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Evaluation of Indoor Thermal Behaviour and Energy Consumption with Roof Insulation

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Abstract-In this review, buildings are identified as the largest consumers of energy in all countries.in order to develop an energy-efficient building, insulation materials are essential. The right use of insulating material in buildings not only reduces the size of the air conditioning system requiredbut also lowers annual cost of energy. Furthermore, it helps to increase thermal comfort without the use of mechanical air conditioning, especially in summertime. Amount of energy savings achieved through thermal insulation depends on various parameter such as building type, local climate, and type of insulating material used.

Expanded polystyrene (EPS), Bamboo material are used as thermal insulation material on the roof. The main objective of this paper is to reduce the indoor air temperature by providing the thermal insulation in the building.

Keywords:Thermal Insulation, Energy Consumption, Thermal comfort, Expanded Polystyrene, Bamboo

1. Introduction

All nations are being touched by climate change, and population increase is causing a sharp rise in the amount of power needed for thermal comfort. According to estimates, the residential and construction industry consumed 36% of all energy in 2018, with global CO2 emissions responsible for 39% of that energy. It is widely recognized that the heat gain in buildings relies heavily on factors such as solar irradiance, heat exchange with the outdoor environment, and the geometry and orientation of the building. As a result, the inhabitants frequently use insulation to attain thermal comfort. In response, the scientific community is actively looking on insulation substitutes that can lower the thermal burden on buildings and cut down on the world's electricity use. Energy required to cool or heat a building is influenced by quality of thermal treatment applied to its envelope. Thermal qualities of the materials used in a building's structure, which govern their capacity to either absorb or emit solar heat, define thermal performance of a building's envelope.

Thermal insulation is a significant factor and crucial initial measure for attaining energy efficiency, particularly in envelope-load dominant buildings situated in sites with challenging climatic conditions. Insulators, referred to as thermal insulation materials, are utilized in commercial buildings to enhance the energy efficiency of the structures. They are also employed in industries to regulate the heat gain or loss in boilers and any other mechanical equipment.For a good insulation material, thermal conductivity should be very low. Several insulation alternatives are available to improve the indoor environmental building, such as rock wool, glass wool, polystyrene, polyurethane etc. In this research paper, we are going to basically focus on the two-insulation material, which are expanded polystyrene (EPS)and bamboo. Without a doubt, the roof is the most crucial component of the entire building surface. Therefore, we are installing insulation materials on the roof to mitigate the significant amount of solar radiation it receives, subsequently reducing the heat load within the building. During the summer, the horizontal roof receives the highest solar radiation and serves as the primary pathway for heat flux to enter the living space. By applying the insulation, the amount of heat flux is restricted, and indoor air temperature is improved.

1.1. Thermal insulation

"Thermal insulation is defined as a material or a combination of materials that, when properly installed, reduces the rate of heat transfer by limiting conduction, convection, and radiation. It effectively minimizes heat flow into or out of a building by offering high thermal resistance. In simple terms, insulating a building involves creating a protective layer that helps maintain indoor temperatures according to the desired comfort requirements.

1.2. Uses of Thermal Insulation

Thermal insulation plays a vital role for professionals in the construction sector. In the present era, the continuous rise in global warming has caused severe climatic changes, resulting in large temperature fluctuations, where some regions experience extreme cold while others endure intense heat. To cope with such conditions, several appliances such as air conditioners and space heaters are commonly used. However, these systems lead to increased electricity consumption and generate emissions that adversely affect the environment. Therefore, constructing thermally insulated buildings is a more sustainable solution than incurring high energy costs. The use of thermal insulation in buildings enhances indoor comfort while simultaneously mitigating the impacts of environmental changes.

1.3. Properties of Thermal Insulation

- Exhibits high resistance to elevated temperatures
- Shows excellent resistance to chemical degradation
- Maintains strong structural stability
- Provides effective resistance to heat transfer
- Demonstrates good moisture resistance
- Has a low capacity for heat absorption
- Characterized by low density and lightweight nature
- Odor-free, making it suitable for indoor use

1.4. Advantages of providing Thermal Insulation

- Minimizes the transfer of heat through various components of the building
- Lowers the energy demand for space heating and cooling
- Helps maintain a stable and uniform indoor temperature

- Leads to reduced energy consumption and lower utility bills
- Decreases fuel usage at power generation facilities
- Exhibits chemical inertness, ensuring material stability
- Contributes to the reduction of greenhouse gas emissions

1.5. Insulation Materials are considered for this Research

- Expanded polystyrene (EPS)
- Bamboo material

1.5.1. Expanded polystyrene (EPS)

Expanded polystyrene (EPS) is manufactured from small polystyrene beads derived from crude oil. These beads contain a blowing agent, such as pentane (C_6H_{12}), which causes them to expand when subjected to heat and water vapour. The resulting expanded beads bond together at their contact points to form a solid structure. EPS insulation is produced either continuously on a production line or moulded into rigid boards. The material possesses a porous structure that includes partially open pores. Generally, EPS exhibits a thermal conductivity in the range of 30–40 W/K.

Figure 1.1- Expanded Polystyrene foam (EPS)

It is important to note that the thermal conductivity of EPS varies depending on factors such as temperature, moisture content, and density. For example, when the moisture content increases from 0% to 10%, the thermal conductivity of EPS rises from approximately 36 W/K to 54 W/K. EPS products can be easily perforated, cut, and shaped on-site without significantly affecting their insulating performance.

Table 1.1- Thermal properties of EPS

Property	Value
Thermal Conductivity (W/m-k)	0.042
Thermal Resistance (m^2-K/W)	23.809

Density (Kg/m^3)	24

1.5.2 Bamboo insulation

Bamboo is a natural fiber known for its breathability, moisture-wicking capability, antibacterial properties, and resistance to ultraviolet radiation. These characteristics enable bamboo-based materials to function as thermo-regulating media, helping to maintain a cool environment during summer conditions. Owing to its ability to allow air circulation, bamboo feels cooler than cotton or many synthetic materials on hot days. Bamboo is a rapidly renewable resource with an exceptionally high growth rate and the ability to grow in diverse climatic conditions. Consequently, bamboo is considered a sustainable, cost-effective, and energy-efficient material.

Figure 1.2- Bamboo insulation

Table 1.2- Thermal properties of Bamboo

Property	**Value**
Thermal Conductivity (Watt/m-k)	0.55 to 0.59
Specific heat (KJ/kg-K)	1.7 to 1.8
Bending Strength (Kg/cm^2)	610 to 1600
Modulus of Elasticity ((Kg/cm^2)	1.5 to $2*10^5$
Ultimate Compressive Strength ((Kg/cm^2)	794 to 864
Specific Gravity	0.575 to 0.655

1.6. Research Gap

- A comparison between insulation materials such as Bamboo and EPS has not yet been reported.

- The energy consumption of these insulation materials has not yet been analyzed or reported.
- The performance of these insulation materials under the climatic conditions of Motihari(Bihar) has not yet been reported.

1.7. Research Objective

- To experimentally evaluate the room air temperature.
- To experimentally assess the relative humidity for different insulation materials.
- To compare and analyse the results obtained for the room, walls, and roof.
- To determine the energy consumption for various building insulation materials.

2. Literature Review

A thermal comfort level plays a crucial role in residential buildings. [In residential buildings, the level of thermal comfort plays a crucial role.] Numerous researchers have conducted studies to determine the comfort level in various locations and seasons. However, none of these researchers have specifically examined in Bihar state. They have utilized different insulation materials to estimate comfort level. In this chapter, a brief review of the roof insulation material is explained.

Tang et al. (2025) addressed the critical fire safety concerns associated with EPS external thermal insulation composite systems (ETICS). Their study evaluated expandable graphite (EG) as a flame-retardant modifier through multi-scale testing, ranging fromthermogravimetric analysis to large-scale LEPIR 2 façade fire tests. The results showed that EG functions primarily as a physical intumescent, effectively reducing heat transfer and peak temperatures during fire exposure. Although char layer detachment and oxidation above 540 °C limited long-term protection, EG-modified EPS façades exhibited peak temperatures approximately 470 °C lower than untreated systems in large-scale tests. The study also highlighted the effectiveness of small-scale bench tests as a reliable screening tool for fire-retardant performance prior to large-scale evaluation.

Ahmed et al. (2025) numerically demonstrated that integrating NEPCMs within a natural convection mechanism significantly enhances heat transfer and reduces the temperature of high heat-generating electronic elements.

Hu et al. (2025) proposed a hybrid passive cooling system combining radiative cooling with latent thermal energy storage, achieving improved cooling efficiency and strong resistance to thermal shock.Improving thermal insulation performance of external walls is essential for energy-efficient buildings, especially in severe cold regions. Conventional EPS-based insulation systems are widely used but often face issues such as thermal bridging, limited mechanical strength, and poor adaptability to assembled construction methods. Recent research has focused on enhancing insulation materials through advanced composites, with graphene emerging as a promising additive due to its high strength and low thermal conductivity.

Lin et al. (2025) developed an innovative graphene-modified EPS thermal insulation structural system for prefabricated buildings in cold regions of China. By integrating graphene into styrene polymerization and adopting modular manufacturing, the proposed system improved structural integrity and construction efficiency. Experimental results showed enhanced mechanical performance, reduced thermal conductivity (≤0.032 W/(m·K)), and a low wall heat transfer coefficient (0.164 $W/(m^2 \cdot K)$). The system achieved up to 75% energy savings, demonstrating its effectiveness for assembled building applications

Overall, these studies highlight that hybrid passive cooling strategies integrating latent heat storage with complementary mechanisms are effective for reliable and energy-efficient electronic thermal management

The increasing use of lithium-ion batteries (LIBs) has intensified the need for effective thermal management to ensure safety and optimal performance. Passive cooling techniques, particularly phase change materials (PCMs), are attractive due to their low energy consumption and structural simplicity. **Li et al. (2025)** demonstrated that a hybrid PCM–immersion cooling system, optimized using a coupled computational fluid dynamics (CFD) and artificial neural network (ANN) approach, can significantly reduce peak battery temperature and improve temperature uniformity. Their results highlight the effectiveness of integrating passive cooling materials with data-driven optimization methods for advanced battery thermal management systems.

Gökçe and Ömer (2025) evaluated the insulation performance of polyethylene (PE) and polyvinyl chloride (PVC) under different temperatures (22 °C and 55 °C) and currents (40 A and 60 A) using numerical simulations. The study showed that PE has higher current capacity at lower temperatures but suffers from increased Joule heating and energy loss, while PVC provides more stable insulation with lower energy dissipation. At higher temperatures and currents, PE experiences significant electrical and thermal stress, increasing the risk of overheating, whereas PVC maintains consistent performance. These findings highlight PVC's reliability under varied conditions and offer guidance for selecting optimal insulation materials in power distribution systems.

Binabid&Anteet, (2024) evaluated the use of vegetation at an elementary public school in Riyadh, Saudi Arabia, as a passive cooling technique. The Universal Thermal Climate Index (UTCI), mean radiant temperature (Tmrt), and air temperature (Ta) are used to study outdoor thermal comfort. Using an experimental design, eight scenarios are compared to a base model in this work. The scenarios represent various vegetation types (grass, bushes, two trees at two different heights, 5-10 m), as well as the distance between them (3.5 m and 7 m). The findings showed that Ta was lowered between (1.4-3.2)◦C, reaching a maximum reduction in August, Tmrt (7.13-64.73)◦C, where a maximum reduction was observed in October, and UTCI at (3.00-17.95)◦C in April when 10 m height trees with 3.5 m spacing between them were used

Improving the thermal performance of building envelopes through thermal insulation materials is essential for enhancing energy efficiency. **Pinchard et al. (2024)** investigated the long-term thermal conductivity and biological durability of thermal insulating mortars containing EPS, cork, and aerogel aggregates. Using accelerated ageing tests, the study showed that thermal conductivity increases over time, particularly in experimentally designed mortars, and that all materials are susceptible to biological colonization under high moisture conditions. These findings highlight the importance of long-term durability considerations when developing and applying advanced thermal insulating mortars for building refurbishment.

Complementing this structural-scale research, **Erünal (2024)** investigated the thermal insulation performance of foam-extruded black EPS produced using an underwater pelletizer process. By blending general-purpose polystyrene and expandable polystyrene with carbon black or graphite powder, the study evaluated thermal conductivity, density, and glass transition temperature. The results indicated improved compatibility and insulation performance when graphite powder was combined with general-purpose polystyrene. Although the achieved thermal conductivity (0.2997 W/m·K) was higher than graphene-based EPS systems, the study demonstrated that carbon-based fillers and alternative processing routes can enhance EPS insulation properties and provide industrially viable production methods.

Complementing this structural approach, **Javaid et al. (2024)** investigated rice straw waste boards focusing primarily on thermal insulation performance and material processing. Their work examined the effects of water and alkali pre-treatments on lignocellulosic straw combined with different polymer matrices (PE, PLA, and epoxy). Among these, epoxy-based composites exhibited superior interfacial bonding and uniform straw dispersion. Microstructural analyses (FTIR, XRD, EDS) confirmed that pre-treatment significantly modified straw morphology, leading to improved thermal performance. Using the guarded hot plate method, the minimum thermal conductivity achieved was approximately 0.023 W m^{-1} K^{-1}, comparable to conventional expanded polystyrene (EPS), indicating strong potential for RS boards as low-carbon insulation materials.

Pal &Netam (2023) evaluated thermal comfort all year in various climatic zones using an online as well as offline questionnaire. The questionnaire assessed how ventilation, moisture, and temperature affected thermal comfort. Over the course of the autumn, spring, and monsoon seasons, 2702 valid surveys were collected from respondents in various locations. The survey also showed that summertime discomfort is a problem for people in Chhattisgarh, with Raipur people reporting higher levels of discomfort as people in other regions.

The relationship between thermal conductivity values, moisture content, and density discovered through experimental inquiry was summarised by **Hung Anh & Pásztory, (2021)**. Depending on the material, the main variables significantly affecting thermal conductivity coefficient are temperature, moisture content & bulk density. Thermal performance is also affected by other elements like as thickness, airflow velocity, pressure, and age. Most of the time, the relationship between thermal conductivity and temperature is linearly rising. Both organic and inorganic materials' thermal conductivity is significantly influenced by their moisture content. key variable in determining thermal conductivity is bulk density, which exhibits opposite tendencies for conventional and organic materials, respectively, with a linear decline for conventional materials & a nonlinear variation.

Muhieldeen et al. (2020) developed a prototype of a wooden room and analyzed the temperature distribution inside and outside the room by using glass wool as roof insulation in different layers. As the insulation layer was increased throughout the experiment, the temperature within the room dropped. To assess how well each glass wool insulation thickness reduced the temperature within the wooden room model, different thicknesses of insulation were utilized.

Transversely sliced bamboo layers are used as a natural thermal insulator in a revolutionary roof slab insulation system that was introduced by **Chandra et al. (2019)**, aiming to minimize the negative environmental impacts associated with artificial insulation materials. The study determined that an optimal insulation layer thickness of 25 mm resulted in 53% reduction in heat within building.

In a case study conducted by **Saiefeddine (2019)**in China, the thermal performance of bamboo as a roofing material was investigated. The results indicated that bamboo exhibited favorable thermal properties. The room insulated with bamboo showed a 4℃ lower indoor temperature compared to the one without bamboo insulation, thereby providing a more comfortable humidity level. The comparative experiment conclusively demonstrated the excellent insulation capabilities of bamboo.

The intermittent heating operation for six typical insulating walls was examined by **Meng et al. (2018)** in their model. The findings demonstrate that the foamed concrete wall & inner insulation wall had the highest thermal response rates, making them best options for intermittent heating operation. On the other hand, self-insulating concrete walls and outside insulation are both comparatively bad options.

Singha & Borah (2017) have reported that bamboo possesses supplementary attributes like easy processability, exceptional strength, high elasticity, and resistance to abrasion. Consequently, due to its diverse properties, its rapid growth, adaptability of most climatic condition, bamboo emerges as a viable alternative as roof insulation material.

Perminder et al.(2016) has reported that Bamboo has become recognized as a contemporary engineering material, with recent research demonstrating its notable antibacterial properties.

Kulatunga, (2015)has reported about the development of sustainable roofing material. The roofing material primarily prioritizes safety, building aesthetics, lightweight design, durability, and minimal environmental impact. Roofing plays a crucial role in maintaining the thermal envelope, shielding the building from extreme temperatures. This research gives an idea of constructing bamboo roof covering by addressing the environmental and social benefits.

A thermal model for a structure with a vaulted ceiling and an earth-to-air heat exchanger was developed by **Chel & G.N. Tiwari, (2009)**. Brick & adobe vaults make up the building's structure. To arrive at the governing equation for the inside air, the equations for overall heat transmission to the building were deduced. The Runge-Kutta numerical approach was then used to resolve this equation. Calculating the building's potential for annual energy savings both before and after adding earth-to-air heat exchanger was another aspect of research.

3. Methodology

3.1 Process to perform the Experiment

The experimental setup and the schematic diagram of the roof insulation system are illustrated in Figures 3.1 to 3.2, while the locations of the sensors are shown in Figure 3.3. The construction details of the test room are provided in Table 3.2. To conduct the experiment, various instruments were employed, including a Testo-60 hygrometer and digital thermocouples. Two sensors were installed on the inner and outer surfaces of the roof. Similarly, two sensors were positioned on the inner and outer sides of the south-facing wall. The entire experiment was carried out during the second week of April 2025. Using this setup, data were recorded on an hourly basis for different insulation materials, as presented in Figure 3.2. The following assumptions were adopted for conducting the experiment in this study:

3.2. Parameter of Building material

Table 3.1 - Parameter of Building material of the Room. (Chel & G.N.Tiwari, 2009)

Parameter for Room	**Values**
h_o (W/m-k)	22.78
h_i (W/m-k)	6.13
Absorptivity (wooden door)	0.4
Absorptivity of wall and Roof surface (cement plaster)	0.55

3.3. Construction detail, thermal properties and Experimental setup of Room

To perform the experiment, 15.808 m^3 size of two concrete room have been taken for analysis. Thermal properties of roof, wall and door are listed in below table 3.3.

3.3.1. Construction Detail of Room-

Volume of Room: 2.6m x1.9m x3.2m

Table 3.2 - Construction details of Room

	Length (m)	Width (m)	Height (m)
Room	2.6	1.9	3.2
Wall	2.6	-	3.2
Roof	3.1	2.2	-
Door	1.3	-	0.7

3.3.2. Experimental Setup and Thermal Properties of Room

Figure 3.1– On Site images of Room with different insulation layer: (a) No insulation (b) Bamboo insulation (c) EPS

Table 3.3- Properties used for Normal Roof, Wall & Door

Layer		**Thermal Conductivity (Watt/m-k)**	**Specific heat (KJ/KG-k)**	**Density (Kg/m^3)**
Wall	Brick with fly ash 23 mm	0.64	0.661	1.24 X 10^3
	18 mm outer and 12 mm inner cement plaster	1.21	0.662	1.88 X 10^3
Roof	100 mm RCC			

	slab+1%steel	2.3	1	2.3 X 10^3
Door	700 mm x 300 mm wooden door	0.1 to 0.2	1.6 to 2.5	0.6-0.8 X 10^3

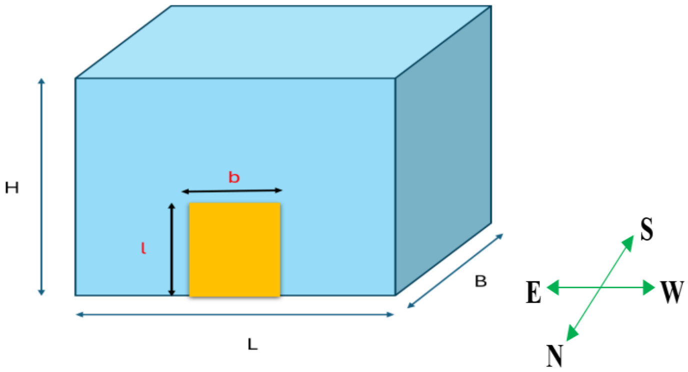


Figure 3.2-Schematic view of the experimental model

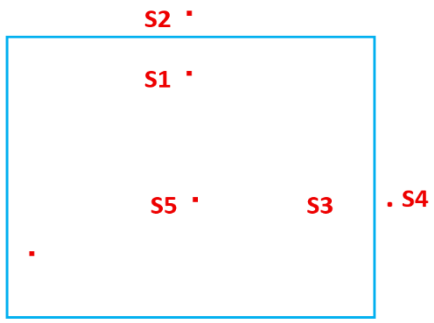


Figure 3.3- Location of the Sensors

Table 3.4 – Thickness of insulation

Thickness of insulation (in mm)	**Value**
Bamboo	10
EPS	45

3.4. Calculation of Cooling Load

The general energy balance for non air conditioned room can be written as below(Arora, 2009)

The total amount of Cooling load= $\sum Q_{nett\ ,room}$

$= Q_{gain} - Q_{loss}$ (1)

Q_{gain} =Net heat enters the room

Q_{loss} = Net heat loss from the room

To calculate the heat gain-

$$Q_{gain} = Q_{roof} + Q_{wall} + Q_{door} + Q_{window} + Q_{internal} \quad (2)$$

Heat gain through Roof is

$$Q_{roof} = (U_{roof}\, A_{roof})\,(ETD_{roof}) \qquad (3)$$

Heat gain through wall is

$$Q_{wall} = (U_{wall} A_{wall}) (ETD_{wall}) (4)$$

Heat gain through Door is

$$Q_{door} = (U_{door} A_{door}) (T_{sol,door} - T_r) (5)$$

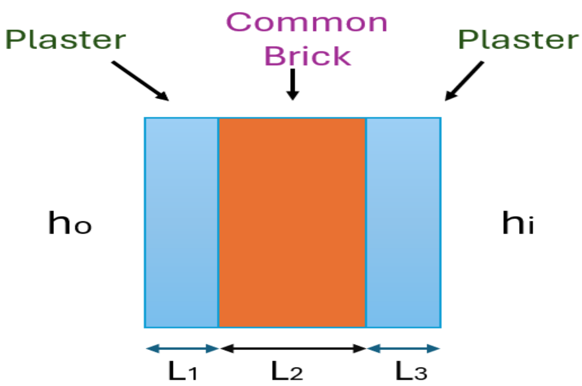
Heat gain through Window is

$$Q_{window} = A_{wind} * \tau * I_t + (U_{wind} A_{wind}) (T_{sol,wind} - T_r) (6)$$

Heat gain through Internal heat generator is

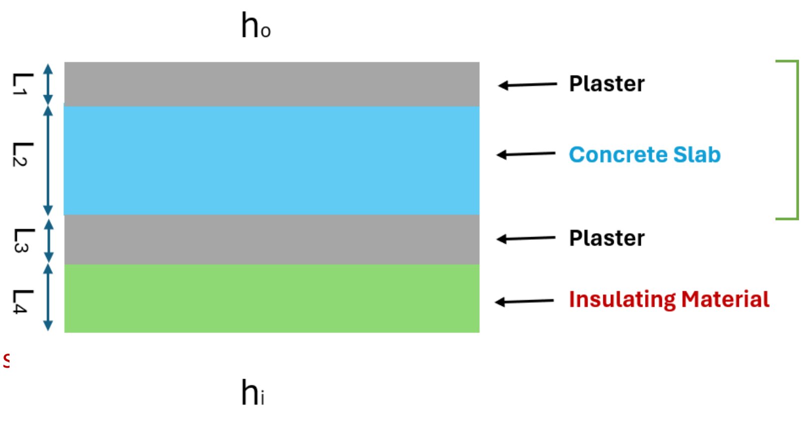
$$Q_{internal} = 0 \text{ (neglected)} (7)$$

In the above equation, overall heat transfer coefficient (U), Estimated temperature difference (ETD) for roof, wall and the sol-air temperature are calculated as below:



Overall heat transfer coefficient for wall(U_{wall})

Overall heat transfer coefficient for roof (U_{roof})



$$\frac{1}{U_{roof}} = \frac{1}{h_o} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{L_4}{K_4} + \frac{1}{h_i}$$

Now, Overall heat transfer for wall, door, roof and various insulating material are shown in below Table 3.5 to 3.8.

Estimated temperature difference (ETD) for roof and wall are:

$$ETD = (T_{sol,avg} - T_r) + \lambda\,(T_{sol,\phi} - T_{sol,avg}) \quad (8)$$

To calculate the heat loss:

$$Q_{loss} = Q_{ground} + Q_{ventilation} \quad (12)$$

Heat loss through ground is

$$Q_{ground} = 0 \text{ (neglected)} \quad (13)$$

Heat loss through Ventilation/Infilteration is

$$Q_{ventilation} = \rho_a V_a C_a (T_r - T_a).\ N \quad (14)$$

Substituting all these value in equation (1), we will be able to calculate the total amount of cooling load.

Overall Heat transfer for different insulation layer is shown below Table 3.5-3.11. By calculating Overall Heat transfer inside and outside heat transfer coefficient are also taken into consideration.

Table 3.5– Overall heat transfer coefficient for wall

S.No.	Material type	Thickness (m)	Conductivity (W/m-k)	R value (m^2-k/W)
1	Outer Plaster	0.018	1.21	0.0148
2	Brick wall	0.23	0.64	0.3593
3	Inner Plaster	0.012	1.21	0.00991
U value of wall			1.765 W/m^2-k	

Table 3.6– Overall heat transfer coefficient for Roof

S.No.	Material type	Thickness (m)	Conductivity (W/m-k)	R value (m^2-k/W)
1	Outer Plaster	0.018	1.21	0.0148
2	Concrete slab	0.1	2.3	0.0434

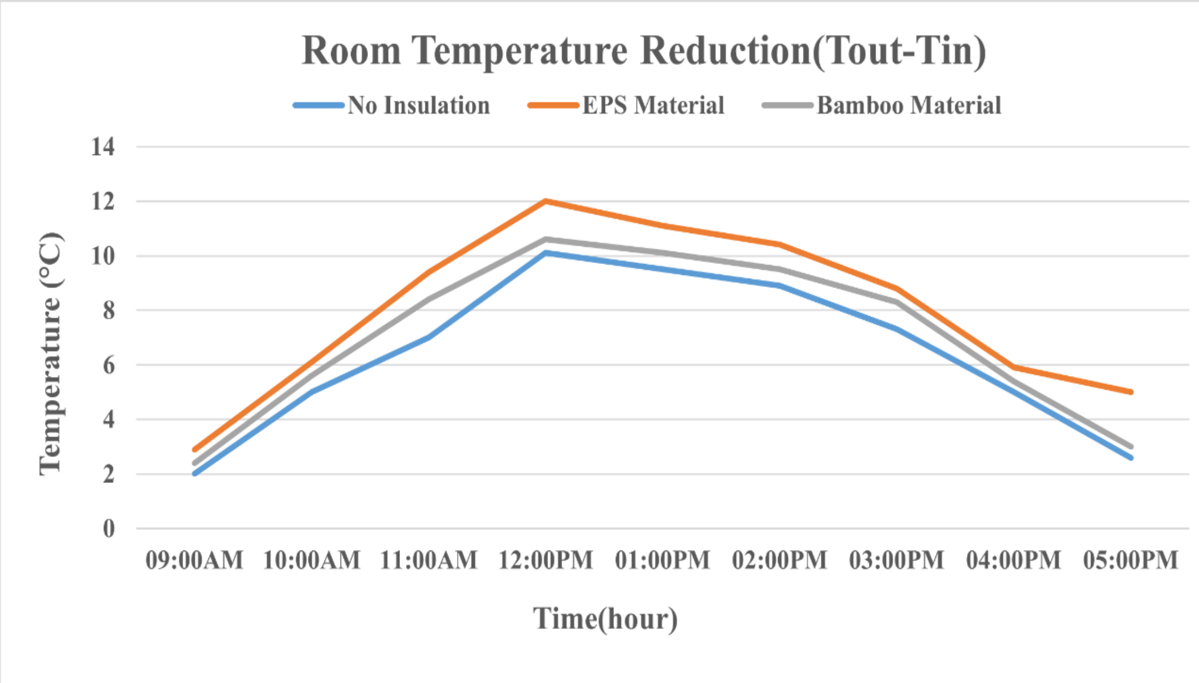
3	Inner Plaster	0.012	1.21	0.00991
U value of Roof			3.630 W/m^2-k	

Table3.7 – Overall heat transfer coefficient for Bamboo

S.No.	Material type	Thickness (m)	Conductivity (W/m-k)	R value (m^2-k/W)
1	Outer Plaster	0.018	1.21	0.0148
2	Concrete slab	0.1	2.3	0.0434
3	Inner Plaster	0.012	1.21	0.00991
4	Bamboo	0.01	0.58	0.0172
U value of Bamboo			3.416 W/m^2-k	

Table 3.8 – Overall heat transfer coefficient for EPS

S.No.	Material type	Thickness (m)	Conductivity (W/m-k)	R value (m^2-k/W)
1	Outer Plaster	0.018	1.21	0.0148
2	Concrete slab	0.1	2.3	0.0434
3	Inner Plaster	0.012	1.21	0.00991
4	EPS layer	0.045	0.042	0.933
U value of EPS insulation			0.742 W/m^2-k	



4. Result and Discussion

Figure 4.1- Comparison of Room temperature reduction for different insulation material

Figure 4.1 shows the variation in room temperature reduction with time. As time progresses, the reduction in indoor temperature increases and reaches its peak around 12 PM, after which it gradually decreases until 5 PM. Among all the cases studied, the maximum reduction in room temperature is observed with EPS insulation, while the minimum reduction occurs in the case of the bare roof without any insulation.).

Figure 4.2 shows the variation of temperature reduction in the south wall with respect to time. The graph indicates that as time increases, the temperature reduction also increases, reaching a maximum around 12 PM to 1 PM. Thereafter, the temperature reduction decreases for all insulation materials. Among the cases studied, EPS exhibits the highest temperature reduction on the south wall, while the bare roof condition shows the lowest reduction.

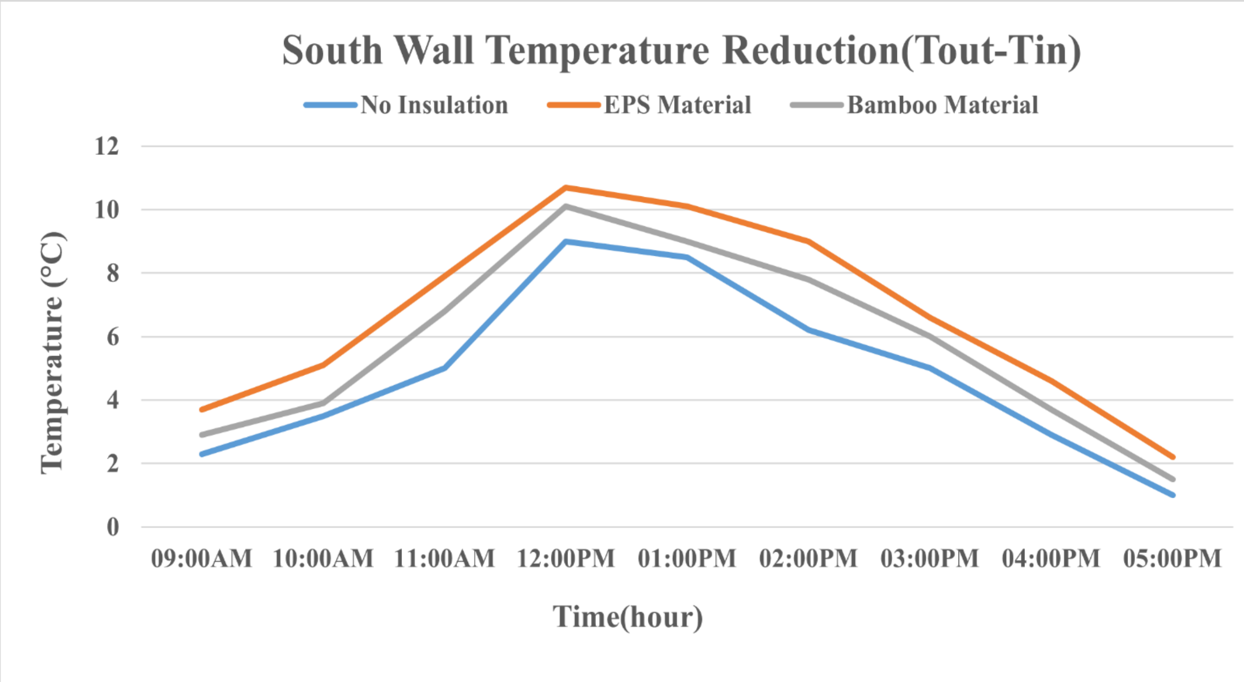


Figure 4.2- Comparison of temperature reduction in South wall for different insulation material

Figure 4.3 shows the variation of temperature reduction in the roof structure over time. From the graph, it is evident that the highest temperature reduction is achieved with EPS insulation, whereas the lowest temperature reduction occurs in the case of the bare roof without insulation

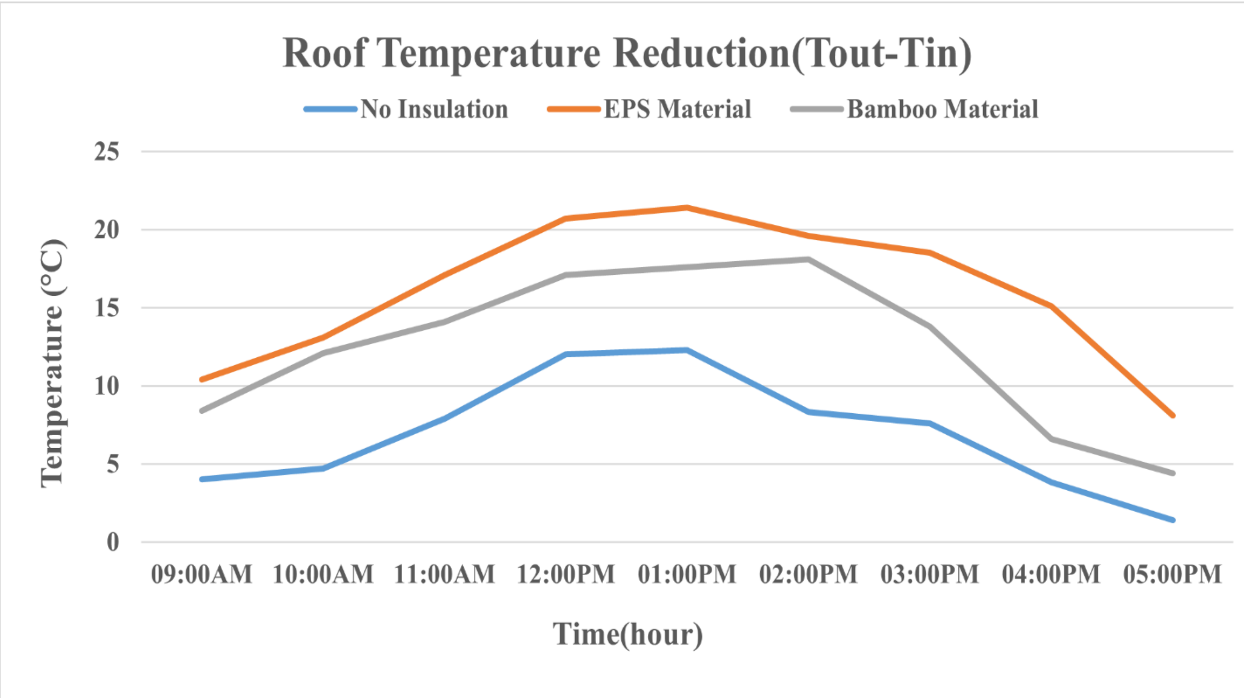


Figure 4.3- Comparison of temperature reduction in Roof structure for different insulation material

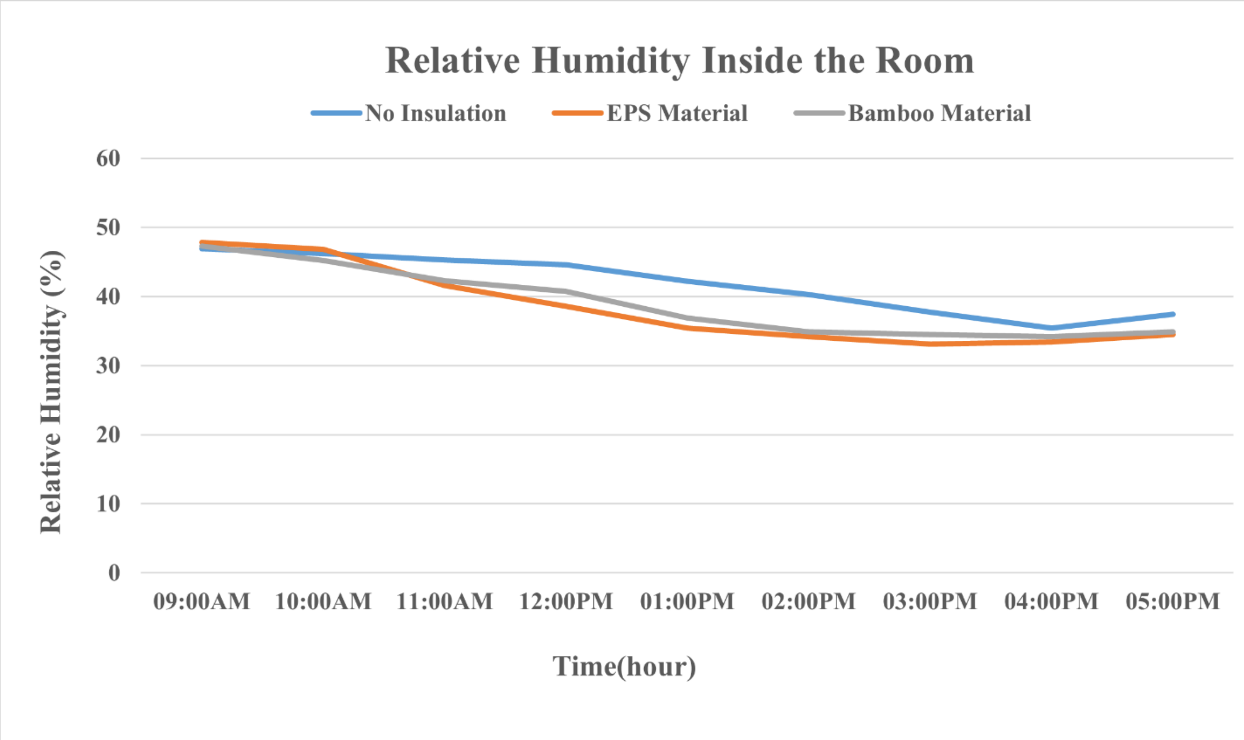


Figure 4.4- Comparison of Relative humidity for different insulation material

Figure 4.4 presents the variation of relative humidity inside the room with respect to time. A relative humidity range of 30–50% is generally considered optimal for human comfort. Based on the observed results, EPS insulation maintains the most favorable indoor humidity conditions compared to the other cases.

Figure 4.5 shows the variation of cooling load over time for different insulation materials. The lowest cooling load is observed in the case of EPS, whereas the bare roof exhibits the highest cooling load. Therefore, based on the cooling load analysis, EPS is identified as the most effective insulation material among all the cases studied.

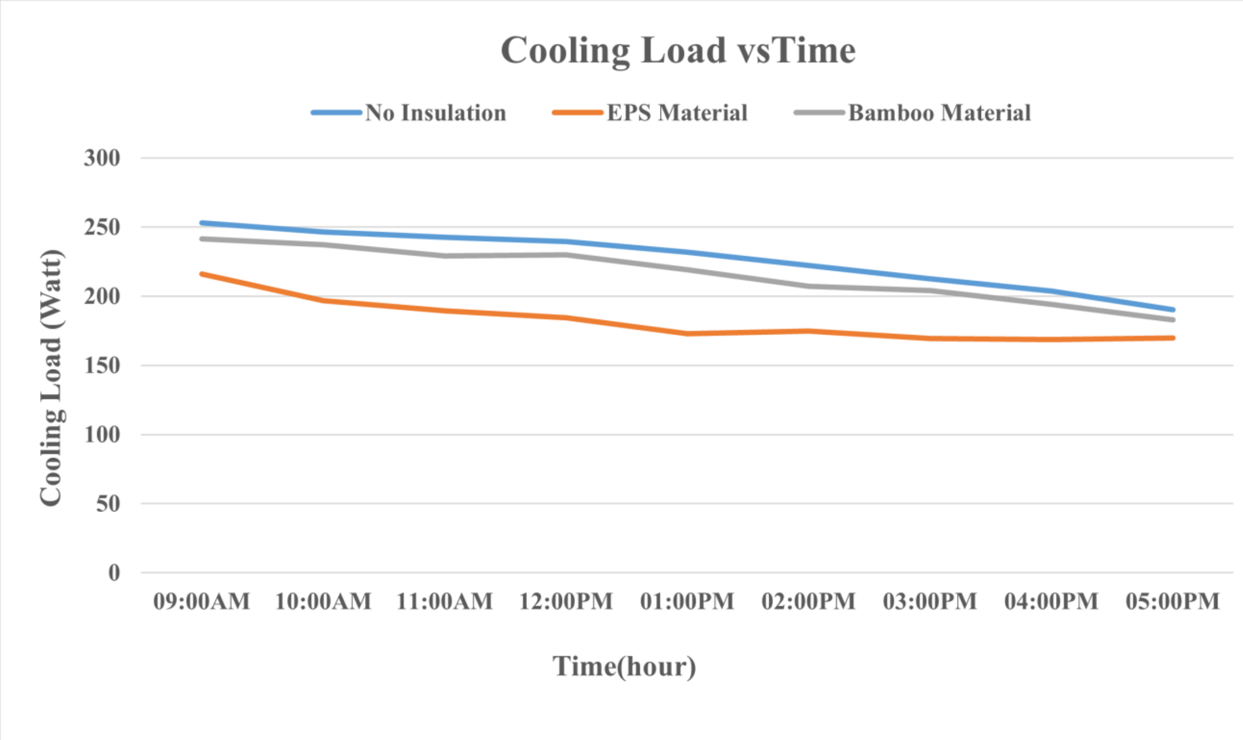


Figure 4.5- Comparison of Cooling load for different insulation material

5. Conclusions & Future Scope

5.1. Conclusions

The experimental study revealed that EPS provides superior insulation performance and results in the lowest energy consumption when compared with the other investigated cases. Based on the results obtained, the following conclusions can be expressed.

- The EPS configuration results in a greater reduction in temperature compared to the other cases, indicating that it maintains a cooler indoor environment, particularly during the summer season.
- For optimal thermal comfort, the relative humidity should lie within the range of 30% to 50%. In the present study, all insulation materials-maintained humidity levels within this acceptable range; however, EPS achieved the most favourable humidity conditions, thereby enhancing occupant comfort, supporting good health, and improving indoor air quality.
- Cooling load is a critical factor influencing the overall energy consumption of buildings. A lower cooling load leads to improved thermal comfort, which is why EPS is identified as the most effective insulating material among the evaluated cases.

5.2.Future Scope

The present study highlights the potential of expanded polystyrene (EPS) and bamboo-based materials as effective roof insulation systems for reducing indoor air temperature and improving thermal comfort in buildings. However, several research directions remain open for further investigation.

Future work may focus on long-term performance analysis of EPS and bamboo insulation under varying climatic conditions, including extreme summer and winter environments. The aging, durability, moisture absorption, and fire resistance characteristics of bamboo-based insulation, in particular, require deeper experimental and field-scale studies.

Further studies can also explore the hybrid use of natural and synthetic insulation materials, combining bamboo with EPS or other eco-friendly materials to enhance both thermal performance and sustainability. The integration of phase change materials (PCMs) with roof insulation systems may be investigated to improve thermal energy storage and reduce peak indoor temperatures.

Advanced numerical simulations and CFD-based thermal modelling can be employed to predict heat transfer behavior more accurately and optimize insulation thickness and placement. Additionally, life-cycle cost analysis and environmental impact assessment should be conducted to compare insulation materials in terms of embodied energy, carbon emissions, and economic feasibility.

Future research may also extend to real-scale building monitoring, incorporating smart sensors and IoT-based systems for continuous thermal performance evaluation. Finally, policy-oriented studies focusing on building energy codes and guidelines can help promote the adoption of cost-effective and sustainable insulation materials in residential and commercial buildings, particularly in hot and tropical regions

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