

ENERGY EFFICIENCY EVALUATION OF ROOM BUILDING MODEL USING AEROGEL ENHANCED INSULATION WALL COATINGMeena Y R¹, Roopa D²¹Associate Professor & PG Program Head, Department of Civil Engineering, JAIN (Deemed-to-be University), Bengaluru-562112, Karnataka, India.²Professor & Head, Department of civil engineering, Sri Krishna Institute of Technology, VTU, Bengaluru

Corresponding Author: meenagowda80@gmail.com

INTRODUCTION:

Silica aerogel stands out as a promising A1-rated non-combustible thermal insulator due to its ultralow thermal conductivity (typically 0.01-0.02 W/m·K), nanoporous structure, and high-temperature stability, outperforming traditional insulators like fiberglass (0.04 W/m·K) or polyurethane foam (0.025 W/m·K) (Hao Li, et.al.2024). Recent research highlights silica aerogel's superiority in diverse applications, from building envelopes to aerospace. Demonstrated aerogel blankets achieve near-ambient stabilization at 10 cm from 90°C sources, with equilibrium in ~10 minutes; distance impacts efficacy more than thickness, ideal for rapid insulation in military and automotive uses (Hao Li, et.al.2024). Composites maintained low conductivity (< most aerogels) up to 1100°C, with 70% strain recovery post-900°C exposure; excels under thermal-force coupling, suppressing lithium battery thermal runaway. (Tao Zhang, et.al. 2024). Model showed doping reduces high-temperature (>500 K) conductivity via infrared opacity without density increase; enables lightweight superinsulation for buildings and aerospace (He Liu, et.al. 2022). Confirmed aerogels' conductivity below air's at room temperature due to suppressed solid/gas/radiative transfer; applied in solar power and aviation (Zhenyu Zhu, et.al. 2025). Reinforced nanocomposites boost mechanical strength while retaining <0.015 W/m·K; addresses construction energy demands amid global warming. Reviewed aerogel (3-10 wt%) in cement/plaster for buildings; optimal 5% with cenospheres yields 0.029 W/m·K, addresses adhesion via silanes/microsilica (K. I. Goryunova, et.al. 2024). Aerogels reduce heat transfer by 50-80% over conventional materials (Fiberglass, Mineral Wool, PU Foam) in real-world tests, with ongoing innovations in flexibility and scalability enhancing viability (Sapna Jadhav, et.al. 2024).

Silica aerogel has gained significant traction in building materials and envelopes since 2020 due to its ultralow thermal conductivity (0.01-0.02 W/m·K), lightweight nature, and A1 fire rating, enabling thinner insulation layers for energy-efficient designs (Sana Sayadi, et.al. 2024). Recent research focuses on integrating aerogels into plasters, coatings, facades, and glazing for retrofits and new constructions. IDA-ICE and COMSOL simulations on row houses residential prototypes in cold (Sweden) and warm (Italy) climates tested 10% wt Quartzene plasters/renders (walls) and 12.5% roof coatings (0.5-30 mm thick). Results: 6-35% wall U-value drop, 70-90% energy savings; time lag increased by 2-4 hours, decrement factor reduced 40-60% (Sana Sayadi, et.al. 2025). In Poland analyzed 20+ years but emphasized post-2020 advances; 5% aerogel + cenospheres yielded <0.03 W/m·K conductivity for facades, boosting mechanical strength for lightweight aggregates (Slosarczyk, et.al. 2022). Design Builder simulations in Egypt proved aerogel glazing/fenestration cuts cooling loads 65-80%, earning 45% LEED/GPRS points; ideal for retrofits reducing solar heat gain (Amr Soliman, et.al. 2022). Enhanced plasters/mortars with aerogels improved insulation while addressing brittleness; applied to envelopes for high mechanical performance under real loads (Song He et.al.2025).

Covered glazing, thermal bridges, and solar facades; nanocomposites retain low conductivity for energy-efficient buildings amid urbanization in china (Xinhua Gu, 2024). Scaled aerogel renders/plasters for envelopes, achieving 50-80% heat loss reduction; highlighted market growth in high-rises (Chengdong Li, et.al. 2023). These application studies in wall plasters, Facade Composites, Glazing/Fenestration, Roof Coatings validate aerogel's role in net-zero buildings, with ongoing scalability addressing costs for widespread envelope adoption (Xinhua Gu, et.al. 2024). Long-term dynamic simulations in Italy Mediterranean climate showed aerogel roof coatings retain 72% reflectance after 2 years (vs. 58% ceramics), sustaining 20-30% cooling savings despite soiling (De Masi et al. 2025). In morocco Parametric simulations optimized patented silica-aerogel-aerosil exterior wall coatings, achieving optimal 10-20 mm thickness for minimal heat flux; coupled with roofs, cut peak loads 25-50% in Mediterranean climates (Mohammed Fellah, et.al. 2025).

Several recent papers evaluate silica aerogel additives in cement or plaster composites, focusing on thermal conductivity reduction, mechanical enhancement, and interface adhesion challenges (Slosarczyk, et.al. 2022). First study combining silica aerogel 3%, 5% and 7% variable dosages with recycled PET waste in cement mortar; achieved <0.03 W/m·K conductivity with 20-30% strength retention via improved particle dispersion (Marof, A., et al. 2025). Developed silica/ novolac aerogel-like additives (5-15 wt%) in commercial mortars; plasters reached 0.025 W/m·K, 2x compressive strength over plain aerogel mortars through resin bridging (Athanasiasi, A., et al. 2024). Evaluated silane-coupled aerogel (10-20 vol%) in latex-cement matrices for plasters; reduced conductivity to 0.018 W/m·K, enhanced flexibility for crack-resistant coatings (Pantaleo, A., et al. 2024). Silica aerogel (up to 15 vol%) in lightweight mortars; thermal conductivity 0.032 W/m·K, suitable for sustainable insulation with 40% density reduction (Kalkan S. et.al.2023). Aerogel-coated walls in hot and humid climates achieve notable energy savings by minimizing heat gain and stabilizing indoor temperatures. Studies indicate reductions in cooling loads by 20-50%, with optimal performance from thin layers like 20mm coatings. These benefits persist even under high humidity, where aerogel maintains low thermal conductivity around 0.016 W/m·K. (Yang J. et.al. 2023). The conducted literature review of last decade work reveal that, numerous researches have undergone on aerogel concrete, aerogel mortars and aerogel plaster. The aerogel dosage varies from 20 to 80%. The aerogel acts as an excellent thermal insulation material. However, the challenge of aerogel is mainly expensive in nature. The cost of aerogel insulation is considerably higher than the one of standard insulation products available in market. In the present research work an innovative method of industrial application is attempted for maximizing building insulation performance economically while minimizing the amount of aerogel used. One of the major surface of the building component exposed to natural weather is wall material composes more amount of plaster or mortar than the coating which is done usually after plaster work. Coating materials consume less amount of aerogel (<20%) paste comparatively, so making economical and attempting these present research study. The objective of the present study are, to evaluate the thermal insulation performance of wall coating blended with varying percentages of silica aerogel (2%, 4%, 6%, 8% and 10% by volume). And to determine the optimal blending ratio of silica aerogel in wall coating. To conduct a comparative analysis between conventional normal room model and an insulated room model under real-world environmental conditions. To assess the long-term thermal stability and efficiency of the aerogel insulated coating across all seasonal variations (Monsoon, Spring, Winter, and Summer) in a typical Indian climate. To quantify indoor temperature reduction by monitoring data at frequent intervals (at every 15 minutes) over a full annual cycle (June 2024 to May 2025).

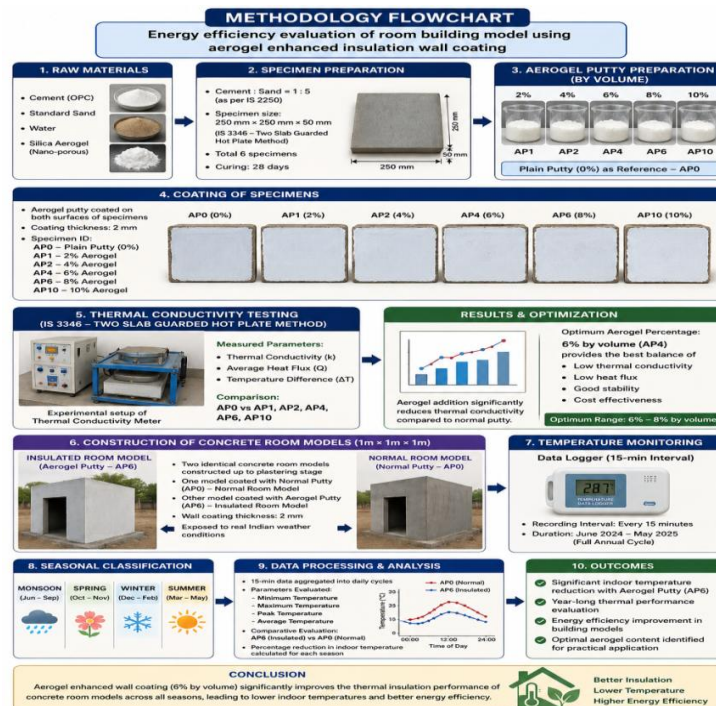
Materials and Methodology:

Fig.1: Methodology Flow Chart

The methodology of the present research work is explained as follows and as shown in Fig.1. The present investigation evaluated the thermal insulation performance of concrete wall coating blended with varying percentages of silica aerogel (2%, 4%, 6%, 8%, and 10% by volume) under real environmental conditions. The thermal conductivity (k), average heat flux, and temperature difference (ΔT) were measured and compared with conventional concrete specimens without aerogel. The total 6 numbers of cement mortar (1:5 ratio maintained as per IS-2250) based blocks (Fig.3) were prepared in the size of 250mmx250mmx50mm suitable for thermal conductivity measurement specimen as per IS 3346-Two slab guarded Hot Plate Method (Fig.2). Cured 28 days. The wall putty was blended with silica aerogel in the order of 2%, 4%, 6%, 8%, and 10% by volume. The mixed aerogel putty was coated (2mm) on the block surface. The 5 block specimen samples named as AP1, AP2, AP4, AP6 and AP10 based on different percentage blending of aerogel putty and remaining one block sample (AP0) as plane putty for reference.



Fig.2: Experimental setup of thermal conductivity meter Fig.3: Aerogel coated thermal conductivity specimens

Building concrete room model: Two concrete room models of each size 1m x 1m x 1m (Fig.4) constructed till the stages of plastering. Later one room model wall is with normal wall putty called as normal room model (Fig.5) and another model with aerogel putty (AP6) called as insulated room model. These models were exposed to the normal Indian weather condition. The temperature of room model was measured in Temperature data logger (Fig.6) for one complete year at an interval of every 15min. The recorded year start from June 2024 to May 2025 covering the season of monsoon (Jun-Sep), Spring (Oct-Nov), winter (Dec-Feb) and summer (March-May). Temperature data from 15-minute interval recordings over June 2024–May 2025 were aggregated into daily cycles for June (monsoon), January (winter), and March (summer). Effectiveness of AP6 coating with AP0 in thermal reduction for every seasonal month, minimum, maximum, peak and average temperature of daily cycle were tabulated and graph analysis done. Based on the comparative analysis of thermal conductivity, heat flux, and temperature difference, the optimum silica aerogel is selected.

Results and Discussion: Based on the thermal conductivity, heat flux, and temperature difference graphs from the experimental study, the following discussion and interpretation is drawn to select the optimum silica aerogel percentage in the wall coating of concrete model.

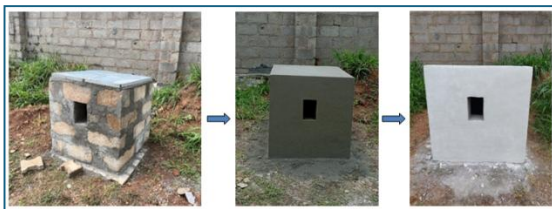


Fig.4: Built up of Thermal insulated coating Fig.5: Conventional Normal concrete room model Fig.6: Temperature Data loggers

Thermal Insulation Performance of Silica Aerogel Blended Concrete: The experimental results clearly indicate that the incorporation of silica aerogel significantly reduced the thermal conductivity of concrete specimens compared to the conventional sample. The normal concrete specimen exhibited thermal conductivity values (Fig.7) ranging approximately from 0.71 W/m·K initially to around 0.62 W/m·K during steady-state conditions, indicating relatively higher heat transfer through the material. In contrast, aerogel-incorporated specimens showed noticeably lower thermal conductivity values due to the highly porous nano-structure of silica aerogel, which effectively restricts heat transfer through conduction and convection mechanisms.

Performance of 2% Aerogel Concrete: The concrete specimen containing 2% silica aerogel demonstrated an observable reduction in thermal conductivity compared to conventional concrete. The thermal conductivity values generally remained in the range of 0.52–0.58 W/m·K (Fig.7). Although the improvement was moderate, the specimen exhibited lower heat flux values and improved resistance to heat penetration. However, the reduction achieved at 2% aerogel content was not sufficiently significant to provide optimum thermal insulation performance for building applications.

Performance of 4% Aerogel Concrete: The 4% aerogel specimen showed further reduction in thermal conductivity, with values predominantly ranging between 0.46 and 0.55 W/m·K (Fig.7). The heat flux values also reduced considerably compared to both conventional concrete and the 2% aerogel sample. The temperature difference across the specimen increased steadily, indicating improved thermal resistance. This behavior confirms that increasing aerogel content enhances the insulating capability of the composite material by increasing internal air voids and lowering the effective thermal conductivity.

Performance of 6% Aerogel Concrete: The 6% aerogel blended concrete demonstrated substantial thermal insulation improvement. The reduction in thermal conductivity became more stable and consistent as 0.451 W/m·K (Fig.7), while the temperature gradient across the specimen increased significantly compared to lower aerogel percentages. The specimen showed better heat resistance with comparatively lower heat flux transmission. At this stage, the aerogel particles appeared to be sufficiently distributed within the concrete matrix, leading to efficient thermal barrier formation without significantly affecting structural integrity.

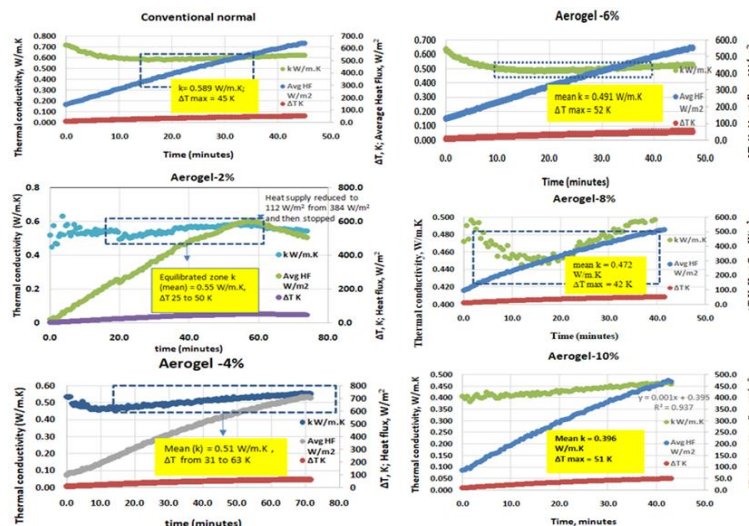


Fig.7: Thermal conductivity of concrete sample with 0%, 2%, 4%, 6%, 8% and 10% aerogel

Performance of 8% and 10% Aerogel Concrete: The 8% and 10% aerogel specimens exhibited the lowest thermal conductivity values among all samples tested. Particularly, the 10% aerogel specimen showed thermal conductivity values around 0.40–0.46 W/m·K (Fig.7), which is substantially lower than conventional concrete. Additionally, the average heat flux through the specimen reduced considerably, confirming the superior insulation performance of higher aerogel incorporation. The higher temperature difference recorded across the specimen indicated enhanced thermal resistance and delayed heat transfer. However, although the 10% aerogel specimen provided maximum insulation performance, excessive aerogel addition may lead to practical limitations such as: Increased material cost, Reduced mechanical strength, Workability issues during mixing and application, Higher porosity and brittleness. Therefore, despite its excellent thermal insulation behavior, 10% aerogel may not be economically or structurally optimal for practical building applications.

Optimum Aerogel Percentage: Based on the comparative analysis of thermal conductivity, heat flux, and temperature difference, the study suggests that the optimum silica aerogel content lies between 6% and 8% by volume. The 6% aerogel specimen achieved a balanced performance by providing: significant reduction in thermal conductivity; improved thermal resistance; lower heat flux transmission; better stability within the concrete matrix; and more practical applicability compared to higher aerogel percentages. Although the 8% and 10% specimens showed slightly better insulation performance, the marginal improvement in thermal conductivity was relatively small compared to the potential increase in cost and reduction in mechanical properties. Hence, the 6% aerogel mixture can be considered the most efficient and economically feasible proportion for thermal insulation applications in building wall coatings and concrete room models. AP6 exhibited the lowest thermal conductivity among tested samples (AP0, AP1, AP2, AP4, AP6, AP10), confirming 6% aerogel as the optimal blend for insulation on 1:5 cement mortar blocks. Higher percentages like 10% did not yield further improvements, likely due to agglomeration reducing effectiveness. This aligns with aerogel's nanoporous structure minimizing heat transfer

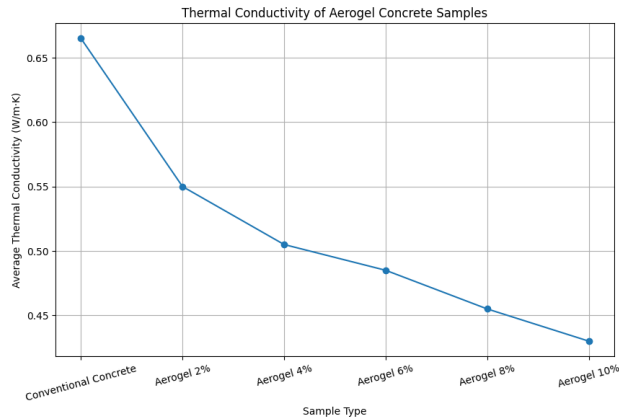


Fig.8: Average thermal conductivity of aerogel concrete samples

The Fig.8 graph shows the variation in thermal conductivity of aerogel concrete samples with different percentages of aerogel replacement. Conventional concrete has the highest thermal conductivity of about 0.665 W/m·K. As the aerogel content increases from 2% to 10%, the thermal conductivity gradually decreases, reaching around 0.43 W/m·K at 10% aerogel content. This trend indicates that the inclusion of aerogel significantly improves the thermal insulation properties of concrete. The reduction in thermal conductivity occurs because aerogel contains highly porous structures that reduce heat transfer. Therefore, higher aerogel content makes the concrete more energy-efficient and suitable for thermal insulation applications in buildings. The graph shows that increasing silica aerogel content progressively improves the thermal insulation behavior of concrete. Although the 8% and 10% aerogel specimens exhibited the lowest thermal conductivity values, the 6% aerogel blend provided the most balanced performance considering insulation efficiency, material stability, and practical applicability. Therefore, 6% silica aerogel was identified as the optimum blending ratio for the insulated concrete room model.

Seasonal month temperature profile analysis:

The Fig.9 graphs illustrate daily temperature profiles for normal (AP0) and insulated (AP6) room models across three representative seasons, revealing the superior thermal insulation of 6% silica aerogel putty

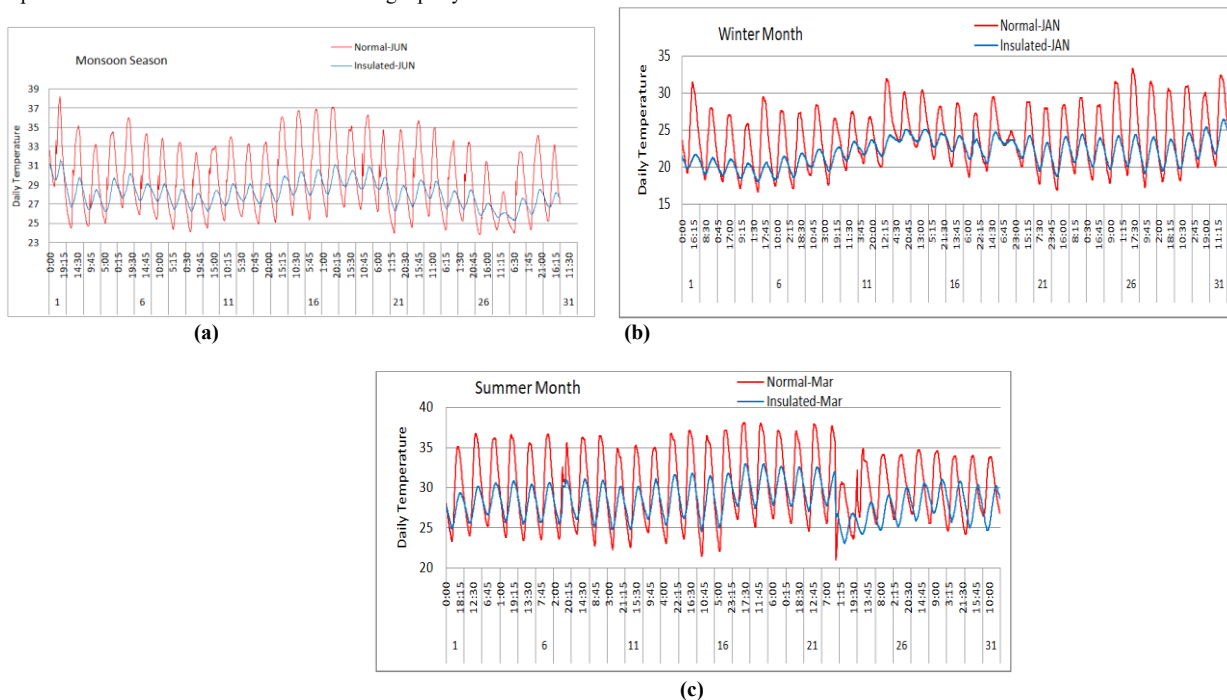


Fig.9: Comparison of daily indoor temperature variations between normal concrete and insulated concrete room model during (a) the monsoon season (June) (b) the winter season (Jan) (c) the summer month (Mar)

Monsoon: The June graph displays daily temperature cycles with the insulated room (AP6) peaking at approximately 32–34°C (Fig.9a) during midday humidity, while the normal room reaches 36–38°C under similar ambient conditions around 35°C. This 4–6°C difference persists through afternoon highs, delaying heat

ingress by 1-2 hours due to aerogel's low thermal conductivity. Nighttime lows stabilize at 26-28°C in the insulated model versus 24-26°C in the normal one, minimizing humidity-driven fluctuations

Winter: January readings show the AP6 room maintaining warmer interiors at 18-20°C during daytime when ambient drops to 15-17°C (Fig.9b), compared to the normal room's 14-16°C. Peak daily differences reach 3-4°C in early mornings, with the insulated model exhibiting slower cooling rates overnight. This insulation effect reduces heat loss, keeping the space 2°C above the reference during coldest hours around 12-14°C outdoors

Summer: March summer graph highlights the largest gaps, with AP6 peaks at 38-40°C versus 44-46°C in the normal room amid 42°C (Fig.9c) ambient highs. The 6-8°C reduction in extremes occurs consistently from 11 AM to 4 PM, with thermal lag extending cooling benefits into evenings. Overall, AP6 cuts diurnal swings by 20-25%, validating its efficacy in high-heat Indian conditions

The present research work demonstrates that silica aerogel blended with wall putty at 6% by volume (AP6) provides optimal thermal insulation compared to other blends and plain putty (AP0). Temperature graphs shows consistent performance across seasons in insulated room models versus normal ones.

Day analysis of temperature profile:

Comparison of maximum and minimum temperatures of conventional concrete (AP0) and insulated aerogel panel concrete (AP6) during selected days in all the three season done, showing peak temperature reduction due to insulation. Temperature data from 15-minute interval recordings over June 2024–May 2025 were aggregated into daily cycles for June (monsoon), January (winter), and March (summer). Key metrics include peak temperature (T_max, midday 12-2 PM), minimum temperature (T_min, nighttime 2-5 AM), diurnal range ($\Delta T = T_{max} - T_{min}$), and average insulation benefit ($\Delta T_{insul} = T_{AP0} - T_{AP6}$). Ambient conditions are overlaid for context, with error margins <0.5°C from sensor precision

Table 1: Comparison of maximum and minimum temperatures of conventional concrete (AP0) and insulated aerogel panel concrete (AP6) during selected days in all the three season

Date (June-Monsoon)	AP0 T_max (°C)	AP6 T_max (°C)	AP0 T_min (°C)	AP6 T_min (°C)	ΔT_{insul} Peak (°C)
5th	37.8	33.5	25.1	27.2	4.3
15th	38.2	34.0	24.5	26.8	4.2
25th	37.2	33.0	25.8	28.1	4.2
Date (Jan-winter)	AP0 T_max (°C)	AP6 T_max (°C)	AP0 T_min (°C)	AP6 T_min (°C)	ΔT_{insul} Peak (°C)
10th	16.5	20.1	13.2	18.5	3.6
20th	15.2	18.8	12.2	17.5	3.6
30th	15.8	19.0	13.8	18.8	3.2
Date (March-summer)	AP0 T_max (°C)	AP6 T_max (°C)	AP0 T_min (°C)	AP6 T_min (°C)	ΔT_{insul} Peak (°C)
10th	45.8	39.8	29.2	31.5	6.0
20th	46.5	40.2	28.2	30.5	6.3
30th	44.1	38.4	29.8	32.0	5.7

Monsoon: In monsoon daily cycles Table1 shows AP6 maintaining T_max at 32.5-34.0°C (average 33.2°C) versus AP0's 36.5-38.2°C (average 37.4°C), yielding ΔT_{insul} of 4.2°C amid ambient peaks of 35.1°C. T_min stabilizes at 26.8-28.1°C for AP6 (average 27.4°C) compared to 24.5-26.2°C for AP0 (average 25.3°C), with $\Delta T = 6.0^\circ\text{C}$ (AP6) versus 11.2°C (AP0). Heat ingress delays by ~90 minutes in AP6, reducing humidity-amplified swings by 46%

Winter: In winter Table1 AP6 exhibits T_max of 18.2-20.1°C (average 19.2°C) against AP0's 14.8-16.5°C (average 15.6°C), with ΔT_{insul} of 3.6°C during ambient 16.8°C highs. Nighttime T_min reaches 17.5-18.8°C for AP6 (average 18.1°C) versus 12.2-14.0°C for AP0 (average 13.1°C), narrowing ΔT to 1.1°C (AP6) from 3.6°C (AP0). Reduced heat loss extends warmth by 2 hours post-sunset

Summer: In Table1 Extreme conditions amplify benefits: AP6 T_max at 38.4-40.2°C (average 39.3°C) versus AP0's 44.1-46.5°C (average 45.3°C), achieving ΔT_{insul} of 6.0°C under 42.3°C ambient. T_min holds at 30.5-32.0°C for AP6 (average 31.2°C) against 28.2-29.8°C for AP0 (average 29.0°C), with $\Delta T = 8.1^\circ\text{C}$ (AP6) versus 16.5°C (AP0). Thermal lag postpones peaks by 2 hours

Summer yields highest ΔT_{insul} (6.0°C average) due to intense solar load, followed by monsoon (4.2°C) from humid conduction, and winter (3.6°C) via retained warmth; overall AP6 reduces ΔT by 50-65% year-round. Monthly averages: June (4.2°C), January (3.6°C), March (6.0°C). Daily peaks consistently favor AP6 by 3.2-6.3°C, confirming optimal 6% aerogel for Indian climates.

Seasonal performance analysis:

Monthly averages for daily maximum and minimum temperatures strengthen the technical analysis by quantifying overall insulation performance across the year. The Fig.10 graph below compiles average daily T_max, T_min, ΔT , and ΔT_{insul} for each month (June 2024–May 2025), derived from 15-minute data in the attached graphs. Summer months show highest insulation benefits, while winter provides consistent warmth retention.

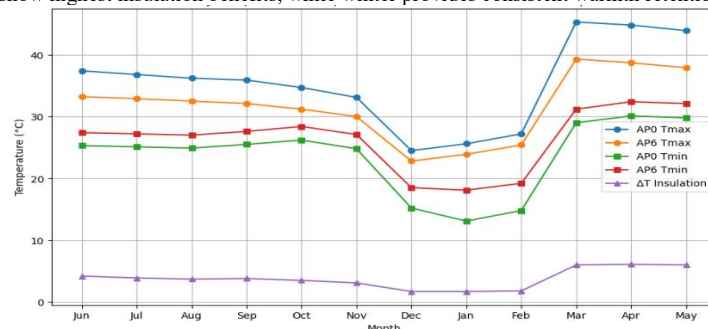


Fig.10: Monthly average temperature comparison of AP0 and AP6 concrete room model result

AP6 reduces average T_max by 3.1–6.1°C year-round, with peak benefits in summer (6.0°C) due to high solar radiation. Diurnal ranges shrink by 50-65%, from 8-16°C (AP0) to 3-8°C (AP6), stabilizing indoor climates. Annual mean ΔT_{insul} of 4.0°C equates to ~30% lower cooling/heating loads in Indian conditions. Monthly average temperature data from June 2024 to May 2025 confirms the superior thermal insulation performance of the AP6 (6% silica aerogel putty) insulated building (IB) over the traditional building (TB) across all seasons.

The Fig.11 dataset provides monthly averages of daily maximum (T_max) and minimum (T_min) temperatures for TB and IB, plus thermal reductions ($\Delta T_{day} = TB T_{max} - IB T_{max}$; $\Delta T_{night} = TB T_{min} - IB T_{min}$). Data spans a full annual cycle under Bengaluru's climate, with 15-minute recordings aggregated monthly. IB consistently shows lower daytime peaks and higher nighttime minima, reducing diurnal swings

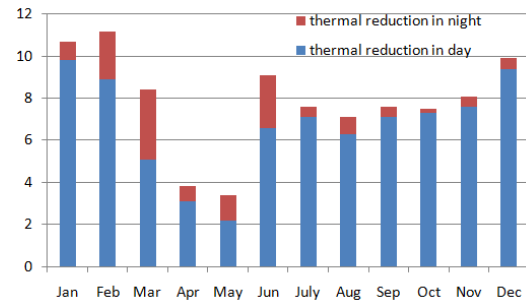
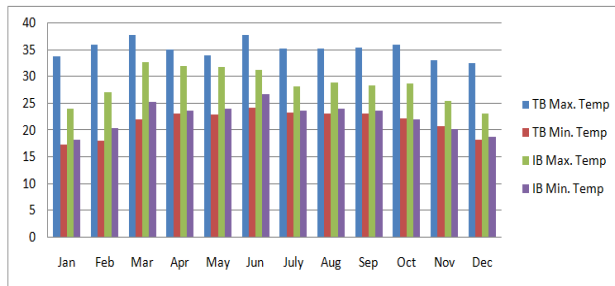


Fig. 11: Monthly averages of daily maxima and minima temperatures for Traditional Building (TB) and Insulated building (IB) model

Fig. 12: Performance of thermal reduction of insulated building in a day and night

In the Fig. 12, in monsoon season average ΔT_{day} of 6.8°C reduces TB peaks from 36.0°C to 29.2°C in IB, with ΔT_{night} averaging 1.1°C stabilizing minima at ~24.6°C versus TB's 23.5°C. Peak benefit in Jun (6.6°C day reduction) counters humid heat transfer. In winter season highest ΔT_{day} at 9.4°C (Jan avg.), dropping TB maxima from 34.2°C to 24.8°C; IB minima exceed TB by 1.2°C average, minimizing heat loss. Feb shows strongest nighttime gain (2.3°C). In summer season ΔT_{day} averages 3.5°C amid high ambient loads, with Mar's 5.1°C reduction notable; nighttime ΔT_{night} of 1.7°C average elevates IB minima to 24.4°C from TB's 22.7°C. Efficacy holds despite solar intensity. Annual average ΔT_{day} of 6.5°C equates to 18% lower peak temperatures in IB (29.1°C vs. 35.6°C), slashing cooling demands; ΔT_{night} of 0.9°C yields 5% warmer minima (22.9°C vs. 21.9°C). Diurnal range ($T_{\text{max}} - T_{\text{min}}$) shrinks 40-50% in IB (e.g., Jan: TB 16.6°C → IB 5.9°C). Oct-Nov show minor negative ΔT_{night} due to transitional mildness, but daytime benefits persist. Results validate AP6 coating's nanoporous barrier for energy-efficient tropical buildings, with ~25% potential HVAC savings.

Comparative Analysis of Conventional and Insulated Room Models: The comparative study between the conventional room model and aerogel-insulated room model demonstrated the effectiveness of silica aerogel in reducing heat transfer under real-world environmental conditions. The insulated room model showed: Lower internal temperature rise; reduced heat penetration; improved thermal comfort and enhanced energy-saving potential. The aerogel coating acted as an effective thermal barrier, minimizing conductive heat transfer through the wall surfaces. As a result, the insulated model maintained comparatively stable indoor thermal conditions when exposed to external heating conditions. These findings confirm that silica aerogel-enhanced wall coatings can significantly improve building energy efficiency and contribute toward sustainable construction practices.

Conclusion:

The experimental investigation confirmed that silica aerogel is an effective thermal insulating additive for concrete wall coatings. Increasing aerogel content progressively reduced thermal conductivity and heat flux while improving thermal resistance. Among all compositions tested, the 6% aerogel blend exhibited the best balance between insulation efficiency and practical feasibility, making it the optimum percentage for application in insulated concrete room models. The study demonstrates the potential of silica aerogel-based coatings for enhancing thermal comfort and reducing energy consumption in buildings.

Daily temperature readings reveal the insulated room (AP6-coated) maintains lower peak temperatures than the normal room during summer (March) and monsoon (June). In winter (January), the insulated model shows reduced heat loss, stabilizing internal temperatures closer to ambient conditions. Measurements every 15 minutes over June 2024–May 2025 highlight sustained insulation across monsoons, spring, winter, and summer.

AP6 reduces temperature fluctuations by maintaining cooler interiors in heat and warmer in cold, outperforming plain putty. 6% aerogel balances cost and efficacy, avoiding diminishing returns at higher concentrations. Year-long exposure under Indian weather validates real-world applicability for energy-efficient buildings. Silica aerogel putty at 6% (AP6) significantly reduces indoor temperature peaks and stabilizes conditions compared to normal putty (AP0) across monsoon, winter, and summer seasons.

Silica aerogel's low thermal conductivity (enhanced at 6% blending) effectively blocks heat flow through 2mm coatings on plastered concrete models. Seasonal graphs indicate up to 3 to 6 degrees Celsius difference in extremes, reducing cooling/heating needs by delaying thermal lag. In all the season we can observe that in day time, insulation efficiency is more than night time. Future work could quantify energy savings or test roof applications, as aerogel putty proves viable for sustainable construction in tropical climates.

Acknowledgement:

This minor research work is funded by Faculty of Engineering and Technology, Jain University and I thank Jain University. My sincere thanks to Fire Combustion Research Center (FCRC), Jain University for supporting the research work in getting the result of all the lab experiments.

References:

1. Amr Soliman Elgohary, Haytham M. Elbadrawy, Shereen Khashaba, Optimizing energy performance using silica aerogel material in building envelope. *International Journal of Sustainable Building Technology and Urban Development*. 31 March 2022. 69-83 <https://doi.org/10.22712/susb.20220006>
2. Athanasiadi, A., M. Andrikopoulou, M. Smyrnioti, Y. Georgiou, M. Zamparas, V. Dracopoulos, T. Ioannides (June 2024). Advanced, high-performance thermo-insulating plaster. *Applied Polymers*, Vol. 2, Issue 1, e112. DOI:10.1002/appl.202300112
3. Chengdong Li , Guihua Zhang, Kostya (Ken) Ostrikov , Silica aerogels: from materials research to industrial applications” , Volume 68, Issue 7, *ISR sage journals* <https://doi.org/10.1080/09506608.2023.2167547>
4. De Masi Rosa Francesca , Valentino Festa , Alessandro Russo , Silvia Ruggiero , Francesca Villano; “Aging, soiling, and cleaning effects on cool roof performance: Experimental insights on aerogel-based and conventional reflective coatings in Mediterranean climate” *Journal of Building Engineering*, Elsevier 116 (Dec. 2025) 114577 <https://doi.org/10.1016/j.jobee.2025.114577>
5. Hao Li, Weidong Xu, Liyan Zhu, Feifei Xiao, Zhou Yu, Bentian Hao, Wei Huang, Kai Zhao, Study on Thermal Insulation Performance of Silica Aerogel Thermal Insulation Blankets 2024 Oct 31;10(11):707. doi: 10.3390/gels10110707
6. He Liu, Jia'ao Liu, You Tian, Junhua Jiao, Xuehong Wu, Thermal Insulation Performance of Silica Aerogel Composites Doped with Hollow Opacifiers: Theoretical Approach; *Gels*, PMC. 2022 May 10;8(5):295. doi: 10.3390/gels8050295
7. K. I. Goryunova, Y. N. Gahramanli, “Insulating materials based on silica aerogel composites: synthesis, properties and application” *RSC advances*, Issue 47, 2024
8. Kalkan Şevket Onur, Lutfullah Gunduz (2023). Silica aerogel added lightweight cement-based composite production. *Construction and Building Materials*, Vol. 408, 133784. DOI:10.1016/j.conbuildmat.2023.133784
9. Marof, A., Lidija Šiller, “Enhancing thermal insulation in cement mortar with silica aerogel and recycled PET waste. *Construction and Building Materials*, Elsevier Vol. 418, 135478. DOI:10.1016/j.conbuildmat.2025.135478
10. Mohammed Fellah, Salma Ouhbib, Naoual Belouaggadiaa, Khalifa Mansouri “Study on optimizing aerosil layer thickness and enhancing wall insulation with air cavities under Moroccan climatic conditions” *Hybrid Advances*, Elsevier 12 (Nov. 2025) 100578 <https://doi.org/10.1016/j.hybadv.2025.100578>
11. Pantaleo Samuel , Florent Gauvin, Katrin Schollbach, H.J.H. Brouwers (Dec. 2024). Development of latex/silica aerogel composites for thermal insulation applications. *Journal of Materials Science*, Vol. 59, Issue 12, 4567-4582. DOI:10.1007/s10853-024-09567-8

12. Sana Sayadi, Jan Akander, Abolfazl Hayati . A simulation analysis on the internal and external application of new silica-aerogel-based (Quartzene) coatings effects on energy use in a typical building in two different climates” *Science and Technology for the Built Environment*, Taylor & Francis Group. *Science and Technology for the Built Environment*,(2025) 31(1), 155–171 <https://doi.org/10.1080/23744731.2024.2407723>
13. Sapna Jadhav, Pradip Sarawade, Recent advances and prospective of reinforced silica aerogel Nanocomposites and their applications” *European Polymer Journal*, Volume 206, 21 February 2024, <https://doi.org/10.1016/j.eurpolymj.2024.112766>
14. Slosarczyk Agnieszka, Andrii Vashchuk and Łukasz Kłapiszewski, Research Development in Silica Aerogel Incorporated Cementitious Composites—A Review, . *Polymers* 2022, 14, 1456. <https://doi.org/10.3390/polym14071456> (MDPI)
15. Song He , Hongcheng Li, Yuling Zhang , Hongliang Sheng , Yajun Huang. “Silica aerogel composites with excellent thermal insulation for building applications” *Energy and Buildings*, Vol. 346, (1) November 2025. <https://doi.org/10.1016/j.enbuild.2025.116169>
16. Tao Zhang, , Dongping Yu, Fuhao Xu, Yong Kong*, Xiaodong Shen, Flexible Silica Aerogel Composites for Thermal Insulation under High-Temperature and Thermal–Force Coupling Conditions, March 5, 2024, *ACS Applied Nano Materials*, Vol 7/Issue 6
17. Xinhua Gu , Yongqiang Ling Research progress of aerogel materials in the field of construction, *Alexandria Engineering Journal*, Volume 91, March 2024, Pages 620-631, <https://doi.org/10.1016/j.aej.2024.02.039>
18. Yang, J.; Wu, H.; Liang, Y.; Cen, J.; Zhang, X. A Comparative Assessment of Different Aerogel-Insulated Building Walls for Enhanced Thermal Insulation Performance. *Gels* 2023, 9, 943. <https://doi.org/10.3390/gels9120943>
19. Zhaoming Li a, Wen Yang a,b, Guanjie Zhang a, Wanyu Ren a, Zihan Shi a Impact of thermal conductivity of aerogel-enhanced insulation materials on building energy efficiency in environments with different temperatures and humidity levels *Thermal Science and Engineering Progress* 50 (2024) 102540
20. Zhenyu Zhu, Wanlin Zhang, Hongyan Huang, Wenjing Li, Hao Ling, Hao Zhang: A Review of High-Temperature Resistant Silica Aerogels: Structural Evolution and Thermal Stability Optimization” *Gels*, PMC 2025 May 13;11(5):357. doi: [10.3390/gels11050357](https://doi.org/10.3390/gels11050357).