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THERMAL PERFORMANCE EVALUATION OF VERNACULAR ROOFING SYSTEMS IN CONTEMPORARY BUILDINGS

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ABSTRACT

This study explores the thermal performance of three vernacular roofing systems—Filler Slab, Hourdi Roof, and Jack Arch Roof—in the moderate climate of Bangalore, India. The objective was to evaluate and compare the thermal performance of these roofing systems under peak summer conditions. Temperature data were continuously monitored during the hottest month, April, using an eight-channel data logger that recorded outdoor air temperature, indoor air temperature, and roof surface temperatures. To evaluate thermal performance, two indicators were used: Maximum Temperature Difference (MTD), which measures the largest temperature difference between the outer and inner roof surfaces, and Temperature Difference Ratio (TDR), which reflects the roof's ability to reduce the impact of outdoor temperature fluctuations. The results showed clear differences in the thermal behavior of the three roofing systems. The Filler Slab Roof achieved the highest average TDR (0.451) and MTD (25.85°C), indicating the strongest resistance to heat transfer and the greatest ability to moderate external heat gains. The Jack Arch Roof also performed well, with a comparable TDR and MTD. The Hourdi Roof, however, recorded the lowest TDR and MTD, suggesting a comparatively lower capacity to resist heat flow under the climatic conditions studied. Overall, the findings indicate that the Filler Slab Roof offers the best thermal performance among the three vernacular roofing systems. These results highlight the continued relevance of vernacular roofing strategies and their potential application in contemporary sustainable architecture and energy-efficient building design.

Keywords: *Maximum Temperature Difference (MTD); Temperature Difference Ratio (TDR); Vernacular Roofing.*

1 INTRODUCTION

Cities are experiencing rapid increases in temperatures year after year. Modern buildings, primarily constructed from Reinforced Concrete (RC) and steel, often trap rather than deflect heat, resulting in higher indoor temperatures and increased energy consumption. As a result, dependence on fans, coolers, and air conditioning is increasing, thereby raising household energy costs and carbon emissions (India Energy Outlook 2021 World Energy Outlook Special Report, 2021). However, long before mechanical cooling systems were invented, traditional builders effectively used local materials and methods to manage thermal comfort (Srivastava & Das, 2023). Roofs are among the most critical

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elements because they receive the greatest solar exposure, which contributes significantly to a building's heat gain. They often account for 50–70% of the total heat transfer into single-story buildings (Sharma & Sharma, 2023). The way a roof is designed its material composition, surface colour, thickness, ventilation strategy, and layering directly shapes indoor thermal comfort. When carefully designed, a roof can serve as a thermal buffer, reducing heat transfer during the day and releasing it gradually at night (Sharma et al., 2018). Traditional systems often relied on thermal mass and shading to regulate heat flow, but in recent decades, new approaches have emerged that combine vernacular knowledge with modern technology. Vernacular roofing can be seen as an evolved form of traditional roofing, characterised by context-specific design responses to environmental and cultural factors. These roofing systems, when rigorously evaluated for their thermal properties, can become integral to both contemporary Green building strategies and future innovations in climate-responsive design (Choi & Lee, 2015).

While many studies have explored passive cooling in buildings, very few have conducted on-field monitoring of vernacular roofs. Most prior research focuses on short-term experiments or thermal simulations (Singh et al., 2010), with limited attention to roofs. Additionally, seasonal variations in urban climates are rarely examined. In Bangalore, despite being considered a moderate-climate city, summer heat waves affect occupant comfort (Indian Meteorological Department, n.d.). Still, systematic monitoring of vernacular roof performance in this region is limited. This study aims to evaluate the thermal performance of several vernacular roofing systems, such as filler slab, jack arch roof, and Hourdi roof, in Bangalore. The objective of this study, which uses hourly surface and ambient temperature measurements over the summer critical month, is to compare the thermal properties of those roofing systems.

2 LITERATURE

2.1 VERNACULAR ROOFING

Vernacular roofing methods, such as jack-arch roofs and filler-slab constructions, were driven by functional performance rather than aesthetic style. These systems efficiently balanced thermal mass delaying heat transfer and natural insulation, thereby reducing indoor temperature fluctuations (Rawat & Singh, 2021). For example, mud and earth roofs, with their high thermal capacity, absorb solar heat during the day and release it at night, while jack arches utilise air cavities to reduce conduction. These roofs often utilise locally sourced materials and construction techniques to enhance natural thermal comfort (Srivastava & Das, 2023). With the increasing focus on sustainable design, such strategies are being reconsidered as alternatives to RCC slabs, which are energy-intensive to produce and less effective at controlling heat transfer. However, much of the current appreciation is based on observations rather than systematic analysis, with limited quantitative evaluation. Studying these roofing systems can provide invaluable insights into sustainable building design.

2.2 PREVIOUS STUDIES ON THERMAL PERFORMANCE OF VERNACULAR ROOFING

The thermal role of roofing in buildings has long been recognised. Globally, vernacular systems were designed to protect against climatic extremes without the aid of mechanical devices. Mediterranean adobe domes, for instance, demonstrated strong thermal resistance by maintaining cooler interiors in summer. In Southeast Asia, steeply pitched thatch roofs enhanced ventilation and minimised overheating, while African earth-and-thatch systems reduced diurnal indoor fluctuations. These studies highlight vernacular ingenuity but often remain qualitative, focusing on cultural or morphological descriptions rather than rigorous thermal metrics. In the Indian context, research has examined traditional roof typologies across climatic zones. Mud roofs in Assam and Himachal Pradesh have been reported to delay the onset of peak indoor temperatures, thereby stabilising comfort conditions (Singh et al., 2010; Sharma & Sharma, 2023). Filler slabs in Kerala and Karnataka combine reduced cement usage with improved thermal moderation compared to reinforced cement concrete (Athmarajah et al., 2017). Jack arch roofs, once common in industrial structures, have been noted for their cavity-based insulation benefits. However, systematic performance evaluation of these systems under year-long climatic cycles remains scarce.

2.3 DESCRIPTION OF THE ROOFING SYSTEMS

2.3.1 Filler Slab with Hollow Blocks

In an RCC slab, the portion below the neutral axis is the tension zone. Concrete is good in compression and weak in tension. The concrete used in the tension zone primarily serves to cover the steel; therefore, some of it can be replaced (Jagadish et al., 2007).

Figure 1: Image showing construction of a filler slab. Source: (Sathya Consultants, 2011)

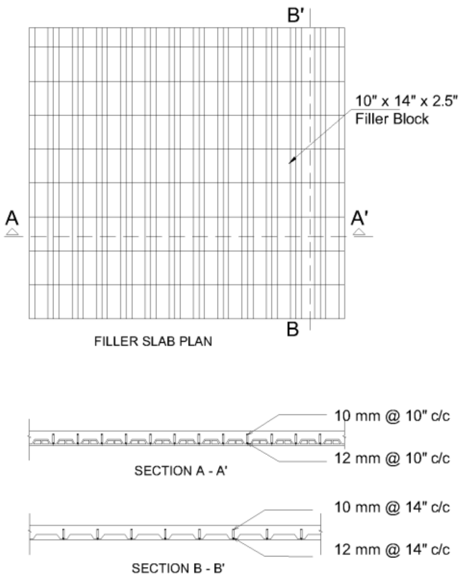


Figure 2: Typical plan and section of a filler slab with hollow filler clay block

Approximately 20–40% of the concrete below the neutral axis in an RCC slab can be replaced with a non-reactive material for various benefits. The material that replaces concrete is called the filler, and the slab is called the filler slab (Acharya et al., 2020). The filler material could be selected for its lower thermal conductivity, lighter weight, reduced dead load, and aesthetic appeal (Sainath & Das, 2020). Various filler materials used include Mangalore tiles, hollow clay blocks, stabilised mud blocks, and clay pots (Amit et al., 2015). For this study, a hollow clay block filler slab (locally known as Maruti blocks) is considered, with its roof section shown in figures 1 and 2.

2.3.2 Hourdi Roof

Hourdi blocks are crafted from natural clay and kiln-baked to produce a durable, hollow roof component. They are installed by placing them between prefabricated beams to form slabs. These blocks are lighter, which accelerates construction and removes the necessity for shuttering, unlike traditional Reinforced Cement Concrete systems. Traditionally, cross beams of stone or timber would be placed over the wall at roof level and filled in with wood planks, stone slabs, Madras terrace tiles, or flat clay tiles. (Harrison & Sinha, 1995).

Figure 3: Image showing construction of Hourdi roof. Source: (Auroville Earth Institute, n.d.)

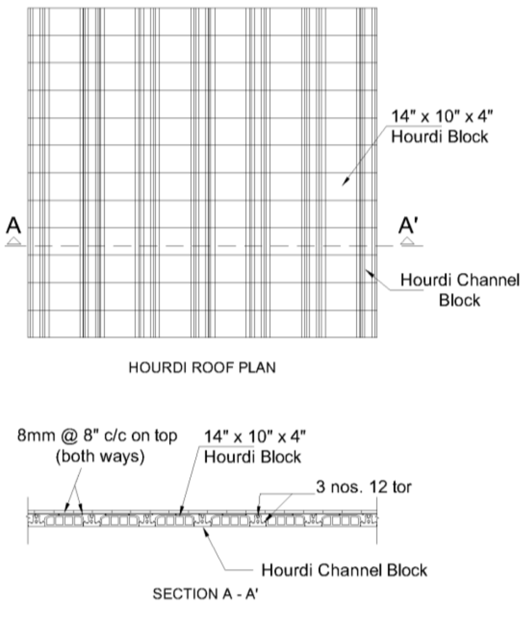


Figure 4: Typical plan and section of Hourdi roof

Over time, innovations led to the introduction of hollow clay blocks, known as 'Hourdi', as the infill material. The stone or timber crossbeams were replaced with precast RC inverted T-beams or precast Hourdi beam blocks (Varanashi, 2022) (refer figures 3 and 4).

2.3.3 Jack Arch Roof

The Jack arch masonry flooring system consists of elongated, shallow brick vaults supported on parallel steel I-beams, intermediate RC beams, or Hourdi channel beams. The spaces over the arches are then filled with concrete to create a flat floor (Maheri et al., 2012). Hollow clay blocks, known as Water-Proof Course tiles (WPC tiles), can serve as an alternative to regular bricks, potentially improving thermal performance and reducing the roof's self-weight. The intermediate beam could be cast in situ or precast, depending on the dimensions of the space to be roofed. They are spaced 1000 mm to 1500 mm centre-to-centre. The arch elevation is kept equal to 1/12 of the span (Ramesh, 2012).

Figure 5: Image showing construction of Jack arch roof. Source: (Varanashi, 2011)

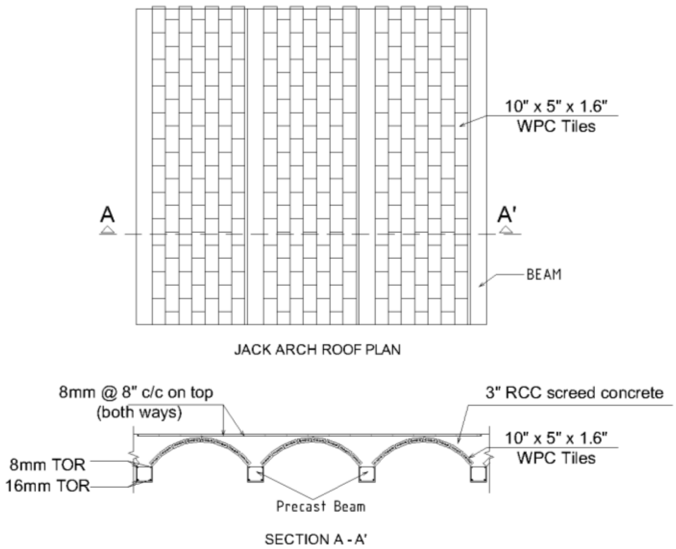


Figure 6: Typical plan and section of Jack arch roof

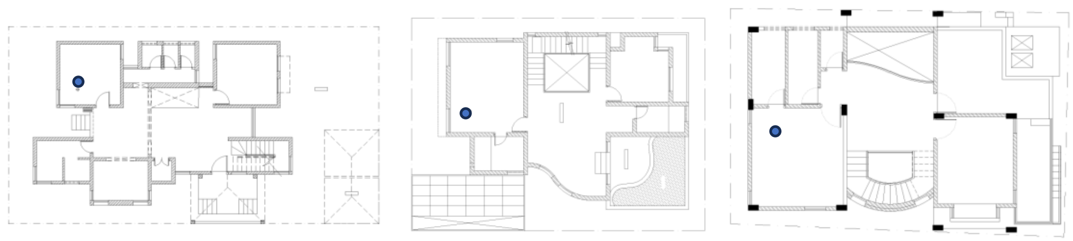
3 METHODOLOGY

3.1 RESEARCH DESIGN

This study used an experimental field-based research design to evaluate the thermal performance of three vernacular roofing systems; filler slab, jack arch, and Hourdi roof in Bangalore, India. The focus was on quantifying roof performance using the Temperature Difference Ratio (TDR) and Maximum Temperature Difference (MTD), based on real-time temperature measurements.

1.2 SITE SELECTION AND CLIMATIC CONTEXT

Bengaluru is the capital city of Karnataka, located in Southern India. It is located at 12°58' N, 77°35' E, with an average elevation of 921m above sea level. Bengaluru falls under a moderate climate. The city experiences distinct summer (March–May), monsoon (June–September), and winter (October–February) periods, with average annual temperatures ranging from 15°C to 36°C (Indian Meteorological Department, n.d.). Bangalore having a moderate climate; summer is the critical season for thermal comfort. Three residences within the city were selected, with each having the above-mentioned vernacular roofs. The rooms were selected with similar orientations and were all naturally ventilated.



● Sensor positions (1.2m from the walls)

Figure 4: Floor plans of the residences selected for case studies and the position of the sensors. Starting from the left residence with filler slab, Hourdi roof, and Jack arch roof.

1.3 ROOF DETAILS

3.1.1 Filler Slab

The filler slab selected for the study had a thickness of 150mm. The lower part of the slab consisted of hollow clay filler blocks of dimensions 254mm x 355.6mm x 63.5mm. On top of this layer was reinforced concrete of 86.5mm thickness. The filler blocks consist of 60% burnt clay and 40% void.

3.1.2 Hourdi Roof

Hourdi roof selected for the study had a thickness of 150mm. The lower part consisted of hollow clay Hourdi blocks of dimensions 355.6mm x 254mm x 101.6mm. On top of this was a 50.8mm thick reinforced concrete layer. Hourdi blocks are composed of 42% burnt clay and 58% void.

3.1.3 Jack Arch Roof

The jack arch that was studied had arches of width 1200mm, with intermediate beams of width 152mm and depth 305mm. The arch was built using water-proof course tiles (WPC tiles) with a burnt-clay volume of 80% and a remaining 20% void. On top of this layer was a 50mm-thick concrete screed (at the centre of the arch).

3.4 INSTRUMENTATION AND DATA COLLECTION

3.1.4 Temperature Measurement

An eight-channel data logger was used to record outdoor and indoor ambient temperatures, as well as outer and inner roof surface temperatures. Thermocouples were securely fixed to surfaces to ensure accurate readings. Temperatures were recorded hourly throughout the critical summer month of April 2025 in Bangalore.

Figure 4: An 8-channel data logger

The sensors for outer ambient temperature were mounted in the shade over the roof; the sensors for outer surface temperature were mounted on the roof surface, ensuring no shadow fell on them. The sensors for the inside ambient temperature were mounted half a meter below the roof, and the sensors for the inside surface temperature were mounted exactly below the position of the outer surface temperature sensors. The sensors were positioned 1.2m from the walls.

3.1.5 Performance Indicators

Temperature Difference Ratio (TDR)

TDR is computed as the ratio of the indoor–outdoor temperature difference to the outdoor variation at a given time step:

$$TDR = (Tmax\_out - Tmax\_in) / (Tmax\_out - Tmin\_out) \qquad (01)$$

Where T_{max_out} = Maximum outside ambient temperature, T_{max_in} = Maximum inside ambient temperature, and T_{min_out} = Minimum outside ambient temperature.

Higher TDR values indicate greater roof resistance and more effective temperature damping under changing external loads (Amos-Abanyie et al., 2013).

Maximum Temperature Difference (MTD)

MTD is the maximum instantaneous difference between the outer and inner roof surface temperatures over the course of a day (Ali & RehmanS, 2020).

$$MTD = Max\ (Tsurf\text{-}out - Tsurf\text{-}in) \qquad (02)$$

Where $T_{surf\text{-}out}$ = outer roof surface temperature, $T_{surf\text{-}in}$ = inner roof surface temperature.

Higher MTD indicates that the roof is effectively resisting heat flow through its thickness and preventing heat from reaching the inner surface. Thus, higher MTD values indicate lesser heat flow and better thermal insulation (Koenigshberger, 2010).

4 RESULTS AND DISCUSSIONS

The thermal performance of three vernacular roof types; filler slab, Hourdi roof, and jack arch roof were evaluated through a real-time field study of three residences in Bangalore, a moderate climatic zone. Hourly data were collected for April, the critical summer month, as it represents the period of maximum solar gain and thermal stress. The results were compared using TDR proposed by Givoni and MTD between the indoor and outdoor. In this comparison, higher MTD and TDR indicate better thermal performance (Ali & Rehman S, 2020). These indices collectively indicate each roof system's ability to moderate heat, withstand high temperatures, and effectively reduce heat gain.

4.1 TEMPERATURE DIFFERENCE RATIO (TDR)

In this study, the filler slab roof recorded the highest TDR, followed by the jack arch roof. The higher TDR of the filler slab suggests it attenuates the outer-to-inner temperature difference more effectively during outdoor fluctuations, even though its absolute inner temperatures are higher. The comparative chart (refer Figure 5) shows that the TDR values of the Jack arch roof are quite close to those of the Filler slab.

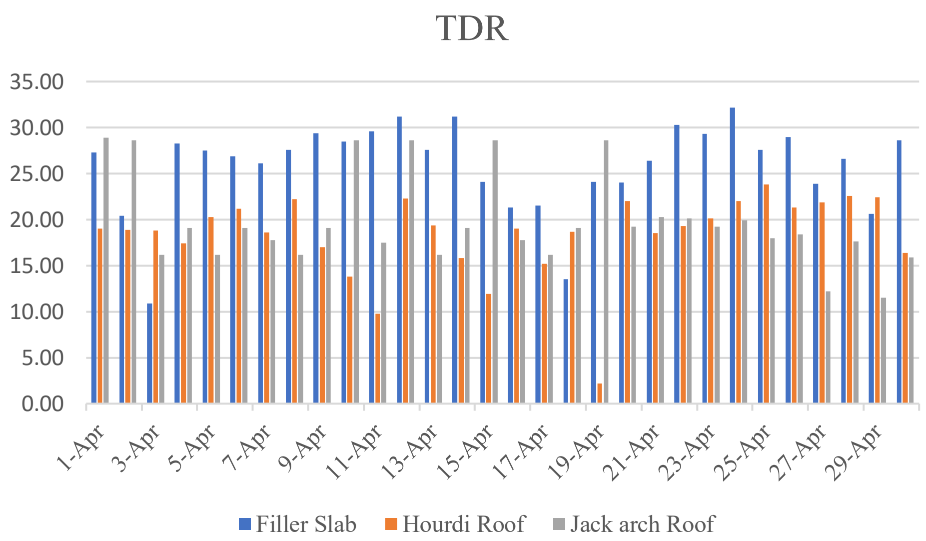


Figure 5: Chart showing the TDR values of all three vernacular roofs.

Thus, indicating that both the Filler slab and the Jack arch roof may offer better heat resistance.

4.2 MEAN TEMPERATURE DIFFERENCE (MTD)

In this study, the Filler slab had the highest MTD across many days. Hourdi roof and Jack arch seem to have similar MTD values, but they are lower than those of the filler slab. This indicates that the filler slab maintains a larger average temperature difference across its section, meaning less heat enters the interior over time. The filler slab, with terracotta fillers and a continuous concrete layer on the exterior, provides good thermal mass, reducing heat conduction. The Jack arch roof and hourdi roof, made of hollow clay blocks with a thin concrete layer on top, perform moderately, benefiting from air voids yet limited by the thin thermal barrier.

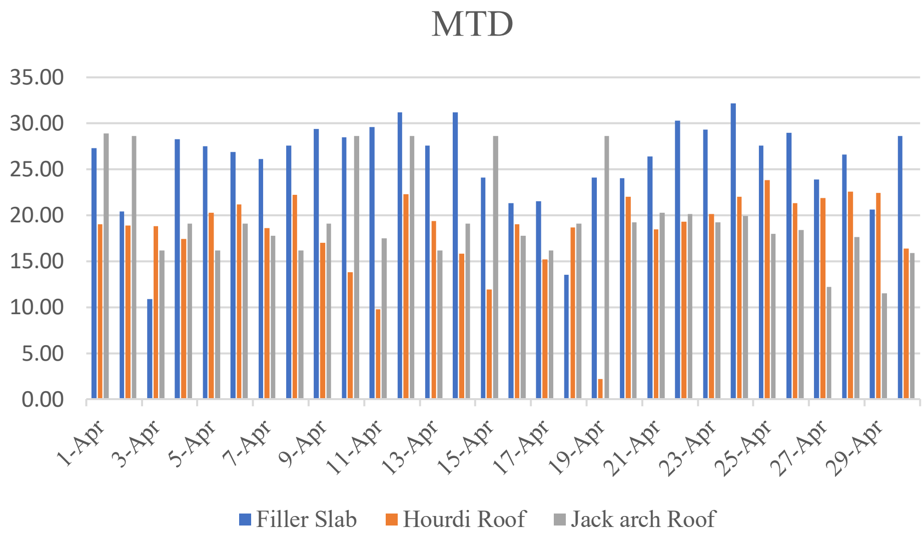


Figure 6: Chart showing the MTD values of all three vernacular roofs.

4.3 Discussion of Findings

The descriptive statistics indicate that the Filler Slab Roof has the best thermal performance among the vernacular roofing systems studied. It has the highest Temperature Difference Ratio (0.451), indicating a strong reduction in peak outdoor temperatures, and the highest Maximum Temperature Difference (25.85°C), reflecting a strong thermal gradient and increased resistance to heat transfer.

Statistics

		Filler_TDR	Filler_MTD	Hourdi_TDR	Hourdi_MTD	Jackarch_TDR	Jackarch_MTD
N	Valid	30	30	30	30	30	30
	Missing	0	0	0	0	0	0
Mean		.4510	25.8500	.2300	18.3933	.4357	19.7933
Median		.4850	27.4000	.2350	19.0000	.4400	19.1000
Std. Deviation		.09887	4.87341	.10079	4.47298	.10546	4.92537
Minimum		.20	10.90	-.20	2.20	.27	11.50
Percentiles	25	.4050	23.9750	.1975	16.8500	.3975	16.2000
	50	.4850	27.4000	.2350	19.0000	.4400	19.1000
	75	.5200	29.0750	.2925	21.9250	.4825	20.1500

Figure 7: Comparative data analysis using a descriptive statistical method in SPSS.

The Jack Arch Roof exhibits similar TDR values and moderate MTD values, suggesting good thermal performance. Conversely, Hourdi Roof shows the lowest values for both metrics, indicating lower thermal resistance and reduced heat transfer.

Table 1: Interpretation of the statistical report

Roof Type	Mean TDR	Mean MTD	Overall Interpretation
Filler Slab	0.4510	25.85	High TDR and highest MTD
Hourdi Roof	0.2300	18.39	Lowest TDR and lowest MTD
Jack Arch Roof	0.4357	19.79	High TDR and relatively low MTD

Overall, these findings suggest that the Filler Slab Roof provides the most effective thermal buffering under the climatic conditions studied.

4.4 IMPLICATIONS FOR CONTEMPORARY CONSTRUCTION

In the context of sustainable design, the findings suggest that reinterpreting vernacular roof systems, such as the filler slab, with modern materials can enhance indoor comfort while reducing reliance on mechanical cooling. The filler slab, popular for its material efficiency, also offers the added benefit of thermal insulation. The roof's thermal performance could be further improved with additional measures such as reflective coatings. Therefore, using design strategies that incorporate thermal mass and air insulation—as demonstrated by the filler slab can greatly enhance passive thermal regulation in modern architecture.

5 CONCLUSIONS

This study evaluated the thermal performance of three vernacular roofing systems Filler Slab, Hourdi Roof, and Jack Arch Roof through field-based temperature monitoring of residential buildings in Bangalore. Thermal performance was assessed using Maximum Temperature Difference (MTD) and Temperature Difference Ratio (TDR) during the peak summer period, representing the most thermally critical conditions of the year.

The results show that the thermal performance of each roofing system is strongly influenced by its material composition and structural design. The Filler Slab Roof had the highest average TDR and MTD values, reflecting its greater capacity to reduce outdoor temperature changes and sustain a significant thermal gradient across the roof. These features imply better resistance to heat transfer and more effective thermal buffering during intense solar exposure.

The Jack Arch Roof exhibited TDR values similar to those of the Filler Slab Roof, highlighting its ability to regulate heat transfer effectively. Its brick-vault design and built-in air cavities enhance thermal mass and slow heat flow, resulting in more consistent thermal performance. However, its MTD values were lower than those of the Filler Slab Roof, suggesting a smaller thermal gradient across the roof structure.

The Hourdi Roof had the lowest TDR and MTD values among the three systems. Although the hollow clay blocks offer some insulation and reduce short-term temperature fluctuations, the system's overall ability to reduce heat transfer was less effective than that of the Filler Slab and Jack Arch roofs under the given climate conditions.

Overall, the results indicate that the Filler Slab Roof demonstrates the highest thermal performance, followed closely by the Jack Arch Roof, while the Hourdi Roof exhibits comparatively lower thermal resistance. These findings highlight the significance of thermal mass, material composition, and roof geometry in improving the thermal efficiency of building envelopes in warm climates.

The study highlights that vernacular roofing principles remain important in modern sustainable architecture. Using traditional construction techniques with today's materials, prefabricated parts, and innovative structural systems can significantly improve passive thermal performance while ensuring ease of construction and structural integrity. Incorporating these climate-responsive methods into current practices can help reduce cooling energy needs and enhance occupant comfort, especially in rapidly urbanizing areas.

Future research should extend this work by combining surface temperature measurements with indoor comfort assessments, heat flux monitoring, energy simulations, and life-cycle performance evaluations to develop a more comprehensive understanding of the thermal and environmental benefits of vernacular roofing systems in contemporary buildings.

6 DECLARATION OF GENERATIVE AI

During the preparation of this work, the author(s) used ChatGPT to aid in structuring some of the sentences.

7 DECLARATION OF INTEREST

The author(s) hereby declare that there are no conflicts of interest regarding the publication of this manuscript. This includes financial, personal, or professional relationships that could have influenced the research, analysis, or interpretation of the findings. All sources of funding for the study, if any, have been fully disclosed in the manuscript.

8 REFERENCES

Acharya, R. R., Kishore, P., Raghuprem, M., Kini, P., Shetty, S., & Raj, A. (2020). Optimization-based feasibility study for filler slabs as a response towards the ECBC roof compliance with respect to thermal transmittance for five climatic zones of India. *Procedia Manufacturing*, *44*, 213–220. https://doi.org/10.1016/j.promfg.2020.02.224

Ali, A. M., & Rehman, S. (2020). Thermal performance of different types of roof in a naturally ventilated building in the warm and humid climate of Vijayawada. *Solid State Technology*, *63*(4), 593–598. https://www.solidstatetechnology.us/index.php/JSST/article/view/1251

Amit, M. R., Chougule, D., Manoj, M. R., & Mota, H. (2015). To study the filler slab as alternative construction technology - A review. *Journal of information, knowledge and research in civil engineering, 3*(2), 199-202.

Amos-Abanyie, S., Akuffo, F. O., & Kutin-Sanwu, V. (2013). Effects of thermal mass, window size, and night-time ventilation on peak indoor air temperature in the warm-humid climate of Ghana. *The Scientific World Journal*, *2013*(1). https://doi.org/10.1155/2013/621095

Athmarajah, G., Baskaran, K., & Thiruvarankan, P. (2017). Study on filler slab construction. In *111th Annual Sessions, Institution of Engineers Sri Lanka*. https://www.researchgate.net/publication/353519768

Auroville Earth Institute (n.d.). *Hourdi Roofing*. https://dev.earth-auroville.com/hourdi-roofing/

Choi, D.S., & Lee, M.E. (2015). Evaluation of the basic characteristics of thermal insulation performance for different parts of outer walls that considers year-on-year change. *International Journal of Applied Engineering Research*, *10*(10), 26871–26878. http://www.ripublication.com

Harrison, S. W., & Sinha, B. P. (1995). A study of alternative building materials and technologies for housing in Bangalore, India. *Construction and Building Materials*, *9*(4), 211–217. https://doi.org/10.1016/0950-0618(95)00012-5

India energy outlook 2021 world energy outlook special report. (2021). www.iea.org/t&c/

Indian Meteorological Department. (n.d.). *1981-2010 CLIM NORMALS (ALPHABETICAL) - IMD.*

Jagadish, K. S., Reddy, B.V.V., & Rao, K. S.N. (2007). *Alternative building materials and technologies*. New Age International Publishers.

Koenigshberger, O. H. (2010). *Manual of tropical housing and building: Climatic design*. University Press (India) Private Limited.

Maheri, M. R., Pourfallah, S., & Azarm, R. (2012). Seismic retrofitting methods for jack-arch masonry slabs. *Engineering Structures, 36*, 49–60. https://doi.org/10.1016/j.engstruct.2011.11.018

Ramesh, S. (2012). Appraisal of vernacular building materials and alternative technoligies for roofing and terracing options of embodied energy in buildings. *Energy Procedia, 14*, 1843–1848. https://doi.org/10.1016/j.egypro.2011.12.1177

Rawat, M., & Singh, R. N. (2021). A study on the comparative review of cool roof thermal performance in various regions. *Energy and Built Environment*, *3*(3), 327–347. https://doi.org/10.1016/j.enbenv.2021.03.001

Sainath, K., & Das, S. (2020). Benefits of filler slab over R.C.C. slab. *Journal of Emerging Technologies and Innovative Research, 7*(8), 1409-1412. https://www.jetir.org/view?paper=JETIR2008183

Sathya Consultants. (2011). *Reduce the concrete in filler slabs.* https://sathyaconsultants.wordpress.com/2011/08/06/reduce-the-concrete-in-filler-slabs/

Sharma, P., Sharma, S. K., & Preet, V. (2018). impact of modern construction practices as compare to traditional construction for sustainable rural houses in the northern eastern part of Rajasthan. *International Journal of Engineering Research & Technology*, *6*(11). https://www.ijert.org

Sharma, R., & Sharma, V. (2023). Thermal performance study of traditional slate roofed mud houses in the sub-tropical submontane and low hills of Himachal Pradesh. *Università Degli Studi Di Torino*. https://doi.org/10.13135/2384-8677/8940

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

Srivastava, A., & Das, B. K. (2023). Vernacular architecture of India: An overview. *ISVS E-journal*, *10*(7), 435–448.

Varanashi, S. P. (2011, August). *Jack arch roofing*. The Hindu. https://www.thehindu.com/features/homes-and-gardens/jack-arch-roofing/article2399821.ece

Varanashi, S. P. (2022, March). *A roof with a fancy name.* The Hindu. https://www.thehindu.com/life-and-style/homes-and-gardens/a-roof-with-a-fancy-name/article65210963.ece