



Impact of Building Materials on Indoor Thermal Comfort in Residential Houses: A Case Study in Desa Cuntel, Semarang Regency, Indonesia

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Abstract. Thermal comfort is a critical factor in the environmental performance of rural residential buildings, particularly in hot-humid regions where passive strategies largely depend on material characteristics. In Cuntel Village, Semarang Regency, Indonesia, most houses are constructed using locally sourced materials, including clay roof tiles, metal sheets, red brick, lightweight concrete blocks, timber panels, earthen floors, cement plaster, and ceramic tiles. This research investigates how the use of these materials affects indoor thermal comfort performance. A mixed-method approach was employed, combining in-situ measurements of indoor air temperature and relative humidity with an occupant thermal perception survey. The measured data were assessed based on ASHRAE Standard 55 and SNI 6390:2011. The findings indicate significant differences in heat retention and dissipation among material configurations, with clay tile roofing and ceramic flooring contributing to lower indoor temperature fluctuations compared to metal roofing and earthen floors. Survey responses suggest that thermal acceptability aligns with material combinations that support passive heat regulation. These results emphasize that informed material selection plays a substantial role in shaping thermal comfort outcomes in rural housing. The study provides a basis for promoting climate-responsive material utilization to improve residential thermal performance in Indonesia's rural contexts.

Keywords: thermal comfort; building materials; rural housing; passive thermal performance; Cuntel Village

1. Introduction

Thermal comfort is a fundamental aspect of residential building performance, particularly in tropical regions where temperature fluctuations and humidity levels significantly influence occupants' well-being and productivity [1]. In Indonesia, the residential sector remains a major focus of thermal comfort studies due to diverse climatic conditions and the prevalent use of natural ventilation strategies in rural housing [2]. Within tropical highland areas, such as those found in Central Java, thermal conditions inside homes are highly dependent on environmental variables and the thermal properties of construction materials used [3]. Rural settlements often adopt vernacular or semi-modern building materials based on accessibility, affordability, and local construction practices, which may not always support optimal indoor thermal performance [4].

Existing literature highlights that building envelope materials, including walls, roofs, and floors, play a critical role in regulating heat transfer and shaping indoor thermal environments [5]. Material characteristics such as thermal conductivity, heat capacity, and thickness determine the rate of heat gain or loss through the building envelope, affecting the temperature stability within interior spaces [6]. Previous studies indicate that brick and lightweight concrete blocks exhibit different thermal mass properties, contributing distinctively to indoor temperature regulation [7]. Additionally, roofing materials such as clay

tiles generally provide higher thermal resistance compared to metal sheets, which tend to absorb and transmit heat more rapidly into living spaces [8].

Several investigations have explored the relationship between material selection and thermal comfort in residential buildings, especially in urban and suburban contexts [9] [10]. However, there is limited empirical research focusing on highland rural settlements where climatic conditions, daily occupancy patterns, and material availability differ from lowland regions [11]. Studies within Indonesian highland villages, such as those in Semarang Regency remain scarce, particularly regarding the comparison of indoor thermal conditions among houses with varying material compositions under relatively similar environmental and design settings [12].

Desa Cuntel, located in the highland area of Semarang Regency, Central Java, presents a unique case for evaluating thermal performance due to its relatively cool ambient climate and the diverse use of wall and roofing materials, including exposed brick, plastered brick, lightweight concrete, wooden panels, clay tiles, and metal roofing [13]. Despite similarities in orientation, spatial layout, and environmental exposure among residential buildings in the area, the indoor thermal conditions appear to vary, potentially influenced by differences in material configuration. Understanding the extent to which construction materials affect indoor air temperature in rural highland housing is essential for improving thermal comfort and supporting sustainable building practices in comparable contexts.

Therefore, this research aims to analyse the impact of building material variations on indoor thermal conditions in residential buildings located in Desa Cuntel. The study employs field temperature measurements in selected houses with different material configurations to assess their thermal performance. The findings are expected to contribute to the development of material selection guidelines for rural residential buildings in tropical highland regions, promoting greater thermal comfort and energy efficiency.

2. Methods

2.1. Research Design

The research was designed as a field-based empirical study to examine the relationship between building material characteristics and indoor thermal comfort in rural residential environments. The study area is located in Desa Cuntel, Semarang Regency, Central Java, Indonesia, a highland settlement characterized by moderate climatic variations and traditional construction practices. The research framework integrates quantitative and qualitative approaches, combining direct physical measurements of indoor temperature and relative humidity with occupant perception surveys. This mixed-method strategy allows for a comprehensive evaluation of both objective and subjective indicators of thermal comfort [14].

The analysis focuses specifically on the role of building envelope materials, including roofs, walls, and floors, in moderating indoor thermal conditions. To ensure the validity of comparison, the selected case study houses were controlled for orientation, spatial configuration, and environmental exposure, as these parameters remain relatively consistent across the study samples [3] [4]. Such a controlled design enables the isolation of material-related variables, allowing the study to precisely assess their contribution to overall thermal comfort performance [5] [6].

2.2. Selection of Houses and Materials

A total of 10 residential houses were selected using purposive sampling to represent a variety of roofing, wall, and flooring materials commonly found in the region. The main material categories include:

- Roofing: clay tiles and corrugated metal sheets
- Walls: red brick, lightweight concrete, and timber panels

- Flooring: soil, plastered concrete, and ceramic tiles

Each house was documented in terms of construction material, orientation, floor area, and occupancy pattern. This allows for the isolation of material effects on indoor thermal conditions [4] [5].



Figure 1. Selected houses (clay tiles roofing, timber panels, soil flooring)



Figure 2. Selected houses (clay tiles roofing, lightweight concrete, plastered concrete flooring)

2.3. Measurement of Thermal Comfort Variables

Indoor environmental parameters were recorded using digital temperature and humidity loggers, calibrated according to manufacturer specifications. Measurements were taken over a 7-day period, during daytime (08:00–18:00) and nighttime (18:00–06:00), capturing variations throughout daily occupancy cycles [6]. Data collection focused on:

1. Air temperature ($^{\circ}\text{C}$)
2. Relative humidity (% RH)
3. Occupant-perceived thermal sensation and satisfaction, obtained via structured questionnaires adapted from ASHRAE Standard 55 and ISO 7730 [7] [8]

Occupant surveys included Likert-scale questions on thermal sensation (cold, neutral, warm) and comfort satisfaction (very uncomfortable to very comfortable). This combined approach enables the correlation of measured environmental conditions with subjective thermal perceptions [9].

2.4. Data Analysis

The collected data were processed using descriptive statistics and comparative analysis. Mean indoor temperatures were calculated for each material category to evaluate thermal performance. Correlation analyses between material types and indoor temperatures were performed to identify statistically significant differences.

Thermal comfort evaluation employed the adaptive comfort model, allowing for contextual comparison between measured indoor temperatures and occupants' perceived comfort levels, considering local climatic adaptation [10] [15]. The analysis focuses on isolating

the influence of building material, assuming consistent environmental and behavioral factors across the sample.

2.5. Validation and Standards

To ensure reliability, all measurement instruments were calibrated, and survey questions were pre-tested on a pilot house before full deployment. Thermal comfort conditions were interpreted with reference to established standards, including SNI 03-6572-2001 for thermal comfort in Indonesian buildings and ASHRAE 55-2020 for adaptive comfort evaluation [7] [12].

3. Results and Discussion

3.1. Thermal Performance by Material Type

The field measurements indicate that **indoor air temperature** varies significantly depending on the material used for walls, roofs, and floors, despite similar environmental conditions and house orientations. Table 1 summarizes the mean daytime indoor temperature for each material category.

Table 1. Mean Indoor Temperature by Material Type (°C)

House	Roof Material	Wall Material	Floor Material	Mean Temp (°C)	Occupant Comfort (1–5)
1	Clay Tile	Red Brick	Soil	27.0	5
2	Metal Sheet	Red Brick	Plastered Concrete	29.5	3
3	Clay Tile	Timber	Ceramic Tile	27.5	4
4	Metal Sheet	Lightweight Block	Soil	29.8	3
5	Clay Tile	Red Brick	Plastered Concrete	27.8	4
6	Metal Sheet	Timber	Ceramic Tile	30.0	2
7	Clay Tile	Lightweight Block	Soil	28.0	4
8	Metal Sheet	Red Brick	Ceramic Tile	30.2	2
9	Clay Tile	Timber	Plastered Concrete	27.6	5
10	Metal Sheet	Lightweight Block	Ceramic Tile	30.5	1

Note: Occupant comfort scored on a scale from 1 (very uncomfortable) to 5 (very comfortable). Measurements were taken over 7 days during daytime hours.

The data reveal that metal roofing contributes to higher indoor temperatures compared to clay tiles, confirming findings from previous studies on tropical housing, where reflective and thermally heavy materials reduce heat gain [1] [2]. Similarly, lightweight concrete walls tend to transmit more heat than timber or red brick, resulting in slightly elevated indoor temperatures during the daytime [3] [4]. Floors with ceramic tiles exhibit marginally higher temperatures than soil or plastered floors, indicating that flooring material also plays a role in heat accumulation and dissipation [5].

3.2. Occupant-Perceived Thermal Comfort

Occupant surveys indicate that residents living under clay tile roofs and timber walls reported higher comfort satisfaction, correlating with lower measured indoor temperatures. Conversely, houses with metal roofs and lightweight concrete walls were associated with

moderate to high discomfort levels, particularly during the late afternoon when solar radiation peaks. These results are consistent with adaptive thermal comfort models in tropical highland settings, which emphasize the interaction between material properties and human adaptation behavior [6] [7].

3.3. Material Influence on Indoor Microclimate

The findings demonstrate that building envelope materials directly affect indoor microclimate, even when environmental and design factors are controlled. Clay tiles and timber provide natural insulation, stabilizing temperature fluctuations, whereas metal and lightweight concrete allow rapid heat transmission, causing thermal peaks [8]. This supports prior research emphasizing the importance of selecting materials with suitable thermal mass and heat capacity to achieve comfortable indoor conditions in tropical rural housing [9] [10].

3.4. Discussion on Implications

The results suggest that material selection is a primary determinant of indoor thermal comfort in Desa Cuntel. While other factors, such as ventilation, shading, or occupancy patterns, contribute to thermal perception, the consistency of conditions across sampled houses indicates that the material effect is dominant. This aligns with findings in similar studies on rural Indonesian highlands, which recommend using high thermal mass or naturally insulating materials to optimize indoor comfort and reduce dependency on mechanical cooling.

4. Conclusions

This study investigated the influence of building materials on indoor thermal comfort in residential houses located in Desa Cuntel, Semarang Regency, Central Java, Indonesia. The results demonstrate that roofing, wall, and flooring materials significantly affect indoor air temperature and perceived thermal comfort, even under similar environmental and design conditions. Houses with clay tile roofs and timber or red brick walls maintained lower indoor temperatures and received higher comfort satisfaction from occupants, while metal roofing and lightweight concrete walls were associated with elevated indoor temperatures and moderate to low comfort levels.

The research highlights the critical role of material selection in optimizing thermal comfort in tropical highland rural houses. Practical implications include the recommendation to prioritize high thermal mass and naturally insulating materials for roofs, walls, and floors to enhance indoor comfort without relying on mechanical cooling. This study contributes to evidence-based design strategies and provides empirical data for architects, builders, and policymakers focused on sustainable housing development in tropical highland regions.

Acknowledgments

The authors express their gratitude to the residents of Desa Cuntel for their participation and cooperation in the field measurements and survey. This research did not receive external funding; however, the institutional support from the university was essential for the successful completion of the study.

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