

Terracotta Performance in Interior Design: A Quantitative Study of Thermal, Acoustic, and User Perception in Semi-Urban India

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Abstract

Terracotta, a clay-based material with strong climatic relevance in Indian architecture, has historically supported passive environmental control through its thermal and porous properties. In contemporary interior design, however, its application has shifted largely toward aesthetics, with limited emphasis on functional performance. This study quantitatively evaluates terracotta as a performance-driven material by examining its thermal and acoustic properties alongside professional awareness and usage patterns in semi-urban India. A mixed-source approach combines primary survey data from 120 design professionals with secondary data from case studies and published material research. Results indicate that terracotta demonstrates effective thermal regulation and moderate acoustic absorption, yet a clear performance–usage gap persists. While awareness levels are high, the relationship between awareness and usage is statistically non-significant ($r = -0.11$), indicating that knowledge alone does not drive adoption. Instead, market trends, client preferences, and cost emerge as dominant constraints. The study concludes that wider application of terracotta depends on systemic interventions, including standardized product systems and integration into contemporary design practice.

Keywords: Terracotta, Passive Cooling, Thermal Performance, Acoustic Performance, Sustainable Interior Design

1. Introduction

Terracotta, commonly understood as kiln-fired clay, is one of the earliest materials used in the built environment. Across the Indian subcontinent, it has been widely employed in construction systems such as masonry units, roofing elements, perforated screens, and decorative features. Its widespread use is not only due to availability but also its strong compatibility with local climatic conditions and construction practices. Particularly in hot and semi-arid regions, terracotta has supported passive environmental control strategies that enhance indoor comfort without reliance on mechanical systems (Asquith & Vellinga, 2006). Beyond its structural and visual roles, terracotta has historically functioned as a climate-responsive material. Its inherent porosity and relatively low thermal conductivity allow it to regulate heat transfer, while its capacity to absorb and release moisture supports evaporative cooling. Architectural elements such as jaali screens improve airflow and reduce solar heat gain, while thick earthen walls introduce thermal lag, stabilizing indoor temperatures over daily cycles (Givoni, 1998). These applications reflect a deep integration of material properties with climatic intelligence developed through vernacular building traditions. Despite this legacy, the role of terracotta in contemporary interior design has shifted significantly. The growing dominance of industrial materials such as reinforced concrete, glass, and gypsum-based systems has repositioned terracotta primarily as a surface or decorative material. In current practice, it is often selected for its texture, color, and artisanal quality, while its functional attributes such as thermal insulation, moisture buffering, and acoustic absorption remain underutilized (Hall et al., 2012). This shift is particularly relevant in the context of rising environmental concerns, including increasing indoor heat stress, higher dependence on mechanical cooling, and the urgent need for sustainable material alternatives. Although existing literature continues to document the environmental performance of clay-based materials, there is limited evidence connecting these properties to their actual application in interior design practice. As a result, a gap persists between what terracotta can achieve and how it is currently used. The present study addresses this gap through a quantitative investigation that combines primary survey data from 120 design professionals with secondary performance data derived from published research and built case studies. By examining thermal and acoustic performance alongside patterns of awareness and usage, the study evaluates terracotta not only as a traditional material but as a viable component of contemporary performance-driven interior design. The research is guided by the

following hypotheses: H1: Terracotta contributes to a measurable reduction in indoor temperature relative to conventional materials.

H2: Terracotta enhances acoustic performance in interior environments.

H3: Increased awareness of terracotta's functional properties leads to higher levels of its application in design practice.

2. Literature Review

2.1 Terracotta in Architecture and Interiors

Terracotta has been integral to traditional Indian architecture, widely used in bricks, roofing tiles, and perforated jaali screens, contributing both to structural systems and passive environmental control. These applications were rooted in vernacular design principles emphasizing climate responsiveness, local material availability, and low-energy construction (Asquith & Vellinga, 2006; Givoni, 1998). Studies confirm that jaali-integrated facades lower indoor temperatures throughout the day by facilitating controlled airflow and shading, demonstrating improvements in passive thermal comfort without mechanical intervention (Ali, 2013). In contemporary practice, terracotta continues to be used in facades and interior surfaces, but its role is largely aesthetic, focusing on texture, color, and artisanal value. Recent advancements in fabrication technologies, including modular terracotta panels and digitally produced clay components, indicate renewed interest, yet its integration as a performance-driven interior element remains limited (Hall et al., 2012).



Figure 1: Traditional terracotta elements integrated with passive ventilation strategies in a climate-responsive residential interior.

Source: AD Pro Directory

<https://www.architecturaldigest.in/story/homes-in-india-that-reconnect-with-regional-design-traditions/>

2.2 Thermal Properties

Terracotta exhibits relatively low thermal conductivity (0.6–0.8 W/m·K) compared to dense materials such as concrete (1.4–1.7 W/m·K), making it an effective insulator. Studies on earthen materials indicate that increased porosity reduces heat transfer by trapping air within the material matrix, thereby improving thermal resistance (Binici et al., 2009; Hall et al., 2012). Additionally, terracotta demonstrates thermal lag, delaying heat transfer and stabilizing indoor temperatures by reducing peak heat gain during the day. The material's contribution to passive cooling is further enhanced through moisture interaction. Research on clay-based systems highlights that evaporative cooling enabled by water absorption and gradual evaporation can significantly reduce ambient temperatures in hot climates (Givoni, 1998). Chelliah et al. (2021) found that PCM-integrated terracotta brick buildings in India's hot-dry climate exhibited lower unsteady heat transmittance than conventional bricks, with measurable reductions in air-conditioning load and carbon emissions in both hot-dry and composite climate zones. A landmark applied case study is Ant Studio's 'Beehive' installation at the Deki Electronics factory in Noida, Uttar Pradesh (2017). Using engineered terracotta cones arrayed in a beehive configuration in front of an industrial vent, the installation leveraged evaporative cooling to

achieve a measured temperature drop of 6–8°C when ambient temperatures exceeded 40°C from 42°C down to approximately 36°C with negligible electricity consumption and zero refrigerants (Ant Studio, 2017; UNEP, 2018).

2.3 Acoustic Properties

The acoustic performance of terracotta is closely linked to its porous structure and surface characteristics. Porous materials absorb sound energy by dissipating it within internal cavities, reducing sound reflection and reverberation (Yang et al., 2018). A dedicated study by Jain et al. (2024), published in the Journal of Salutogenic Architecture, evaluated unglazed terracotta tiles in an indoor office environment using ASTM C423 and ISO 3382-2 methodologies. Sound absorption coefficients ranged from 0.05 to 0.19, with the highest absorption at 125 Hz. Reverberation time (RT60) values for terracotta specimens fell within acceptable thresholds for speech intelligibility per ISO 3382-2 standards, indicating its viability as an acoustic treatment material in office interiors (Jain et al., 2024).

2.4 Porosity and Hygroscopic Behavior

Terracotta's porosity enables it to absorb and release moisture, making it hygroscopic. This supports indoor humidity regulation and enhances thermal comfort. The combined effect of porosity and moisture interaction contributes to evaporative cooling, particularly effective in dry and semi-arid climates (Hall et al., 2012). Ant Studio's computational fluid dynamics analysis confirmed that clay's hygroscopic qualities, its affinity for water molecules, are key to maintaining sustained cooling surfaces over extended periods (Siripurapu, 2017).



Figure 2: Terracotta pipe installations cool and purify hot, humid air through the process of evaporation.

Source: designboom © 1999-2026

<https://www.designboom.com/design/terracotta-pipe-installations-coolant-coral-beehive-ant-studio-07-26-2022>

2.5 Passive Design and Comparative Performance

Passive design strategies achieve thermal and environmental comfort through material properties, building orientation, and natural energy flows. Terracotta aligns with these principles due to its low embodied energy, recyclability, and climate-responsive performance. When compared with conventional interior materials, terracotta demonstrates distinct advantages over concrete (high thermal mass but lacks evaporative cooling) and gypsum (limited thermal and acoustic performance due to low density and non-breathability), making it a multifunctional material suitable for passive interior design (Binici et al., 2009; Yang et al., 2018).

2.6 Research Gaps

Despite the established thermal and acoustic properties of terracotta, critical gaps remain in the literature: limited quantitative validation within interior environments (as opposed to building envelopes); absent integration of

performance data with user perception among design professionals; underutilization as a functional interior material despite proven environmental benefits; and a lack of comparative data positioning terracotta alongside commonly used interior materials such as gypsum, concrete, and engineered panels in terms of both performance and usability.

3. Research Methodology

3.1 Research Design

This study adopts a quantitative research approach integrating descriptive, correlational, and comparative methods. The descriptive component summarizes patterns of awareness, usage, and perceived performance. The correlational approach examines relationships between awareness of functional properties and the extent of usage. Comparative analysis uses secondary data from case studies and material databases to evaluate terracotta's thermal and acoustic performance relative to conventional materials.

3.2 Data Sources

Primary data was collected through a structured questionnaire administered to interior designers, architects, and design students using a 5-point Likert scale. Key variables captured included: Awareness Level (knowledge of thermal insulation, acoustic absorption, passive cooling); Usage Frequency (never / rarely / occasionally / frequently); Perceived Performance (respondents' evaluation of thermal and acoustic effectiveness); and Barriers to Application (cost, availability, technical knowledge, market trends).

Secondary data was drawn from 3–5 architectural and interior case studies where terracotta was used as a functional material, including the Ant Studio Beehive (Noida, 2017), and published literature providing thermal conductivity values, acoustic absorption coefficients, and comparative material performance datasets (Binici et al., 2009; Chelliah et al., 2021; Jain et al., 2024).

3.3 Sampling and Variables

Purposive sampling targeted 120 design professionals (interior designers, architects, and design students) with academic or professional exposure to material selection. The independent variable was awareness of terracotta's functional properties; the dependent variables were usage frequency and perceived performance (thermal and acoustic); the control variables were profession and years of experience.

3.4 Analysis Techniques

Descriptive statistics (mean, frequency distribution, standard deviation) summarized survey responses. Pearson/Spearman correlation examined relationships between awareness and usage. Regression analysis determined the extent to which awareness predicted usage. Hypothesis testing accepted or rejected H1, H2, and H3. Comparative analysis evaluated performance across materials using bar charts, scatter plots, and data tables.

4. Results and Analysis

4.1 Respondent Profile

The respondent profile reflects a professionally relevant sample, dominated by architects (39.2%) and interior designers (28.3%), followed by design students (23.3%) and other fields (9.2%). In terms of experience, the largest group had 3–5 years (32.5%), followed by 5+ years (27.5%) and 1–3 years (26.7%), with a smaller segment of beginners at 0–1 year (13.3%). The sample captures a balanced mix of emerging and experienced design professionals.

4.2 Awareness of Functional Properties

Responses across all awareness items were strongly positive. The tables below summarise the distribution for each functional dimension.

Thermal Insulation Awareness

Rating	Count	% Share
Disagree	6	5.0%
Neutral	17	14.2%
Agree	41	34.2%
Strongly Agree	56	46.7%

Passive Cooling Awareness

Rating	Count	% Share
Disagree	4	3.3%
Neutral	19	15.8%
Agree	48	40.0%
Strongly Agree	49	40.8%

Acoustic Absorption Awareness

Rating	Count	% Share
Disagree	9	7.5%
Neutral	21	17.5%
Agree	36	30.0%
Strongly Agree	54	45.0%

Functional Material Perception

Across all awareness dimensions, the majority of respondents selected “Agree” or “Strongly Agree” most notably for Thermal Insulation (80.9%), Passive Cooling (80.8%), Acoustic Absorption (75.0%), Functional Material Perception (72.5%), and Modern Applications Familiarity (81.6%). Acoustic Absorption showed comparatively higher Neutral (17.5%) and Disagree (7.5%) responses, reflecting slightly lower clarity in this domain. Overall, respondents demonstrate well-established knowledge of terracotta’s thermal capabilities, while awareness of its acoustic properties remains less uniform.

4.3 Usage Patterns

Most respondents use terracotta regularly: 36.7% report frequent use and 23.3% very frequent use, while 25.0% use it occasionally. Only 15.0% use it rarely or never. However, its application remains concentrated in aesthetic and

surface-level uses, such as wall cladding (23.0%), decorative elements (19.7%), and acoustic panels (19.7%), while passive cooling systems (19.4%) and flooring/tiles (18.1%) are comparatively less common. This pattern suggests that despite strong awareness of terracotta's functional benefits, its practical use is still more design-oriented than performance-driven.

4.4 Perceived Thermal Performance (H1) Reduces Indoor Temperature

Rating	Count	% Share
Disagree	2	1.7%
Neutral	16	13.3%
Agree	47	39.2%
Rating	Count	% Share
Strongly Agree	55	45.8%
Total	120	100.0%

Improves Thermal Comfort

Rating	Count	% Share
Disagree	6	5.0%
Neutral	16	13.3%
Agree	44	36.7%
Strongly Agree	54	45.0%
Total	120	100.0%

The results show a strong positive perception of terracotta's thermal performance. The vast majority of respondents agreed or strongly agreed that it reduces indoor temperature (85.0%) and improves thermal comfort (81.7%), with negligible disagreement. Statistical testing confirms that these responses are well above the neutral midpoint ($t(239) = 23.94$, $p < 0.001$), meaning the result is highly unlikely to be due to chance. H1 is accepted, supported by both professional perception and scientific material data.

4.5 Perceived Acoustic Performance (H2) Q14 Acoustic Performance

Rating	Count	% Share
Disagree	6	5.0%

Neutral	16	13.3%
Agree	42	35.0%

Rating	Count	% Share
Strongly Agree	56	46.7%
Total	120	100.0%

Acoustic performance received strong endorsement, with 81.7% of respondents agreeing or strongly agreeing. Statistical testing confirms this is significantly above neutral ($t(119) = 15.58, p < 0.001$), supporting H2. However, 13.3% remained Neutral, and 5.0% disagree,d the highest proportion of uncertain responses across all performance items, ms indicating that confidence in terracotta’s acoustic properties is real but less uniform than for thermal performance.

4.6 Barriers to Adoption

Respondents identified multiple barriers to terracotta adoption across 247 total responses. Market Trends was the most frequently cited barrier (45 responses, 18.2%), followed by Client Preference (41, 16.6%), Cost (38, 15.4%), Installation Challenges (33, 13.4%), Limited Availability (33, 13.4%), Lack of Technical Knowledge (32, 13.0%), and Lack of Awareness (25, 10.1%). Importantly, none of these reflect inherent deficiencies in the material itself; all are systemic and perceptual in nature. When asked whether terracotta should be used more as a functional material, an overwhelming 88.3% of respondents said Yes, underscoring strong professional endorsement despite persistently low functional adoption.

4.7 Correlation and Regression Analysis (H3)

The Pearson correlation between awareness scores and usage frequency returned $r = -0.11$ ($p = 0.226$), a result that is statistically non-significant. In plain terms, knowing more about terracotta’s properties does not make a designer more likely to use it. The regression model further confirmed this, with awareness accounting for just 1.2% of the variance in usage frequency ($R^2 = 0.012$). H3 is therefore not supported by the data. This finding redirects the study’s conclusions away from awareness campaigns. The barrier analysis makes clear why: market trends, client preferences, and cost collectively account for over half of all identified constraints, structural forces that professional knowledge alone cannot override.

4.8 Descriptive Statistics Summary

Survey Item	Min	Max	Mean	SD	Interpretation
A1. Thermal Insulation Awareness	2	5	4.23	0.87	High
A2. Passive Cooling Awareness	2	5	4.18	0.82	High

A3. Acoustic Absorption Awareness	2	5	4.13	0.96	High
A4. Functional Material Perception	2	5	4.16	0.85	High
A5. Modern Applications Familiarity	2	5	4.23	0.86	High
Section A Mean			4.18	0.87	
B1. Reduces Indoor Temperature	2	5	4.29	0.76	High
B2. Improves Thermal Comfort	2	5	4.22	0.86	High
B3. Acoustic Performance	2	5	4.23	0.87	High
B4. Better than Conventional Materials	2	5	4.15	0.89	High
B5. Performance-Based Use Intent	2	5	4.31	0.82	High
Section B Mean			4.24	0.84	
Overall Mean (all 10 items)			4.21	0.86	High

Section A (Awareness) mean: 4.18 | Section B (Performance) mean: 4.24 | Overall mean: 4.21 | Pooled SD: 0.86

4.9 Comparative Material Performance (Secondary Data)

Secondary data comparing terracotta with conventional interior materials yields the following picture:

Material	Thermal Conductivity (W/m·K)	Acoustic Absorption (NRC)	Moisture Regulation	Sustainability
Terracotta	0.6–0.8	0.05–0.19	High (hygroscopic)	High
Material	Thermal Conductivity (W/m·K)	Acoustic Absorption (NRC)	Moisture Regulation	Sustainability
Concrete	1.4–1.7	0.01–0.05	Low	Moderate
Gypsum Board	0.17–0.25	0.05–0.10	Low	Moderate

Fired Brick	0.6–1.0	0.02–0.05	Low	Moderate–High
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Sources: Binici et al. (2009); Chelliah et al. (2021); Jain et al. (2024); Hall et al. (2012).

Terracotta's lower thermal conductivity and hygroscopic capability provide measurable advantages over concrete and gypsum in passive cooling contexts. Its acoustic absorption coefficients, while moderate, exceed those of concrete and fired brick across key frequency ranges.

4.10 Hypothesis Validation Summary

Hypothesis	Result	Statistical Evidence
H1: Terracotta improves thermal performance	Accepted	$t(239) = 23.94, p < 0.001$; mean = 4.26 (SD = 0.81). Supported by perception data and secondary material evidence.
H2: Terracotta improves acoustic performance	Accepted	$t(119) = 15.58, p < 0.001$; mean = 4.23 (SD = 0.87). Statistically significant, though 18.3% remained neutral/disagreed.
H3: Awareness positively influences usage	Rejected	$r = -0.11, p = 0.226$; $R^2 = 0.012$. No significant relationship found. Systemic barriers dominate over awareness.

5. Discussion

5.1 The Performance–Perception Gap: Reframed

One of the key findings of this study is the existence of a performance–perception gap. Scientific studies already confirm that terracotta performs effectively in thermal insulation and acoustic absorption. The survey also showed high professional awareness, with an average score of 4.18 out of

5. However, greater awareness did not lead to greater usage. This indicates that the issue is not lack of knowledge, but practical and market-related barriers. Although 88.3% of respondents supported wider use of terracotta, factors such as market trends, client preferences, and cost continue to limit its adoption.

5.2 Thermal Performance and Passive Cooling (H1)

The thermal findings strongly support H1. Respondents showed high confidence in terracotta's ability to improve indoor comfort and reduce heat gain, with mean scores of 4.29 and 4.22. The results indicate a clear professional agreement regarding its thermal efficiency. These findings align with earlier studies on passive cooling and heat reduction in Indian climates. Real-life examples, such as Ant Studio's Beehive installation in Noida, further demonstrate terracotta's cooling potential under extreme temperatures with minimal energy use.

5.3 Acoustic Performance (H2)

H2 was also supported statistically, with an average acoustic performance score of 4.23. However, responses showed more variation compared to thermal performance, as acoustic qualities are less visible and harder to experience directly. While people can easily notice thermal comfort, they may not immediately connect reduced sound reverberation with wall materials. Existing research confirms that terracotta provides measurable sound absorption and

acceptable reverberation control in interior spaces. The findings suggest that practical demonstrations and real-world applications may help improve confidence in its acoustic capabilities.

5.4 The Rejection of H3: Structural Barriers Trump Awareness

The rejection of H3 is one of the most important outcomes of this research. Statistical analysis showed almost no relationship between awareness and actual usage of terracotta. Awareness explained less than 2% of usage variation, proving that knowledge alone does not encourage adoption. The survey identified market trends, client preferences, and cost as the main barriers. Even when professionals understand the benefits of terracotta, they are still influenced by budgets, modern material preferences, and limited availability of standardised terracotta systems.

5.5 Implications for Sustainable Design

Terracotta supports important principles of sustainable interior design due to its low embodied energy, recyclability, local availability, and climate responsiveness. As India's energy demand for cooling continues to rise, passive materials like terracotta can help reduce dependence on mechanical cooling systems. Its underuse reflects a broader shift toward modern engineered materials instead of improving traditional materials with proven environmental benefits. Integrating terracotta into performance-based design strategies can support sustainable interiors, reduce cooling loads, and strengthen local craft industries.

5.6 Contribution to Research and Practice

This study contributes to existing research in three ways. First, it establishes a quantitative connection between terracotta's performance and professional perception in interior design. Second, it highlights the performance–perception gap as a structural barrier to sustainable material adoption. Third, it combines material performance studies with professional survey data, creating a practical research approach for evaluating sustainable materials in design applications.

6. Design Recommendations

Based on the findings of this study, the following recommendations are proposed for integrating terracotta as a performance-driven interior material within contemporary design practice in semi-urban India:

- Terracotta can be used in modular panels, layered wall systems, and jaali designs to reduce heat gain, improve airflow, and enhance thermal comfort, especially in hot and semi-arid climates
- Its porous nature also makes it suitable for passive cooling in semi-open spaces such as atriums, corridors, and transition areas when combined with airflow and moisture circulation systems. Projects like the Ant Studio Beehive demonstrate its practical cooling potential.
- Unglazed terracotta can be applied in acoustic wall panels and ceiling treatments, particularly in offices and institutional interiors. Sound absorption can be improved further by adding air cavities or foam backing.
- Developing standardised prefabricated terracotta panels and tile systems can reduce installation difficulties and encourage wider adoption in modern interior projects.
- Terracotta may also be combined with materials such as concrete, metal, or gypsum to improve structural stability, durability, and fire resistance while maintaining its thermal and acoustic benefits.
- Installing terracotta-based systems in public, institutional, and hospitality spaces can help demonstrate their real-world performance and increase professional confidence in the material.
- Including terracotta performance studies, thermal data, and passive cooling examples in architecture and interior design education can also help bridge the technical knowledge gap among future professionals.

7. Limitations and Future Scope

This study is constrained by its dependence on perception-based, self-reported survey data ($n = 120$), which may reflect subjective understanding rather than direct application experience and may not fully capture the diversity of design practices across different regions of India. The findings are further limited by the use of secondary performance data and selected case studies in place of controlled, real-time experimental testing within interior environments, restricting the extent to which results can be generalized. In addition, the scope focuses primarily on thermal and acoustic performance, without addressing other critical factors such as durability, fire safety, long-term maintenance, and lifecycle cost, which significantly influence material adoption in practice.

Future research should therefore prioritize controlled experimental studies and live case-based evaluations within interior settings to validate performance under real conditions. Comparative investigations across varied climatic zones in India would help establish context-specific application guidelines. Integrating life cycle assessment and economic analysis can further strengthen the material's viability in practice. Additionally, exploration of advanced terracotta systems including modular, hybrid, and digitally fabricated solutions along with interdisciplinary collaboration between design, engineering, and material science fields, can support its transition from a traditional material to a widely adopted performance-driven solution in contemporary interiors.

8. Conclusion

This study examined terracotta as a performance-based material in contemporary interior design by analysing its thermal and acoustic qualities along with the perceptions of 120 design professionals in semi-urban India. The findings show a clear gap between awareness and actual usage. Although professionals recognize terracotta's benefits, its practical application remains limited due to structural and market-related barriers. The study strongly supports terracotta's thermal and acoustic performance. Most respondents agreed that it helps reduce indoor temperature and improves acoustic comfort, with statistical analysis confirming these results. These findings are consistent with existing scientific research, leading to the acceptance of H1 and H2. However, H3 was rejected, as awareness showed no significant relationship with actual usage. Despite high awareness levels, factors such as client preferences, market trends, cost, and installation challenges continue to restrict adoption. The study therefore highlights that the issue is not lack of knowledge, but limitations within current design and construction systems.

In conclusion, terracotta has strong potential as a sustainable and climate-responsive interior material. Wider adoption will require standardized systems, cost-effective solutions, and performance-focused design approaches rather than awareness campaigns alone.

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