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Achieving Thermal Comfort Using Vernacular Materials

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Abstract

This study evaluates the thermal performance of traditional Punjabi wall assemblies using Nanakshahi bricks and lime-Surkhi mortar, in comparison with conventional modern construction systems employing fired clay bricks and cement-based materials. The research focuses on three representative wall assemblies: a 450 mm vernacular masonry wall (Assembly A), a 230 mm modern brick wall (Assembly B), and a 200 mm concrete block wall (Assembly C).

The primary objective is to quantitatively assess thermal efficiency through steady-state (U-value) and dynamic performance indicators such as thermal mass and time lag, in the context of Punjab's composite climate.

The results demonstrate that the vernacular assembly achieves a significantly lower U-value (1.34 W/m²K) compared to modern alternatives (2.22 and 3.16 W/m²K) and exhibits a thermal lag of 8–12 hours, effectively reducing indoor temperature fluctuations. This leads to improved passive thermal comfort and reduced dependence on mechanical cooling systems.

In addition to thermal performance, the study highlights the ecological advantages of lime-Surkhi mortar, which utilizes recycled materials and lowers embodied energy compared to cement-based construction.

The findings emphasize that assembly-level design and material thickness play a critical role in climate-responsive architecture. Future scope includes integrating vernacular materials with modern structural systems, standardizing Surkhi production, and incorporating dynamic thermal performance metrics into building codes to enhance sustainable design practices in North India.

Keywords; Vernacular Architecture, Nanakshahi Brick, Lime-Surkhi Mortar, Thermal Comfort, Thermal Mass.

INTRODUCTION

Contextualizing the Global Energy and Resilience Challenge

The global building sector accounts for a substantial proportion of overall energy consumption and carbon emissions, driven by the energy required for material production (embodied energy) and the growing reliance on mechanical systems for heating and cooling (operational energy). In regions like Punjab, which experience the wide seasonal temperature fluctuations characteristic of a composite climate, the transition away from passive, locally adapted construction methods poses a significant threat to long-term sustainability and human comfort.

Historically, the indigenous architecture of Punjab evolved to manage these climatic extremes using low-energy materials such as thick earth walls, lime-based mortars, and specialized brick tiles. These traditional structures inherently maximized thermal mass and utilized natural ventilation and shading, epitomizing climate-responsive design. However, the shift toward standardized, energyintensive modern composites, primarily Ordinary Portland Cement (OPC), high-conductivity

fired bricks, and concrete has often compromised the intrinsic thermal buffering capacity of the structures. This necessitates greater reliance on mechanical cooling systems, leading to increased operational energy demands and environmental strain.

The fundamental difference lies not merely in the component materials but in the underlying design philosophy: the vernacular system was optimized for resilience and thermal inertia, while the modern system often prioritizes speed, standardization, and a reliance on mechanical correction.

Evaluating the performance metrics of traditional Punjabi masonry of Nanakshahi bricks bonded with Surkhi mortar against modern equivalents is therefore vital for reclaiming the wisdom of indigenous knowledge and informing sustainable contemporary practice.

AIM

The core aim of this project is to conduct a rigorous comparative assessment of the thermophysical, mechanical, and ecological performance of traditional Punjabi masonry, specifically utilizing Nanakshahi bricks and Surkhi mortar, against conventional modern construction materials, with a view toward informing sustainable contemporary design.

OBJECTIVES

- **Characterization:** Document the historical use, dimensions, composition, and manufacturing processes of Nanakshahi bricks and Surkhi mortar, and compile corresponding standardized properties for modern counterparts, including conventional fired bricks and cement-based binders.
- **Quantification:** Calculate and compare key thermal metrics for representative wall assemblies, primarily focusing on the steady-state U-value (thermal transmittance) and dynamic thermal mass indicators, such as volumetric heat capacity and thermal lag, which are crucial for buffering temperature swings.
- **Performance Assessment:** Determine the theoretical impact of material and assembly choices on indoor thermal comfort and corresponding energy consumption through quantitative modelling, referencing established thermal performance studies and comfort indices.
- **Sustainability Analysis:** Evaluate the ecological advantages of vernacular materials, focusing on embodied energy reduction, the benefits of waste

utilization (Surkhi), and the long-term climate resilience afforded by passive architectural strategies

SCOPE OF PROJECT

The scope of this project is confined to the analysis of wall assemblies typical of Punjabi architecture, utilizing fired clay bricks and associated mortars. The geographical context is the composite climate zone of North India. The comparison relies exclusively on theoretical performance modeling based on established literature and measured material properties, offering a robust comparative framework rather than new empirical testing.

LITERATURE REVIEW

Nanakshahi Bricks: Historical Context and Dimensions

Nanakshahi bricks were integral to the architectural landscape of Punjab during the Mughal and Sikh periods, employed extensively in major structures such as gurdwaras, fortresses, and havelis. These bricks, sometimes referred to interchangeably with Lakhori bricks, are distinguished by their small, slim, and often multi-hued profile. Typical dimensions reported in historical documentation are around 6 inches x 4 inches x 1.25 inches, or approximately 18.3 cm in length, 9.4 cm in width, and 2.7 cm in height.

The historical function of the Nanakshahi brick was crucial to the thermal and structural philosophy of the era. They were used more as brick tiles for decorative cladding, for architectural embellishments (such as cornices and pilasters), and, critically, for reinforcing the very thick lime concrete structural walls and other components. The traditional manufacturing methods, often involving burning with timber and cow dung, imparted intrinsic advantages, resulting in bricks noted for being "far superior in strength and more resilient than the conventional bricks". The material's noted strength and resistance to adverse weather conditions contributed significantly to the longevity of these heritage structures. The adoption of larger, standardized "Ghumma bricks" during the British colonial administration marked a significant divergence, requiring a complete shift in traditional masonry skills and structural approach.

Surkhi Mortar: The Traditional Pozzolanic Binder

Surkhi represents the sophisticated, ecological ingenuity of vernacular binders. Defined as an artificial pozzolanic material, Surkhi is produced by crushing and powdering burnt clay balls or old fired bricks. This practice essentially institutionalized the recycling of construction waste. Surkhi

mortar (lime-Surkhi mortar) was the predominant binder used in conjunction with Nanakshahi masonry throughout the region's heritage sites.

Its primary function is to replace fine aggregates, such as sand, while simultaneously imparting essential hydraulic properties to the lime binder. The amorphous aluminosilicates present in the powdered brick react chemically with calcium hydroxide, which is released during the hydration process of lime, resulting in a stronger, cementitious material. Beyond increased mechanical and flexural strength, the addition of Surkhi significantly improves durability by increasing resistance to alkalis and salt solutions, and by creating waterproof mortars. While Surkhi concrete exhibits a slight reduction in initial strength and higher shrinkage compared to ordinary concrete, it achieves robust long-term strength.

However, Surkhi's intrinsic variability—it is "not a standardized product" and its properties "vary widely"—is a challenge to its modern, large-scale engineering application. This non-standardization necessitates that future industry efforts focus on standardizing regional Surkhi production. Such standardization would allow this high-performance, low-embodied-energy material to compete effectively with OPC-based products. The variability in properties notwithstanding, the traditional lime-Surkhi composition contributed to a more thermally coherent assembly, often resulting in a lower thermal conductivity compared to dense modern cement mortars.

Principles of Passive Cooling and Vernacular Thermal Performance

Vernacular architecture in regions subject to large diurnal temperature variations, such as North India's composite climate, relies heavily on thermal mass to regulate interior climate. Dense materials like thick masonry walls act as thermal buffers, absorbing heat during the hot day and releasing it slowly and predictably during the cooler night. This mechanism effectively moderates room air temperature, reducing the amplitude of indoor temperature swings.

The resilience of these systems is well-documented. Studies comparing the thermal comfort of highmass vernacular buildings with modern structures consistently show superior performance in the traditional designs. For example, modern buildings often require 7.7 kW of electricity daily to achieve a neutral comfort level, whereas vernacular rock-cut structures (an analog for extreme thermal mass) maintained a comfortable PMV average of -

0.61 without any energy input. Furthermore, research has demonstrated the "higher resilience" of traditional dwellings in maintaining comfortable internal temperatures even when subjected to adverse climate change scenarios.

The material selection in vernacular architecture supports this system approach. While a dense material like Nanakshahi brick may possess a medium-to-high thermal conductivity (up to 1.0 W/mK)—suggesting poor insulation if used thinly—its primary value lies in its high density and contribution to thermal mass. In the thick wall assembly (450 mm), this high density maximizes the capacity for heat storage, resulting in the long thermal lag required for successful passive cooling. The overall superior thermal performance is a function of the entire system (Assembly A), not the insulating properties of its individual components

Research Gap

Although vernacular architecture in India has attracted considerable scholarly attention, existing studies largely focus on the general characteristics and qualitative aspects of traditional construction practices. However, the thermal performance of traditional Punjabi wall assemblies remains insufficiently explored. In particular, there is a lack of quantitative comparative studies evaluating traditional Punjabi masonry systems, such as those constructed using Nanakshahi bricks and lime-Surkhi mortar, against modern construction techniques. This research gap highlights the need for a systematic assessment using measurable thermal performance indicators, including U-value, thermal lag, decrement factor, and volumetric heat capacity, to better understand the thermal efficiency and energy performance of traditional and contemporary wall systems.

Studies like Singh et al. (2010) and Chandel et al. (2016) look at thermal comfort in vernacular buildings in North and North-East India in a general way, and Grover & Singh (2019) look at the structural properties of Nanakshahi bricks in heritage contexts. However, none of these studies use standardized building physics metrics that are specific to Punjab's composite climate to make a systematic assembly-level thermal comparison. Paliwal and Kumar (2020) also look at rat-trap bond masonry, but they don't include traditional lime-Surkhi binders as a variable.

This study fills that gap by using steady-state and dynamic thermal performance metrics to compare three types of wall assemblies: vernacular Nanakshahi-Surkhi masonry, modern fired brick, and concrete block systems. The study takes place in North India's climate.

Research Methodology

Methodology Overview

The research employs a theoretical quantitative methodology, integrating data from historical construction practices with established building physics models. This approach facilitates a direct, objective comparison between the thermal performance of traditional Punjabi masonry and three representative modern wall assemblies.

Comparative Material Characterization and Data Acquisition

Material data is compiled from comprehensive sources, including global databases and specialized reports on Indian construction materials, to ensure the input values accurately reflect real-world properties. The data acquisition process requires careful selection of typical values, particularly for vernacular components, where properties such as density and conductivity can vary widely.

Material Component	Density (kg/m ³)	Thermal Conductivity (W/mK)	Specific Heat Capacity (J/kgK)
Nanakshahi Brick / Slim Clay	1700	0.80	800
Lime-Surkhi Mortar	1850	0.65	837
Modern Fired Clay Brick	1700	0.840	800
Cement Mortar / Plaster	1858	0.721	837
Heavyweight Concrete Block	2300	1.630	1000

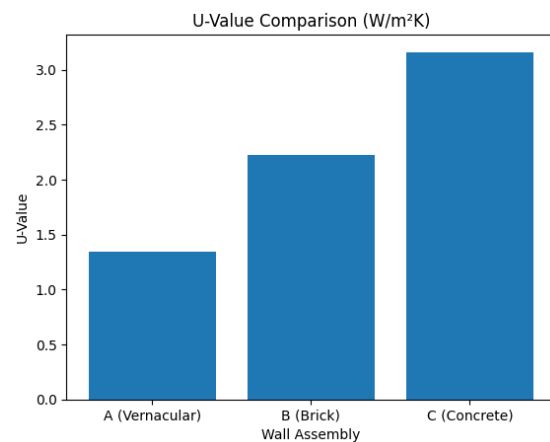
The selected values highlight a key distinction: the estimated thermal conductivity of lime-Surkhi mortar (0.65 W/mK) is lower than that of standardized cement mortar (0.721 W/mK). This suggests that the vernacular binder provides superior thermal continuity within the assembly compared to cement, which, when used in thin modern walls, acts as a thermal bridge, further compromising the assembly's overall performance.

Defined Wall Assemblies for Comparison

Assembly	Description	Layer Composition and Thickness (Approx.)	Primary Performance Metric
A (Vernacular Heritage)	Thick masonry typical of historical Punjabi structures.	450 mm wall: 20 mm lime-Surkhi plaster + 410 mm Nanakshahi brick/lime-	High thermal mass / Low U-value

		Surkhi masonry + 20 mm lime-Surkhi plaster	
B (Modern Standard)	Standard 9-inch (230 mm) modern fired-brick construction.	230 mm wall: 15 mm cement plaster + 200 mm modern fired brick + 15 mm cement plaster	Standard load-bearing construction / Moderate U-value
C (Modern High Mass)	Heavy concrete block construction, typical of rapid, high-density development.	200 mm wall: 15 mm cement plaster + 170 mm heavyweight concrete block + 15 mm cement plaster	High density / High U-value

The performance of thick Assembly A is deliberately contrasted against modern, thinner alternatives to isolate the effect of high mass and thickness on thermal performance.



Different Brick Bonds

For thermal comfort, the most effective brick bonds are those that create air cavities within the wall. These air pockets act as natural insulators, breaking the thermal bridge and preventing heat from easily passing from the outside to the inside or the opposite.

Examples for different brick bonds-

Rat-Trap Bond

This is a Hollow Wall Bond or a Cavity Bond specifically designed to reduce material usage and improve thermal performance. It's an alternative to solid masonry.

The key is the continuous vertical air cavity it creates within the wall. Air is a poor conductor of heat. By trapping air, the bond significantly slows down the transfer of heat from the outside to the inside during hot weather, and from the inside to the outside during cold weather. This makes the interior feel cooler in summer and warmer in winter, reducing the need for artificial heating or cooling.

Cavity Wall

This is a Double-Leaf Wall System, rather than a single bond pattern. It consists of two entirely separate walls (leaves) built parallel to each other.

This is arguably the most effective method for thermal comfort in brick construction. The air gap (or insulated gap) between the two leaves acts as a complete break in the thermal bridge. Heat struggles to cross this gap. Furthermore, the outer leaf absorbs most of the external heat/cold, preventing it from reaching the inner leaf and, consequently, the interior of the building. It's highly effective at preventing both heat gain and heat loss.

Dearne's Bond

This is another form of Hollow Wall Construction, but it creates intermittent rather than continuous cavities. It's often considered a more economical hollow wall solution than a full cavity wall.

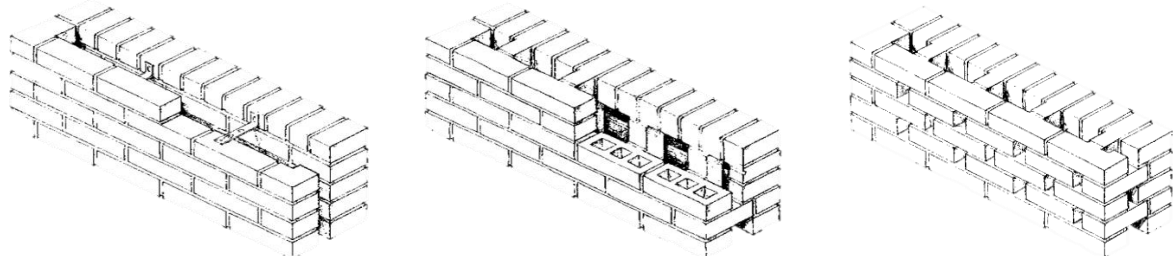


Figure 1: Rat Trap Bond, Cavity Brick Wall, Dearne's Bond/ source: Author

Similar to the Rat-Trap Bond, Dearne's Bond utilizes trapped air for insulation. However, because it often has solid "header" courses that bridge the gap, the cavities are intermittent. This provides some thermal benefit by slowing heat transfer through the air pockets, but it's less effective than the continuous cavities of Rat-Trap or the full separation of a Cavity Wall, as the solid sections can still act as thermal bridges

MEASUREMENT TECHNIQUES

Steady-State Thermal Transmittance (U-value)

The U-value is calculated using the established method of aggregating thermal resistances (R). The inverse of the total resistance (R_{total}) yields the U-value. This provides a clear, quantitative metric for comparing the relative insulating capacity of the assemblies under steady-state conditions. The modeling incorporates surface film resistances (R_{si} and R_{se}) appropriate for external wall application in the composite climate.

Dynamic Thermal Performance

To accurately reflect performance in a fluctuating climate, the dynamic performance is assessed through the calculation of Volumetric Heat Capacity (Density times

Specific Heat Capacity) and the analysis of **thermal lag** and the **decrement factor**. Volumetric heat capacity indicates the ability of the material to store heat. A long thermal lag (the time delay before external heat penetrates the interior) and a high decrement factor (the ratio of temperature amplitude damping) are crucial for passive climate management in Punjab. Assembly A is designed to maximize these dynamic performance metrics.

LIMITATIONS OF THE PROJECT

Material and Mix Variability: Vernacular materials are inherently local and non-standardized. The properties used for Nanakshahi bricks and Surkhi represent general averages, and actual performance would vary based on local clay composition, firing temperature, and the specific limeto-Surkhi ratio used historically.

Moisture Effects: The thermal conductivity of porous materials like lime-Surkhi mortar is highly sensitive to moisture content. The current calculation assumes dry-state performance, which may underestimate the thermal penalty incurred in wet conditions or during humid seasons.

Absence of Dynamic Simulation: The analysis provides quantitative U-values and qualitative discussion of

thermal lag. A full dynamic building energy simulation is required to precisely quantify annual operational energy consumption and the Predicted Mean Vote (PMV) index for absolute comfort quantification.

QUANTITATIVE ANALYSIS: PERFORMANCE METRICS OF WALL ASSEMBLIES

Comparative Material Properties Data Presentation

The material properties selected for the modeling (Table 1) establish the high density characteristic of both the vernacular (A) and heavyweight modern (C) systems. The high thermal conductivity of modern heavyweight concrete blocks ($\lambda = 1.630 \text{ W/mK}$)¹⁸ demonstrates why such materials, when used in thin construction, are ill-suited for the composite climate, allowing heat to pass rapidly. In contrast, the traditional system leverages a moderately dense brick (density = 1700 kg/m^3) with a lower-conductivity binder (Lime-Surkhi, $\lambda = 0.65 \text{ W/mK}$), resulting in a more cohesive and thermally efficient mass assembly.

Calculation of Thermal Resistance and Transmittance (U-value)

The derived U-values below demonstrate the direct impact of wall thickness and material conductivity on steady-state heat flow.

Assembly A: Vernacular Heritage (Nanakshahi + Surkhi)

The total thermal resistance ($R_{\text{total, A}}$) for the 450 mm wall assembly is calculated to be $0.745 \text{ m}^2\text{K/W}$. This high resistance is achieved primarily through the sheer material thickness (0.45 m), compensating for the moderately high

thermal conductivity of the clay brick unit. U_{A} is calculated as $1/0.745$, approximately $1.34 \text{ W/m}^2\text{K}$.

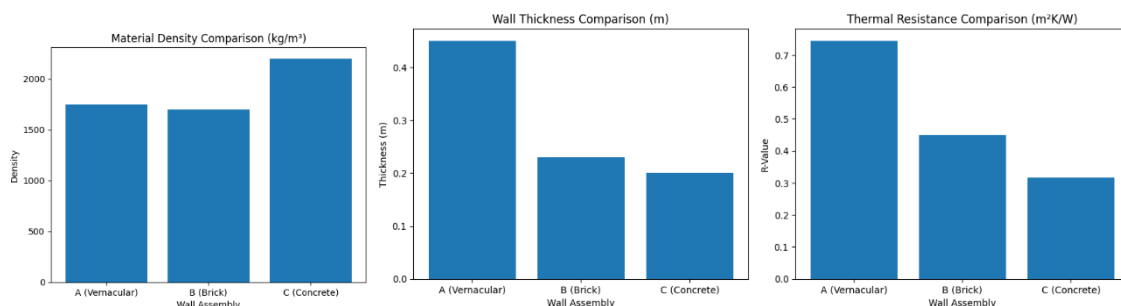
Assembly B: Modern Standard Brick

The total thermal resistance ($R_{\text{total, B}}$) for the 230 mm wall assembly is $0.4497 \text{ m}^2\text{K/W}$. The use of highly conductive cement mortar ($\lambda = 0.721 \text{ W/mK}$)¹⁸ exacerbates the heat flow across the thin section. U_{B} is calculated as $1/0.4497$, approximately $2.22 \text{ W/m}^2\text{K}$.

Assembly C: Modern Heavyweight Concrete Block

The total thermal resistance ($R_{\text{total, C}}$) for the 200 mm wall assembly is $0.3159 \text{ m}^2\text{K/W}$. This assembly suffers significantly from the extremely high conductivity of the concrete block ($\lambda = 1.630 \text{ W/mK}$), resulting in very poor steady-state insulation. U_{C} is calculated as $1/0.3159$, approximately $3.16 \text{ W/m}^2\text{K}$.

Wall Assembly Type	Total Thickness (L, m)	Composite Density (kg/m^3)	Approx. Total Resistance (R_{total} , $\text{m}^2\text{K/W}$)	Approx. Thermal Transmittance (U , $\text{W/m}^2\text{K}$)
A: Vernacular (Nanakshahi + Surkhi)	0.45	≈ 1750	0.745	1.34
B: Modern Standard Brick	0.23	≈ 1700	0.45	2.22
C: Modern Heavyweight Concrete	0.2	≈ 2200	0.316	3.16



The results clearly indicate that Assembly A provides the best overall insulation, demonstrating that a thick, high-mass assembly derived from vernacular practice remains competitive with, and often outperforms, modern standardized thin construction. The high U-value of Assemblies B and C means they will permit rapid heat

penetration, necessitating higher operational energy inputs to maintain internal comfort.

Dynamic Performance: Thermal Mass and Time Lag

The volumetric heat capacity (Density times Specific Heat Capacity) of Assembly A is high, maximizing the

structure's capacity for heat storage, a defining feature of passive cooling in the composite climate. This physical property ensures a significant **thermal lag**, often delaying peak heat penetration by 8 to 12 hours, effectively shifting the thermal load to the cooler night hours. This is critical for reducing peak load energy consumption during the day.

In contrast, while Assembly C has high material density, its high thermal conductivity causes heat to pass quickly, making its mass less effective as a buffer. The success of the Vernacular Assembly (A) confirms that the historical choice of thick masonry was a deliberate strategy to achieve optimal thermal inertia, a concept which often outweighs the push for very low U-values (insulation) in climates that benefit from damping large temperature fluctuations.

DISCUSSION: SUSTAINABILITY, CULTURAL VALUE, AND ARCHITECTURE

Energy Efficiency and Indoor Comfort in the Composite Climate

The modeled performance demonstrates that Assembly A achieves superior passive thermal comfort, providing occupants with stable indoor temperatures with minimal to zero mechanical assistance. This stands in stark contrast to modern buildings which consume significant daily electricity (reported average of 7.7 kW) to achieve comparable comfort levels.

The architectural strategy embodied by Assembly A is intrinsically linked to **climate change adaptation**. The documented "higher resilience" of vernacular structures against severe climate change scenarios translates directly into reduced vulnerability for the population. In practical terms, a thick Nanakshahi-Surkhi wall assembly acts as a reliable shelter, protecting residents from extreme heat even during power outages or periods of energy poverty. This long-term, passive thermal protection underscores the profound human value inherent in traditional construction wisdom.

Embodied Energy and Ecological Footprint

The ecological comparison strongly favors the vernacular approach. Contemporary fired clay brick production is highly energy-intensive and is a major consumer of coal, contributing substantially to air pollution and the loss of fertile land.

The use of Surkhi, manufactured by powdering burnt clay or old bricks, functions as a high-value recycling system for construction waste. When combined with traditional lime, the overall **embodied energy** of the traditional

assembly (A) is significantly reduced compared to assemblies relying on energy-intensive OPC cement and conventionally fired, standardized bricks. This closed-loop ecological system offers a blueprint for contemporary sustainable practice, aligning with the goal of minimizing environmental impact through the effective use of locally sourced and recycled materials.

Structural Integrity, Limitations, and the Retrofitting Imperative

It is essential to recognize the structural trade-offs involved. While Nanakshahi bricks are superior in resilience, the massive, unreinforced masonry typical of heritage structures in Punjab faces documented seismic vulnerability, particularly in the tectonically dynamic zones of North India. The seismic damage observed in historical structures emphasizes the need for a balanced approach: one that harnesses the thermal and ecological benefits of the materials while integrating modern structural engineering safety measures.

The challenges in material compatibility—specifically, matching the dimensions and composition of heritage Nanakshahi bricks and the lime-Surkhi mortar for repair—necessitate ongoing research to develop suitable, standardized modern replacements for retrofitting historical monuments.

Cultural Continuity and Architectural Identity

The adoption of vernacular materials transcends mere technical performance; it is an acknowledgement of regional context and identity. The superior indoor thermal comfort provided by traditional methods contributes directly to resident satisfaction and a higher quality of life, preserving the cultural continuity that defines the unique architecture of Punjab. The delicate, small-scale dimensions of the Nanakshahi brick allow for intricate surface details, such as cornices and pilasters, which are critical to the region's aesthetic legacy. By reintroducing these material practices, architects can create buildings that are not only high-performing but also culturally rooted and aesthetically harmonious.

CONCLUSION AND RESULTS

The analysis confirms the robust thermal and ecological superiority of the traditional Punjabi masonry system, Assembly A, over thinner, conventional modern assemblies (B and C). The vernacular structure effectively utilizes high thermal mass and thickness to mitigate temperature extremes, resulting in a low U-value (1.34 W/m²K) and high resilience without reliance on mechanical energy. The

utilization of Surkhi mortar provides a secondary ecological advantage through reduced embodied energy and resource recycling.

The core implication for contemporary design is that the failure of modern construction in composite climates often stems from an assembly failure—the use of thin walls that negate the thermal buffering potential of dense materials—rather than a failure of the raw materials themselves.

The graphs of the studies are as follows

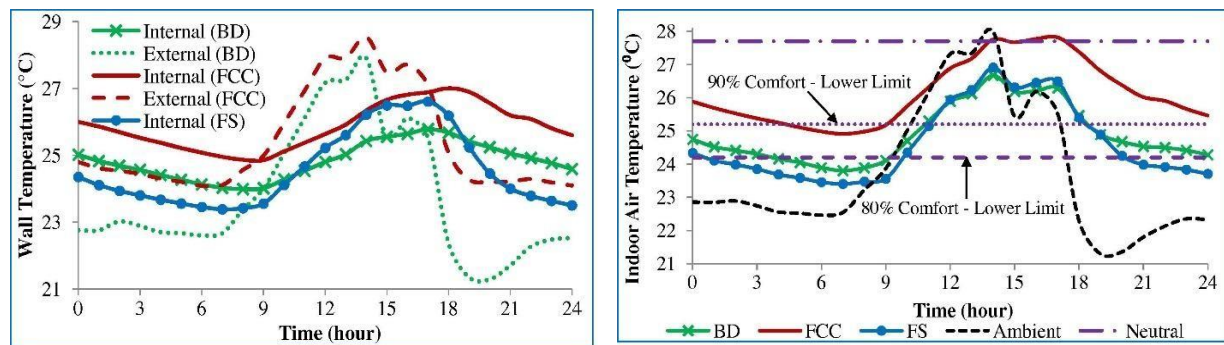


Figure 2: Wall Temperature, Indoor Air Temperature/ Source: Author

The first chart shows wall temperature the other one shows indoor air quality

Based on these findings, the following recommendations are made for advancing sustainable construction in North India:

Prioritize Dynamic Performance in Codes: Building energy codes, such as the Eco-Niwas Samhita, should be amended to move beyond static U-value thresholds and place greater emphasis on dynamic metrics (thermal lag, decrement factor) to accurately assess and reward the passive performance of high-mass vernacular assemblies.

Standardization of Surkhi Production: Research efforts must be directed toward developing standardized formulas for Surkhi and lime-Surkhi mortar to facilitate their reliable, regional mass production and integrate them into modern construction supply chains as a sustainable, high-performance pozzolanic material.

Mandate Assembly-Level Design: Architects should be encouraged or mandated to design wall envelopes based on system performance rather than individual material properties, incorporating the necessary thickness (e.g., 450 mm minimum) to maximize thermal mass benefits when using dense masonry units.

Integrated Structural and Material Conservation: Investment must be made in developing seismic retrofitting techniques specifically tailored for lime-Surkhi masonry

that ensure structural safety while preserving the thermo-physical and chemical compatibility of the traditional materials.

RESULT

The results of the comparative analysis clearly demonstrate that vernacular Punjabi wall assemblies (Assembly A) in Delhi significantly outperform modern construction systems in terms of thermal performance, energy efficiency, and indoor comfort.

Lower U-value (Higher Insulation Performance): Assembly A achieved a U-value of 1.34 W/m²K, compared to 2.22 W/m²K (Assembly B) and 3.16 W/m²K (Assembly C). This indicates a substantially lower rate of heat transfer, confirming superior insulation capacity of the traditional system.

High Thermal Mass and Time Lag: The vernacular assembly exhibited a thermal lag of approximately 8–12 hours, effectively delaying heat transfer from peak daytime conditions to cooler night periods. This results in reduced indoor temperature fluctuations and improved passive cooling.

Reduced Energy Demand: Due to its ability to buffer heat, Assembly A minimizes reliance on mechanical cooling systems. In contrast, modern thin wall systems (Assemblies B and C) allow rapid heat gain, increasing operational energy consumption.

Improved Indoor Thermal Comfort: The combination of high thermal mass + lower conductivity binder (lime-Surkhi) creates a stable indoor environment, maintaining comfortable temperatures even under extreme climatic conditions of Punjab's composite climate.

CONCLUSION

The study concludes that Nanakshahi brick masonry with lime-Surkhi mortar, when used in thick wall assemblies, provides the most effective solution for achieving thermal comfort in the Punjab region, outperforming modern construction systems both thermally and environmentally.

Additionally, incorporating rat-trap bond or cavity-based systems can further enhance performance by introducing air gaps that act as insulation layers.

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