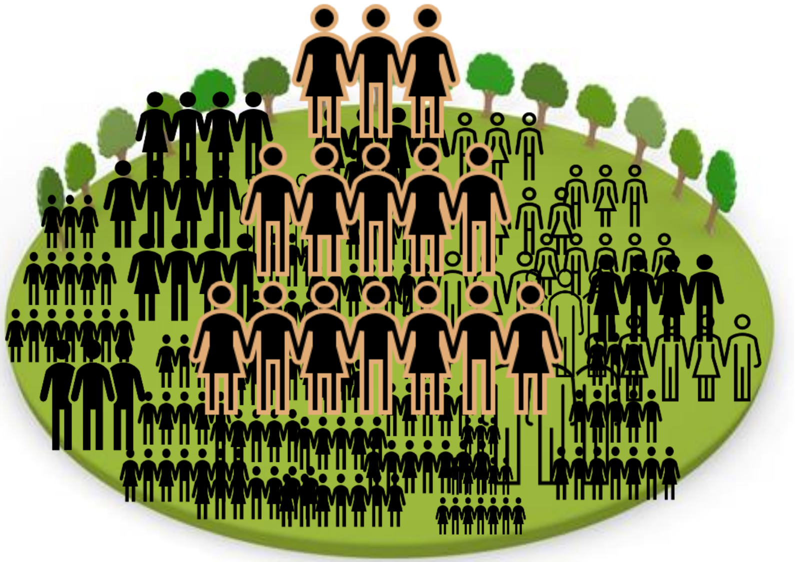
Source: Abdelrahman Z, Li M and Wang X (2020) Comparative Review of SARS-CoV-2, SARS-CoV, MERS-CoV, and Influenza A Respiratory Viruses. Front. Immunol. 11:552909.

Source: WHO Coronavirus (COVID-19) Dashboard, World Health Organization, accessed: December 2021, url: https://covid19.who.int/

Energy and Space Efficient Room

Current pandemic scenario:

- In present COVID-19 situation, 12 ACH fresh air supply recommended in buildings.
- To deal with any **unforeseen airborne pathogen** with unknown infectious particle size – controlling base airflow is the safest initial preventive action.
- Large population getting infected at the same time – requirement of additional safe space.
- Space requirements – need to accommodate a large number of infected patients
- Indoor thermal comfort – high energy requirements



Objectives of the study

1. **Maintain safe, healthy and comfortable indoor atmosphere within existing space constraint**
2. **Minimize HVAC power consumption through envelope retrofitting's (PCM and Insulation)**

ncbi.nlm.nih.gov/pmc/articles/PMC8438806/

NCBI Resources How To

PMC
US National Library of Medicine
National Institutes of Health

PMC

Advanced Journal list

COVID-19 Information

Public health information (CDC) | Research information (NIH) | SARS-CoV-2 data (NCBI) | Prevention and treatment ir

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Journal List › Elsevier Public Health Emergency Collection › PMC8438806

Elsevier Public Health Emergency Collection
Public Health Emergency COVID-19 Initiative

Journal of Building Engineering. 2021 Dec; 44: 103296. PMCID: PMC8438806
Published online 2021 Sep 14. doi: 10.1016/j.jobe.2021.103296

Energy performance and indoor airflow analysis of a healthcare ward designed with resource conservation objectives

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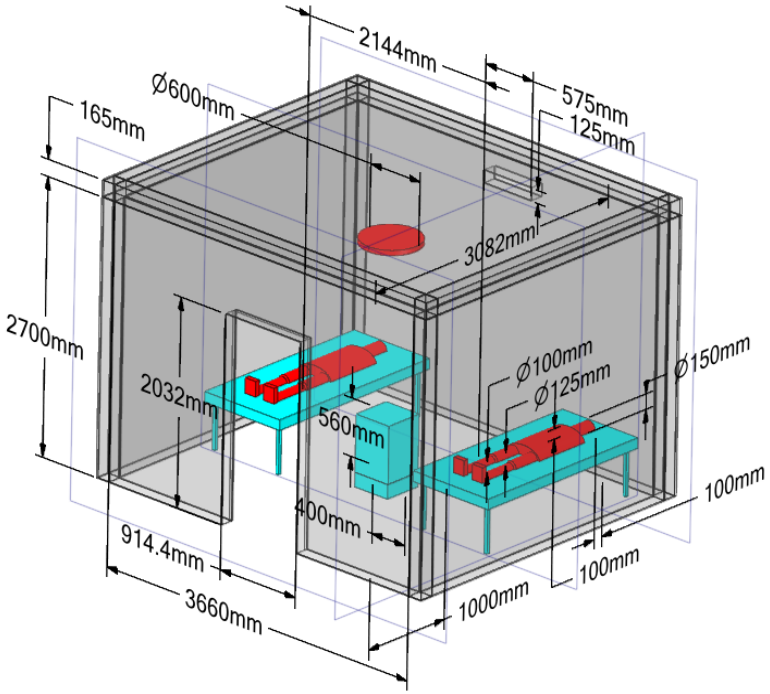
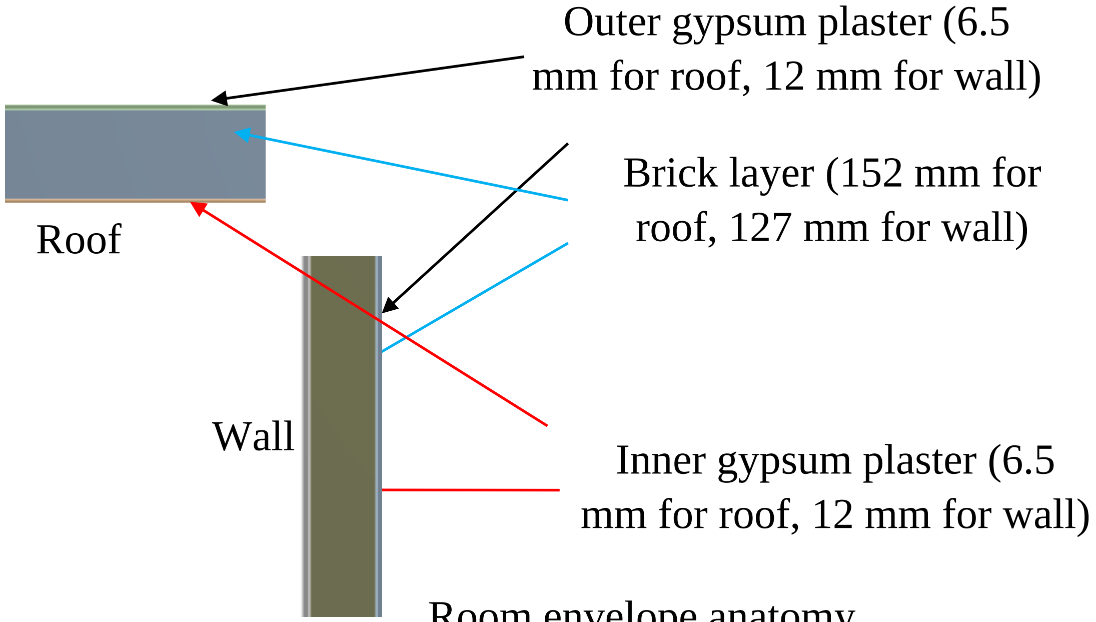
Elsevier Public Health Emergency Co

Ward schematic, material properties and envelope anatomy

Material	Solid phase density (kg/m^3)	Liquid phase density (kg/m^3)	Solid phase specific heat (J/kg-K)	Liquid phase specific heat (J/kg-K)	Solid phase thermal conductivity (W/m-K)	Liquid phase thermal conductivity (W/m-K)	Melting point (K)	Latent heat of fusion (kJ/kg)
Brick	1700	-	800	-	0.73	-	-	-
Gypsum	1300	-	1000	-	0.5	-	-	-
Zinc Nitrate Hexahydrate (ZNH)	1828	1828	1340	2260	0.464	0.464	309 ± 0.5	147
Polystyrene	23	-	1280	-	0.034	-	-	-
Wood (door)	700	-	2310	-	0.173	-	-	-



Proposed schematic



Room envelope anatomy

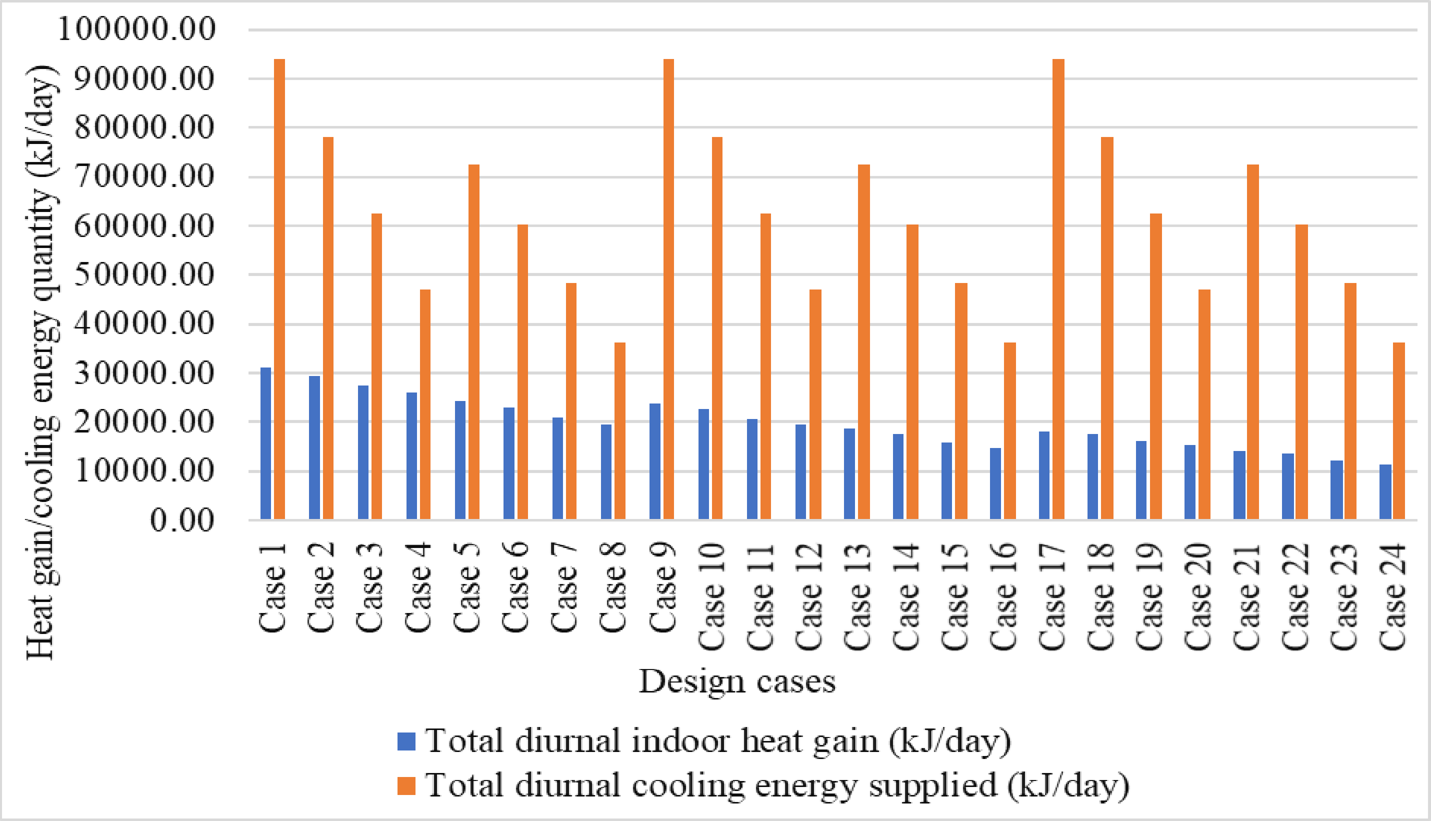
Test matrix for parametric analysis

Design Case no.	ACH	Inlet air temperature	Retrofit
1	**12**	24℃	None
2	10		
3	8		
4	6		
5	**12**	26℃	
6	10		
7	8		
8	6		
9	**12**	24℃	PCM
10	10		
11	8		
12	6		
13	**12**	26℃	
14	10		
15	8		
16	6		
17	**12**	24℃	Thermal insulation
18	10		
19	8		
20	6		
21	**12**	26℃	
22	10		
23	8		
24	6		

Cooling energy supplied and indoor heat gain

- $q = \dot{m}_a c_{pa}(T_{mean\ outdoor} - T_{inlet})$
- $Q_{total} = q \times \Delta t_{diurnal\ cycle}$

- High cooling energy supply – high indoor heat gain
- Higher ACH – larger value of h_{indoor} – more heat gain
- Colder interior – higher temperature gradient



Heat gain and cooling energy supplied for different design cases

Key Insights

- Results emphasize the use of thermal insulation as an effective envelope retrofit for the present requirements.
- For the final optimal case, use of lower ACH value (=8 ACH) than the maximum limit considered (=12 ACH) needs to be stressed upon.
- Stale air tends to accumulate near the central roof region for all the retrofitting options considered.
- High cooling energy supply (by high supply air ACH and/or low supply air temperature) to the room could lead to higher amount of indoor heat gain.
- With this design, a larger infected community can be catered to simultaneously. ***(Save life)***
- Less construction resources will be required for widescale infrastructure expansion. ***(Save Earth)***
- Less HVAC energy requirement to maintain safe and comfortable indoor atmosphere. ***(Save Energy)***

Overall Conclusions

- PCM mapping is necessary for their effective utilization.
- For buildings in composite climatic conditions, OM35 and Eicosane (99% pure, Alfa Aesar) were found suitable for utilization, using which, a reduction (up to 10°C) in temperature fluctuations with PCM incorporated bricks can be obtained, while heat gain reduction by 8% to 12% for experiments carried out in summers, as compared to the conventional bricks was observed.
- PCM Major share of cost is due to PCM. OM35 (INR 600/kg) is preferred during experiments over Eicosane as its cost is thirty times lower as compared to the Eicosane. Eicosane (99% pure, Alfa Aesar) costs around 2000 INR per 100 g, which is too high. OM35 (Pluss Polymer Pvt. Ltd.) turns out to be a much cheaper alternative with cost of 600 INR/kg.
- Other costs include cost of encapsulation. The PCM encapsulations made up of polyethylene can be a lucrative solution however, during the test runs it was found that leak which was a major issue in them. Polyethylene cannot sustain the abrasiveness of the brick surface and are susceptible to leakage.
- With the right combination of passive design techniques, significant improvements in thermal comfort conditions are possible (around 14% to 27%).

Overall Conclusions

- Spatial discretization of multi-retrofit building envelope coupled with Genetic Algorithm to optimize the number of elementary units of each constituent layer of a composite envelope could be an efficient way to realize the suitable size and location of each thermal retrofit to obtain maximum benefits in terms of indoor heat gain reduction.
- With an optimized design of building envelope, up to 33.5% of heat gain reduction and 9.2 kWh/day of electricity savings can be achieved in a single PMAY unit. The net energy saving by replicating the optimized design in lakhs of such units envisaged to be constructed can certainly be a big leap towards energy sustainability in the country.
- Thermal retrofitting in healthcare wards can lead to significant improvement in indoor heat gain reduction. Adequate thermal retrofitting can ensure indoor thermal comfort and health safety of occupants while helping to achieve energy and space efficient healthcare infrastructure to accommodate a large population with airborne infection.
- Daylight utilization using light pipe is an effective technique that can be employed for lighting energy reductions and enhanced indoor environment quality.
- A considerable difference can be observed in the equivalent wattages of the artificial lighting devices in both cases, wherein, more equivalent watts of the artificial lighting devices were obtained in the case of the modified light-pipe since it produced more illuminance in the room, as compared to the case of the conventional light-pipe.

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Thank You